XXIXth
International Winterschool
on Electronic Properties
of Novel Materials

Molecular Nanostructures

Program

Hotel Sonnalp
Kirchberg/Tirol
Austria

07 - 14 March, 2015
SUPPORTERS
Verein zur Durchführung der International Winterschool on Electronic Properties of Novel Materials
Verein zur Förderung der Internationalen Winterschulen in Kirchberg Austria

PATRONAGE
Helmut Berger
Major of Kirchberg

LAYOUT
María Machón, Felix Herziger
Logo designed by Felix Herziger
The logo shows a Raman map of the laser-written “IWEPNM 2015” logo in CVD graphene.

SPONSORS
HORIBA Jobin Yvon GmbH
Neuhostrasse 9, 64625 Bensheim
Germany

Nature Publishing Group
Brunel Road, Houndmills, Basingstoke RG21 6XS
United Kingdom

Wiley VCH
Boschstrasse 12, 69469 Weinheim
Germany

Financial assistance from the sponsors and supporters is greatly acknowledged.
Dear Friend:

Welcome to the 29th International Winterschool on:

**Electronic Properties of Novel Materials: "Molecular nanostructures"**

This Winterschool is a sequel of twenty-eight previous meetings held in Kirchberg in the last decades on problems related to the electronic structure of novel materials. The idea of the meeting is to bring together experienced scientists from universities and industry with advanced students working in the selected field and thus create a fruitful and prosperous community for the exchange of scientific information and personal experience. It is a tradition of the Winterschools in Kirchberg that this exchange is not restricted to the lectures and poster sessions but occurs throughout the whole week.

The Winterschool is dedicated to molecular nanostructures as a new class of materials. Like the previous Winterschools it runs on an informal level.

If you have any questions concerning the organization and the program, come and see one of us or one of the colleagues involved in the preparation of the meeting. These persons are:

- Janina Maultzsch: program
- Hans Tornatzky, Dirk Heinrich: accommodation
- Amelie Biermann: finances
- Asmus Vierck, Harald Scheel: website
- Nils Scheuschner, Roland Gillen: technical assistance, video transfer, sponsoring
- Sevak Khachadorian: announcements
- Emanuele Poliani, Aurélie Pierret: technical assistance
- Felix Kampmann: website assistance, visa applications
- Felix Herziger, Christoph Tyborski: abstract booklet
- Anja Sandersfeld: visa applications, general assistance

Also the managers of the hotel, Mrs. Mayer and Mr. Mayer, and their staff promised to help us wherever they can. We want to acknowledge their help.

We wish you an interesting, successful, and pleasant week in Kirchberg. We are very much looking forward to your contributions at the event.

Sincerely yours,

Christian, Janina, Andreas, Hans, Stephanie, and Siegmar
Chairpersons

C. Thomsen (Berlin)
J. Maultzsch (Berlin)
A. Hirsch (Erlangen)
H. Kuzmany (Vienna)
S. Reich (Berlin)
S. Roth (Munich)

Program Committee

E. Andrei (US)  A. Loiseau (FR)  A. Rubio (ES)
A. Bachtold (ES) J. Maultzsch (DE) P. Rudolf (NL)
P. Dinse (DE)    F. Mauri (FR)    C. Schönenberger (CH)
M. Dresselhaus (US) G. Mele (US) P. Sheng (CN)
L. Forro (CH)    K. S. Novoselov (UK) N. Shinohara (JP)
M. Fuhrer (AU)   E. Obraztsova (RU) F. Simon (HU)
T. F. Heinz (US) A. Penicaud (FR) C. Stampfer (DE)
A. Hirsch (DE)   Th. Pichler (AT) Z. K. Tang (CN)
A. Jorio (BR)    M. Prato (IT)    C. Thomsen (DE)
H. Kataura (JP)  S. Reich (DE)    A. Zettl (US)
H. Kuzmany (AT)  J. Robertson (UK)
Y. H. Lee (KR)   S. Roth (DE)

Scope

This winterschool will provide a platform for reviewing and discussing new developments in the field of electronic properties of molecular nanostructures and their applications. Subjects included are:

- Materials science of graphene and nanographene
- Novel two-dimensional materials
- Carbon nanotube / graphene optics and electronics
- Carbon nanotube / graphene growth and selection
- Theory of novel materials
- Applications of novel materials
- Nanostructure spintronics
- Topological insulators
- Single-molecule experiments
INFORMATION FOR PARTICIPANTS

Time and location
The IWEPNM 2015 starts on Saturday, 7 March, evening, at the hotel Sonnalp in Kirchberg/Tirol, Austria and extends to Saturday, 14 March, breakfast. There will be a reception party on 7 March, after dinner, and a farewell party including dinner on Friday, 13 March.

Transport
The hotel Sonnalp can be reached by private car from downtown Kirchberg by driving about one kilometer towards Aschau. Participants arriving at the railway station in Kirchberg or Kitzbühel should hire a taxi to get to the hotel.

Addresses
The address of the Winterschool is:
IWEPNM 2015, Hotel Sonnalp, A-6365 Kirchberg/Tirol, Austria
e-mail: info@hotelsonnalp.info, web: www.hotelsonnalp.info

All questions concerning the IWEPNM 2015 should be directed to:
Prof. Dr. Christian Thomsen,
Institut für Festkörperphysik, Technische Universität Berlin
Hardenbergstr. 36, 10623 Berlin, Germany
Tel: 0049-(0)30-31423187, Fax: 0049-(0)30-31427705
e-mail: iwepnm-info@physik.tu-berlin.de, web: www.iwepnm.org

Participation
Participation at the IWEPNM 2015 is possible for students and scientists working in the field covered by the scope of the meeting. Because of the limited space the participation requires prearranged acceptance by the organizers.

Contributions
All oral contributions will be presented in the big seminar room of the Hotel Sonnalp. Participants are invited to contribute comments to research and tutorial lectures where 10 minutes for discussion are reserved after each lecture. Video projection will be available for presentations. Presentation of video films needs prearranged confirmation. Invited speakers please test the video projection with the technical staff at the latest a few minutes before your session begins. Posters will be presented in the hall of the seminar room.

Childcare
Childcare is provided by Michaela Kisch and her team (michaela@kitzkids.com, Tel.: 0043-664-5225265). If you need childcare during the winterschool, please contact us at the registration desk.
Ski pass and internet connection
If you wish to buy a ticket for the ski lifts, please ask at the hotel reception on Saturday evening.
Internet connection through WLAN is available for all participants, even if they are not accommodated at the Hotel Sonnalp. Please check at the front desk. There will be a room in the basement with fixed LAN connections, and limited number of laptops for free internet use.

Poster awards
There will be a poster award for the best poster presentation in each poster session on Monday, Tuesday, and Thursday. All participants are welcome to cast their vote and choose the best poster presentation. Poster awards are kindly provided by Wiley VCH and Nature Publishing Group.

Conference Publication
Invited and contributed presentations from IWEPNM 2015 are scheduled for publication in physica status solidi (pss). Manuscript submission is due on April 15th. The publication is planned as a special issue with regular articles to be published in the journal pss (b) (Feature Articles/topical reviews, Original Papers) or pss (c). In selected cases articles are highlighted in pss (RRL) (Reviews@RRL, Rapid Research Letters). A hardcover edition will be distributed to the participants. Accepted manuscripts will fulfill the standards and requirements of the journal and are peer-reviewed in the same way as regular submissions. Acceptance of a contribution for presentation at the winterschool does not automatically include acceptance for publication in the special issue. Detailed information will be provided at the winterschool.

Manuscript preparation and submission
Preparation instructions and templates are available at http://www.pss-b.com → Author guidelines. Manuscripts of contributed presentations are limited to 6 pages (no page limit for invited presentations). We strongly recommend using the Word or Latex templates to get an accurate estimate of the article length. Do not modify any pre-settings in the style files such as font sizes, margins, and other formats, to avoid an incorrect layout of the publication.
Please submit one complete PDF- or Word-file for review (Word or Latex source files are required after acceptance for production).
The submission system is here:
http://www.editorialmanager.com/pssb-journal
Select article type "Original Paper" and section "IWEPNM 2015: Electronic Properties of Novel Materials". If you intend to submit a "Rapid Research Letter" or a "Feature Article" manuscript, please consult with the editors.
pss editorial office e-mail: pss@wiley-vch.de
The following participants are asked to support the program of the Winterschool by serving as chairperson:

Sunday, 08.03.  
- morning: Kuzmany  
- morning, after coffee break: Lotsch  
- evening: Reich

Monday, 09.03.  
- morning: Ernst  
- morning, after coffee break: Jorio  
- evening: Obraztsova

Tuesday, 10.03.  
- morning: Thomsen  
- morning, after coffee break: Backes  
- evening: Haigh

Wednesday, 11.03.  
- morning: Rudolf  
- morning, after coffee break: Berciaud  
- evening: Skákalová

Thursday, 12.03.  
- morning: Kaiser  
- morning, after coffee break: Andrei  
- evening: Roth

Friday, 13.03.  
- morning: Krupke  
- morning, after coffee break: Pichler  
- evening: Hirsch

Chairpersons are asked to start the sessions in time and to terminate the lectures according to schedule. The discussions may be extended up to 5 minutes beyond the schedule.

Chairpersons please remember:  
You have to ask for questions from the sideroom (bar)!

For questions from the main room please ask the speaker to repeat the question. The chairperson’s microphone should only be passed on to questions from the first row.

If there are any objections to the suggested list of chairpersons, please let us know at the beginning of the Winterschool.

We acknowledge your support.  

The Organizers
<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Growth of graphene: In-situ observations and chemical considerations</td>
<td>Schöler</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>Functional organic frameworks as platforms for light-driven hydrogen evolution</td>
<td>Tanaka</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Structure separation of SWCNTs by column chromatography using mixed solvent</td>
<td>Garcia de Abajo</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Optoelectronics with Aligned Carbon Nanotube Films</td>
<td>Konno</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Ultrafast electronic read-out of a diamond nitrovacancy center coupled to graphene</td>
<td>Bockrath</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Manipulating the magnetic state of a carbon nanotube using the superconducting phase</td>
<td>Deblock</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Quantum Design in Carbon Nanotubes</td>
<td>Prato</td>
<td>Conference Room G</td>
</tr>
<tr>
<td>12:00</td>
<td>Coffee break</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Monday, March 09**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Two-dimensional materials and heterostructures</td>
<td>Geim</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>The rise of van der Waals heterostructures</td>
<td>Koster</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene</td>
<td>Müller</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Van der Waals heterostructures composed of thin 2D semiconductors sensitive to atmospheric exposure</td>
<td>Gorbachev</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Coupling in quasi-atomically thin transition layer dichalcogenides crystals</td>
<td>Cui</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Elicitors and many-body phenomena in atomically thin 2D materials</td>
<td>Chernikov</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Quantum spectroscopy and reflection/transmission measurements for graphene characterization</td>
<td>Pallot</td>
<td>Conference Room G</td>
</tr>
</tbody>
</table>

**Tuesday, March 10**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Graphene functionalization and nano-mechanics</td>
<td>Prato</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>Variations of Functionalized Carbon Nanostructures</td>
<td>Shafer</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Plasmons in nanographene and other atomic scale systems</td>
<td>Garcia de Abajo</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Quantum interference in plasmon-enhanced Raman scattering</td>
<td>Müller</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene</td>
<td>Bockrath</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer</td>
<td>Maruyama</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Quantum Design in Carbon Nanotubes</td>
<td>Prato</td>
<td>Conference Room G</td>
</tr>
</tbody>
</table>

**Wednesday, March 11**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Artificial Atoms in Graphene</td>
<td>Andrei</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>Electronic properties of 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene</td>
<td>Müller</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Topological Winding Number and Broken Inversion Symmetry in a Holzer-Buchanan system</td>
<td>Gori</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene</td>
<td>Müller</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Van der Waals heterostructures composed of thin 2D semiconductors sensitive to atmospheric exposure</td>
<td>Gorbachev</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Coupling in quasi-atomically thin transition layer dichalcogenides crystals</td>
<td>Cui</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Elicitors and many-body phenomena in atomically thin 2D materials</td>
<td>Chernikov</td>
<td>Conference Room G</td>
</tr>
</tbody>
</table>

**Thursday, March 12**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>The rise of van der Waals heterostructures</td>
<td>Koster</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene</td>
<td>Müller</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Plasmons in nanographene and other atomic scale systems</td>
<td>Garcia de Abajo</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Quantum interference in plasmon-enhanced Raman scattering</td>
<td>Müller</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene</td>
<td>Bockrath</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer</td>
<td>Maruyama</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Quantum Design in Carbon Nanotubes</td>
<td>Prato</td>
<td>Conference Room G</td>
</tr>
</tbody>
</table>

**Friday, March 13**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Growth of graphene: In-situ observations and chemical considerations</td>
<td>Schöler</td>
<td>Hall A</td>
</tr>
<tr>
<td>09:00</td>
<td>Functional organic frameworks as platforms for light-driven hydrogen evolution</td>
<td>Tanaka</td>
<td>Hall B</td>
</tr>
<tr>
<td>09:30</td>
<td>Structure separation of SWCNTs by column chromatography using mixed solvent</td>
<td>Garcia de Abajo</td>
<td>Hall C</td>
</tr>
<tr>
<td>10:00</td>
<td>Quantum interference in plasmon-enhanced Raman scattering</td>
<td>Müller</td>
<td>Hall D</td>
</tr>
<tr>
<td>10:30</td>
<td>Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene</td>
<td>Bockrath</td>
<td>Conference Room E</td>
</tr>
<tr>
<td>11:00</td>
<td>Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer</td>
<td>Maruyama</td>
<td>Conference Room F</td>
</tr>
<tr>
<td>11:30</td>
<td>Quantum Design in Carbon Nanotubes</td>
<td>Prato</td>
<td>Conference Room G</td>
</tr>
</tbody>
</table>

**Final program**

- **Sunday, March 08**
  - 08:30 Growth of graphene: In-situ observations and chemical considerations
  - 09:00 Functional organic frameworks as platforms for light-driven hydrogen evolution
  - 09:30 Structure separation of SWCNTs by column chromatography using mixed solvent
  - 10:00 Quantum interference in plasmon-enhanced Raman scattering
  - 10:30 Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene
  - 11:00 Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer
  - 11:30 Quantum Design in Carbon Nanotubes

- **Monday, March 09**
  - 08:30 Two-dimensional materials and heterostructures
  - 09:00 The rise of van der Waals heterostructures
  - 09:30 Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene
  - 10:00 Van der Waals heterostructures composed of thin 2D semiconductors sensitive to atmospheric exposure
  - 10:30 Coupling in quasi-atomically thin transition layer dichalcogenides crystals
  - 11:00 Elicitors and many-body phenomena in atomically thin 2D materials

- **Tuesday, March 10**
  - 08:30 Graphene functionalization and nano-mechanics
  - 09:00 Variations of Functionalized Carbon Nanostructures
  - 09:30 Plasmons in nanographene and other atomic scale systems
  - 10:00 Quantum interference in plasmon-enhanced Raman scattering
  - 10:30 Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene
  - 11:00 Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer
  - 11:30 Quantum Design in Carbon Nanotubes

- **Wednesday, March 11**
  - 08:30 Artificial Atoms in Graphene
  - 09:00 Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene
  - 09:30 Plasmons in nanographene and other atomic scale systems
  - 10:00 Quantum interference in plasmon-enhanced Raman scattering
  - 10:30 Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene
  - 11:00 Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer
  - 11:30 Quantum Design in Carbon Nanotubes

- **Thursday, March 12**
  - 08:30 The rise of van der Waals heterostructures
  - 09:00 Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene
  - 09:30 Plasmons in nanographene and other atomic scale systems
  - 10:00 Quantum interference in plasmon-enhanced Raman scattering
  - 10:30 Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene
  - 11:00 Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer
  - 11:30 Quantum Design in Carbon Nanotubes

- **Friday, March 13**
  - 08:30 Growth of graphene: In-situ observations and chemical considerations
  - 09:00 Functional organic frameworks as platforms for light-driven hydrogen evolution
  - 09:30 Structure separation of SWCNTs by column chromatography using mixed solvent
  - 10:00 Quantum interference in plasmon-enhanced Raman scattering
  - 10:30 Ultrastable electronic read-out of a diamond nitrovacancy center coupled to graphene
  - 11:00 Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer
  - 11:30 Quantum Design in Carbon Nanotubes
| 12:00-17:00 | Mini workshops | Mini workshops | Special workshop Nano & Society | Mini workshops | Mini workshops | Mini workshops |
| 17:00-18:30 | Dinner | Dinner | Dinner | Dinner | Dinner | Dinner |
| 18:30-19:00 | Why do nanotubes grow mostly chiral? Why would graphene grow not as hexagon? YAKOBSON | Strategies of imaging low-dimensional electron-beam-sensitive objects with low-voltage aberration-corrected TEM KAISER | Spin and valley dynamics of excitons in transition metal dichalcogenides GLAZOV | Nematic, topological and Berry phases when a flat and a parabolic band touch DORA | Powerful, Giant-Stroke Artificial Muscles From Twisted and Coiled Carbon Nanotube Yarns BAUGHMAN | 17:00 High Performance X-ray Transmission Windows Based on Graphenic Carbon KREUPL |
| 19:30-20:00 | Molecular Bandgap Engineering in Bottom-Up Fabricated Graphene Nanostructures FISCHER | Cross sectional scanning transmission electron microscope imaging and analysis of multi-layered graphene based heterostructures HAIGH | Vapour phase Synthesis and Functionalisation of 2D Transition Metal Films DUESBERG | Magneto Raman spectroscopy of suspended graphene layers BERCIAUD | 18:00 Conference Summary STAMPFER | 18:30 - 20:00 Break |
| 20:00-20:30 | Electronic and Optical Properties of Atomically Precise Graphene Nanoribbons RUFFIEUX | Poster I Monday | Poster II Tuesday | Poster III Thursday | Bauernbuffet Farewell |
| **Topics** | Carbon materials: design, growth, and applications | Graphene plasmonics, optics, and imaging | Two-dimensional materials and heterostructures | Graphene spectroscopy, topological materials | Graphene functionalization and nano-mechanics | Superconductivity, spins, and applications |
| **Days** | Sunday, March 08 | Monday, March 09 | Tuesday, March 10 | Wednesday, March 11 | Thursday, March 12 | Friday, March 13 |
PROGRAM

AND

ABSTRACTS
New from the ADVANCED MATERIALS journal family

ADVANCED SCIENCE

Premium open access journal publishing research from all areas of science

Submit your work now: www.editorialmanager.com/advancedscience

- Fast, rigorous peer-review
- Highest quality research
- Covers all areas of science
- Rapid publication of accepted articles
- Freely available on Wiley Online Library and PubMed Central
- Authors retain copyright
- Articles published with Creative Commons Attribution (CC-BY) licenses

www.advancedscience.com
08:30 – 09:00  R. Schlögl, Berlin
Growth of graphene: In-situ observations and chemical considerations

09:00 – 09:30  B. Lotsch, Stuttgart
Functional organic frameworks as platforms for light-driven hydrogen evolution

09:30 – 10:00  T. Tanaka, Tsukuba
Structure separation of SWCNTs by column chromatography using mixed surfactant

10:00 – 10:30  coffee break

10:30 – 11:00  J. Kono, Houston
Optoelectronics with Aligned Carbon Nanotube Films

11:00 – 11:30  R. Deblock, Orsay
Manipulating the magnetic state of a carbon nanotube Josephson junction using the superconducting phase

11:30 – 12:00  S. Ilani, Rehovot
Quantum Design in Carbon Nanotubes

12:00 – 17:00  mini workshops

17:00 – 18:30  Dinner

18:30 – 19:00  B. Yakobson, Houston
Why do nanotubes grow mostly chiral? Why would graphene grow not as hexagon?

19:00 – 19:30  K. Amsharov, Erlangen
Atomically Precise Synthesis of Carbon Based Nanostructures

19:30 – 20:00  F. Fischer, Berkeley
Molecular Bandgap Engineering in Bottom-Up Fabricated Graphene Nanostructures

20:00 – 20:30  P. Ruffieux, Dübendorf
Electronic and Optical Properties of Atomically Precise Graphene Nanoribbons
**08:30**

**Growth of graphene: In-situ observations and chemical considerations**

Robert Schögl

1Fritz-Haber-Institut der MPG, Department of Inorganic Chemistry, Berlin, Germany

The growth of graphene has been the subject of many morphological and conceptual studies. Mostly morphological features and chemical properties evaluated post-growth were used as arguments to formulate several concepts of graphene formation. The chemistry of metallic supports as catalysts and transport phenomena at the growth surface were not frequently considered.

Owing to the ability to observe the growth of graphene in-situ by a chemical scanning electron microscope we were able to delineate processes of substrate transformations from those of graphene formation. The combination of microscopic studies with NAP-XPS experiments[1] performed under identical conditions allows drawing conclusions about the chemical state of growing graphene systems.

We discriminate three different modes of growth from the different control modes of carbon species. These modes are controlled by the choice of the metallic substrate acting in different ways as source of the carbon building blocks. The relation of these modes to the chemical and morphological quality of the final product will be discussed.

09:00

**Functional organic frameworks as platforms for light-driven hydrogen evolution**

Bettina Valeska Lotsch\(^1,2\)

\(^1\)Max-Planck-Institut für Festkörperforschung, Stuttgart

\(^2\)Ludwig-Maximilians-Universität München

The conversion of sunlight into storable chemical fuels has been identified as a viable strategy to alleviate future energy shortage. To this end, the development of efficient photocatalysts capable of splitting water into hydrogen and oxygen has become a major thrust in materials science. While heterogeneous systems excel through their stability, homogeneous catalysts offer the potential to tune every step in the photocatalytic mechanism through molecular engineering. Combining the best of both worlds in molecularly defined heterogeneous systems therefore opens up new possibilities for the rational design of photocatalysts with optimized efficiencies.

In this talk, polymeric photocatalysts based on 1D or 2D carbon nitrides and covalent organic frameworks (COFs) will be highlighted and catalyst optimization strategies - through doping[1], exfoliation[2], functionalization[3], as well as hybridization with bio-inspired co-catalysts[4] - will be discussed.


09:30
Structure separation of SWCNTs by column chromatography using mixed surfactant

Takeshi Tanaka¹, Yohei Yomogida¹, Xiaojun Wei¹, Mayumi Tsuzuki¹, Atsushi Hirano¹, Shunjiro Fujii¹, Hiromichi Kataura¹
¹Nanosystem Research Institute, AIST, Tsukuba, Japan

Single-wall carbon nanotubes (SWCNTs) are produced as a mixture of various structures, and the inhomogeneity hinders their fundamental research and applications. We have developed methods for single chirality and isomer separations of SWCNTs by overloading separation and temperature control separation using gel column chromatography (1). In this presentation, we show improved separation methods using mixed surfactant. The first separation method was combined overloading selective adsorption and stepwise elution using a mixed surfactant system. This method could separate not only chiralities but also isomers of SWCNTs at very high purities. The second separation method was combined different mixed surfactant systems for selective adsorption and desorption. This method is simpler than overloading method and enables us to achieve high-throughput separation up to mg/day production of (9,4) and (10,3) SWCNTs. This work was supported by KAKENHI No. 25220602. (1) H. Liu et al.: Nature Commun., 14, 309 (2011), Nano Lett., 13, 1996 (2013), Nano Lett., 14, 6237 (2014).
The one-dimensional (1D) character of confined carriers and excitons in carbon nanotubes (CNTs) leads to extremely anisotropic electric, magnetic, and optical properties. Individual metallic CNTs have been shown to be excellent conductors with long coherence lengths, while individual semiconducting CNTs have been shown to strongly absorb and emit light only when the light polarization is parallel to the tube axis. Even in macroscopic assemblies of CNTs, their anisotropic properties are expected to be preserved, but systematic optical, photonic, and optoelectronic studies have been limited. Here, we present results of a variety of electrical and optical measurements of large-area films of aligned single-wall, double-wall, and multiwall CNTs, demonstrating a rich array of phenomena promising for optoelectronic applications. In particular, we will provide a detailed description of their anisotropic response in the terahertz region of the electromagnetic spectrum due to their inherently 1D intraband carrier dynamics.
Manipulating the magnetic state of a carbon nanotube Josephson junction using the superconducting phase

R. Delagrange\textsuperscript{1}, D. J. Luitz\textsuperscript{2}, R. Weil\textsuperscript{1}, A. Kasumov\textsuperscript{1}, V. Meden\textsuperscript{3}, H. Bouchiat\textsuperscript{1}, R. Deblock\textsuperscript{1}

\textsuperscript{1}Laboratoire de Physique des Solides, Orsay (France)
\textsuperscript{2}Laboratoire de Physique Théorique, Toulouse (France)
\textsuperscript{3}RWTH Aachen University and JARA, Aachen (Germany)

When a metal contains magnetic impurities, their associated moments can be screened by the conduction electrons, resulting in a singlet state. This many-body phenomenon is at the heart of the Kondo effect. If the metal is replaced by a superconductor, the singlet can be destroyed in favor of a magnetic doublet. This is accompanied by a sign change of the supercurrent in a junction geometry. This singlet-doublet transition was shown to depend on the relevant energy scales: the Kondo temperature and the superconducting gap, as well as the position of the impurity level. In the present work we show that the superconducting phase difference across a quantum dot can also control this magnetic transition of a Kondo impurity. We measured the relation between the supercurrent and the superconducting phase difference of a carbon nanotube Josephson junction. It exhibits distinctively anharmonic behavior, revealing the phase mediated singlet to doublet transition, in excellent agreement with finite temperature quantum Monte Carlo calculations and provides insights on the phase controlled level-crossing transition at zero temperature.
11:30
Quantum Design in Carbon Nanotubes
Shahal Ilani$^1$
$^1$Weizmann Institute, Rehovot

Recent years have seen the development of several experimental systems capable of tuning local parameters of quantum Hamiltonians, including ultracold atoms, trapped ions, superconducting circuits and photonic crystals. These systems excel in studying the physics of bosons in disorder-free settings. A solid state analog, in which Hamiltonians of interacting electrons are designed and studied, remains a major open challenge, since in conventional solids electrons exist inside an imperfect host material that generates uncontrolled disorder. In this talk, I will describe our newly-developed platform for realizing in suspended carbon nanotubes such disorder-free, locally-tunable electronic systems. This platform becomes possible due to a new technique for nano-assembly of carbon nanotubes on complex electrical circuits without damaging their pristine electronic behavior. I will show a new experiment in which we have used this system to radically change the nature of interactions between electrons.
Why do nanotubes grow mostly chiral? Why would graphene grow not as hexagon?

Boris I. Yakobson

Rice University, Houston, USA

In spite of similar edge dynamics of a tube or sheet, their topologies impact profoundly their morphology evolution. The closed loop of graphene edge by necessity contains different crystallographic orientations; the tube edge can preserve same crystallographic direction all around. Graphene flake can change shape on the fly; the tube helicity is locked after its cap is complete with 6 pentagons. The first title-?n is answered in 1991 paper by Iijima, yet it took decades to derive a formula, \( R = \sin x \) (growth rate \( R \), helical angle \( x \)). An alternative view - of which Smalley was loud proponent - is that thermodynamics favors the low energy armchair edge. A subtle balance of these views reveals sharply peaked abundance distribution \( A = x \exp(-x) \) and explains the puzzling (n,n-1) types in many experiments [Artyukhov-Penev, Nature Comm. 5, 489, 2014]. To the second title-?n, DFT and MC modeling explain the shapes of symmetry lower than the symmetries of graphene and substrate. In equilibrium, edge energy variation \( dE \) manifests in slightly distorted hexagons. In growth, it enters as \( \exp(-dE/kT) \), amplifying the symmetry breaking to triangle, ribbon, rhomb [Artyukhov et al. PRL, 2015].
19:00

**Atomically Precise Synthesis of Carbon Based Nanostructures**

Konstantin Amsharov

Institute of Organic Chemistry II, Universität Erlangen-Nürnberg, Erlangen

Carbon based nanostructures such as fullerenes, nanotubes, nanographenes and nanoribbons attract considerable attention because of their unique properties and many potential applications. Since the diversity in properties strongly depends on the molecular structure, new methods for fabrication of these materials on atomically precise level are needed. Our methodology is based on the domino-like condensation of respective precursor molecules, which are pre-programmed for the construction of desired nanostructure exclusively. The approach allows access to isomer pure fullerenes, atomically precise nanographenes, and helicity pure nanotubes. The approach is not limited to the synthesis of fullerenes, carbon nanotubes and nanographenes but can be applied as well to the fabrication of various carbon based nanostructures including, but not limited to, exo-, endo-hedral, hetero- or open cage fullerenes, functional SWCNT, nanocones and many other related systems.
Bandgap engineering has long played a vital role in technology by enabling semiconductor heterostructures to exhibit important behaviors such as resonant tunneling and enhanced solar conversion efficiency. As the dimensions of conventional electronic devices reduce further in size, however, their performance suffers due to short-channel effects and rough interfaces. Graphene-based molecular electronics has emerged as a possible candidate to overcome these obstacles by enabling control of electronic transport down to single-molecule scales. It has been predicted that bandgap engineering within single graphene nanoribbons (GNRs) may be achieved by varying the width of covalently bonded GNR segments, but the experimental realization remains challenging. We demonstrate the rational bottom-up synthesis of width-modulated armchair GNR (AGNR) heterostructures, obtained by fusing segments of two different molecular building blocks. We study the resultant heterojunctions at sub-nanometer length-scales via scanning tunneling microscopy (STM) and spectroscopy (STS), and identify spatially modulated electronic structure that demonstrates molecular-scale bandgap engineering.
Electronic and Optical Properties of Atomically Precise Graphene Nanoribbons

Pascal Ruffieux

1nanotech@surfaces Laboratory, Empa, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

Graphene nanoribbons (GNRs) are predicted to be semiconductors with an electronic band gap that sensitively depends on the ribbon width. This opens new ways for the design of GNR-based structures and heterostructures with specific and widely tunable electronic properties, but requires structuring at the atomic level. Recently, we reported the successful bottom-up fabrication of atomically precise GNRs1 based on surface-assisted synthetic routes using specifically designed precursor monomers. Here, I will review the bottom-up fabrication of prototypical GNRs and their electronic and optical characterization2,3. An important handle for further tuning the electronic properties of GNRs is achieved by deterministic chemical doping. In particular, heterocycle containing precursor monomers can be used for the fabrication of nitrogen-doped GNRs and related GNR heterostructures4.

AFM-Raman made easy
Versatile, powerful and reliable TERS solutions

Horiba Jobin Yvon GmbH
Tel. 06251-8475-0
info-sci.de@horiba.com
www.horiba.com/de/scientific
08:30 – 09:30  S. Maier, London
Tutorial: Exploitation of plasmon and phonon polariton modes for sub-wavelength confinement in graphene and polar dielectrics

09:30 – 10:00  J. García de Abajo, Barcelona
Plasmons in nanographene and other atomic scale systems

10:00 – 10:30  coffee break

10:30 – 11:00  S. Heeg, Manchester
Quantum interferences in plasmon-enhanced Raman scattering unraveled by graphene

11:00 – 11:30  A. Holleitner, Garching
Ultrafast electronic read-out of diamond nitrogen-vacancy centers coupled to graphene

11:30 – 12:00  S. Maruyama, Tokyo
Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer for Solar Cells

12:00 – 17:00  mini workshops

17:00 – 18:30  Dinner

18:30 – 19:00  U. Kaiser, Ulm
Strategies of imaging low-dimensional electron-beam-sensitive objects with low-voltage aberration-corrected TEM

19:00 – 19:30  K. Suenaga, Tsukuba
Atomic Imaging and Spectroscopy of Low-Dimensional Materials

19:30 – 20:00  S. Haigh, Manchester
Cross sectional scanning transmission electron microscope imaging and analysis of multi-layered graphene based heterostructures

20:00  Poster I
08:30
Exploitation of plasmon and phonon polariton modes for sub-wavelength confinement in graphene and polar dielectrics
Stefan Maier¹
¹Physics, Imperial College London, London

Surface plasmon and surface phonon polaritons allow the two-dimensional confinement below the diffraction limit at interfaces between conductive and dielectric media. For the case of graphene, we will discuss the dynamics of hot electron generation mediated by localised surface plasmons of metal nanoparticle arrays, and evaluate the potential for ultrafast photodetection in hybrid graphene/metal nanoparticle structures. For polar dielectrics such as SiC, the confinement relies on the excitation of low loss phonon modes, allowing both high quality factors and ultrasmall mode volumes in the mid-infrared. This will be elucidated for the case of SiC nanopillar arrays. Lastly, hBN combines polar character with a natural multilayer structure due to weak van der Waals bonding between adjacent crystal planes. This leads to optical anisotropy and hence hyperbolicity. Arrays of nanocones of hBN therefore allow an intriguing avenue for creating truly three-dimensional sub-wavelength confinement in the mid infrared.
09:30
Plasmons in nanographene and other atomic scale systems
Javier García de Abajo\textsuperscript{1}
\textsuperscript{1}ICFO - The Institute of Photonic Sciences, Barcelona

We will review recent advances in the control and understanding of plasmons in systems that have atomic dimensions along one or more directions. In particular, we will discuss plasmons in graphene, carbon nanotubes, and fullerenes, as well as thin metal layers and molecules such as polycyclic aromatic hydrocarbons. A simple, powerful, analytical eigenmode expansion formalism will be reviewed in the electrostatic limit, along with tutorial examples of application to the understanding of plasmons in these systems, including the derivation of approximate expressions for the plasmon frequencies and wave functions. Intrinsic advantages of plasmons in atomic-scale systems will be also discussed, and in particular, their large electrical tunability, their strong nonlinear response, and the possibility of reaching quantum strong coupling.
Quantum interferences in plasmon-enhanced Raman scattering unraveled by graphene

Sebastian Heeg\textsuperscript{1,2}, Patryk Kusch\textsuperscript{1}, Christian Lehmann\textsuperscript{1}, Niklas Müller\textsuperscript{1}, Sören Wasserroth\textsuperscript{1}, Antonios Oikonomou\textsuperscript{2}, Nick Clark\textsuperscript{2}, Aravind Vijayaraghavan\textsuperscript{2}, Stephanie Reich\textsuperscript{1}

\textsuperscript{1}Fachbereich Physik, Freie Universität Berlin, Berlin, Germany
\textsuperscript{2}School of Materials, The University of Manchester, Manchester, UK

Plasmons are the collective excitations of free electrons in metals. They focus light into nanoscale volumes thereby enhancing local electromagnetic fields by orders of magnitude. A striking consequence is surface-enhanced Raman scattering, the giant enhancement of inelastic light scattering close to localized surface plasmons. We propose a quantum theory of plasmon-enhanced Raman scattering \cite{1}. It is based on the quantum mechanical description of the Raman effect and predicts quantum interferences between scattering channels. Using graphene as a non-resonant Raman probe coupled to a plasmonic nanodimer, we demonstrate experimentally the predictions of our approach. At the dimer resonance, the G-mode of graphene is enhanced by $10^5$, but differs by a factor of two for the regimes of enhanced absorption and emission. In resonance, we further observe an altered polarization dependence of the G-mode and the appearance of defect-type modes in perfect graphene. Our results cannot be explained within the conventional framework of plasmon-enhanced Raman scattering: They verify the quantum nature of plasmon-enhanced Raman scattering. The proposed model provides a unified theory of surface- and tip-enhanced Raman spectroscopy.

11:00

Ultrafast electronic read-out of diamond nitrogen-vacancy centers coupled to graphene

Alexander Holleitner

Walter Schottky Institut and Physik-Department, Technische Universität München, Garching

We apply an ultrafast photocurrent spectroscopy to detect the non-radiative energy transfer from diamond nitrogen vacancy centers to graphene [1-4] with a time resolution of picoseconds [5,6]. Such centers are considered to play a fundamental role in new quantum information technologies. Our findings demonstrate that the transfer can be exploited as an electronic read-out process of the electron spin in the nitrogen vacancy centers. Furthermore, the ultrafast detection gives access to fast energy transfer processes, which are quenched in fluorescence measurements for short transfer distances [7].

We thank A. Brenneis, L. Gaudreau, M. Seifert, H. Karl, M.S. Brandt, H. Huebl, J.A. Garrido, and F.H.L. Koppens for a very fruitful collaboration and the ERC-grant "NanoREAL" for funding.

1. Z. Chen et al. ACS Nano 4, 2964 (2010).
11:30

**Single-Walled Carbon Nanotubes and Graphene as Highly Efficient Hole Extraction and Transport Layer for Solar Cells**

Shigeo Maruyama¹, Kehang Cui¹, Takaaki Chiba¹, Xiao Chen¹, Rong Xiang¹, Shohei Chiashi¹

¹Department of Mechanical Engineering, The University of Tokyo, Tokyo

Structured single-walled carbon nanotubes (SWNTs) and millimeter-scale monocrystalline graphene are investigated as an advanced hole extraction and transport layer in various kinds of solar cells [1-4]. We found out that three-dimensional honeycomb structured SWNTs fabricated by breath figure directed self-assembly demonstrated higher fill factor and low serial resistance compared with random network. We also obtained a ten-fold increase in the power conversion efficiency (PCE) by using millimeter-scale monocrystalline graphene compared with polycrystalline graphene, with the PCE over 11% before any intentional doping process. The hole collecting and transport function of SWNTs was also demonstrated in perovskite solar cells [3] and organic solar cells [4] with high PCE. More importantly, all these solar cells have high stability in the ambient.

References:

18:30

Strategies of imaging low-dimensional electron-beam-sensitive objects with low-voltage aberration-corrected TEM

Ute Kaiser¹
¹Ulm University, Ulm

Structural and electronic properties of different low-dimensional electron-beam-sensitive crystalline (ion-implanted graphene, MoS2, MoSe2, SiO2, CN, square water, transition-metal clusters) and amorphous (monolayer carbon, SiO2) objects are obtained by analytical low-voltage aberration-corrected transmission electron microscopy following three main strategies:

(1) Theory and image processing: For exact calculation of the contrast of dose-limited high-resolution TEM images for low-Z materials at low voltages, image theory and image processing needs to be improved taking into account elastic and inelastic scattering.

(2) Sample preparation: We demonstrate our method to clean graphene. We show that sandwiching clean radiation-sensitive low-dimensional objects in-between two graphene layers or embedding them into single-walled carbon nanotubes allows to reduce electron-induced damage of the objects.

(3) Low-voltage transmission electron microscope: We outline our unique voltage-tuneable low-voltage (20-80kV) spherical and chromatic aberration-corrected TEM and show first results obtained from its prototype.
19:00
Atomic Imaging and Spectroscopy of Low-Dimensional Materials
Kazutomo Suenaga¹
¹AIST, Tsukuba

In the Nanotube Research Center at AIST, we have been developing the top-level facilities of electron microscopy which enables the atomic resolution analysis of low-dimensional materials. Point defects and edge structures of graphene have been intensively studied with atomic precision in the last decade. Because the studies of atomic defects and boundaries are of general interest in the fundamental researches and becoming more and more crucial for technological applications of any nanoscale materials, the atomic scale studies can be also expanded to the other low-dimensional materials. Here I demonstrate some examples for atomic-scale imaging and spectroscopy of various low-dimensional materials with interrupted periodicities. Active 4|8 defects are most recently found to be responsible for plastic deformation of hexagonal boron-nitride (h-BN) layers. Vacancies and edges with radical bonds are also successfully assigned in h-BN. Doping and boundary behaviors of single-layered dichalcogenides (MX2) are also intensively studied. More recently, the impurity atoms such as nitrogen and silicon are proved to affect the properties of graphene.
19:30
Cross sectional scanning transmission electron microscope imaging and analysis of multi-layered graphene based heterostructures
Sarah Jane Haigh¹, Roman Gorbachev², Fred Withers², Aidan Rooney¹, Konstantin Novoselov², Andre Geim²
¹Materials, University of Manchester, Manchester, UK
²Physics, University of Manchester, Manchester, UK

By combining different two dimensional crystals within a Van der Waals heterostructure stack it is possible to produce devices with bespoke electronic bandstructures and advanced functionality. The individual crystal layers are produced by mechanical exfoliation and layered sequentially onto a Si substrate. Despite the necessity of employing polymeric support layers that are deposited and removed as part of the transfer procedure, our high resolution scanning transmission electron microscope (STEM) imaging has revealed that the heterostructure stacks form large areas of pristine synthetic crystal, free from hydrocarbon contaminants at the atomic scale (Haigh, et al. Nat Mater, 2012, 11, 764; Georgiou et al. Nat. Nano., 2013, 8, 100). More recently we have applied this technique to study devices incorporating transition metal dichalcogenides. For example, we demonstrate that STEM imaging is unique in being able to obtain critical information on the width of the h-BN tunnelling barriers as well as on the thickness and uniformity of MoS2 layers for a multiple quantum well LED heterostructure (Withers et al., Nat Mater, 2015, online).
MON 1
Hybrid Magnetic Systems based on 2D Materials: a Molecular Perspective
Gonzalo Abellán$^{1,2,3}$, Eugenio Coronado$^3$, Andreas Hirsch$^{1,2}$  
$^1$Institute of Advanced Materials and Processes (ZMP), Fürth, Germany  
$^2$Department of Chemistry and Pharmacy, University Erlangen-Nuremberg, Germany  
$^3$Institute of Molecular Science, University of Valencia, Paterna, Spain  

Hybrid inorganic/organic materials have found many applications because they allow combining the properties of inorganic solids such as robustness, durability or mechanical strength with those introduced by the organic component such as functionality, tunability and convenient derivatization by synthesis. Recently, graphene (G) and related 2D materials have attracted a considerable attention due to their appealing electronic properties and the possibility to be tailored by chemical modification. In this sense, layered double hydroxides (LDH) are promising candidates for the development of hybrid functional materials due to their chemical versatility and the broad range of applications they exhibit. Herein we will show some examples of stimuli-responsive layered magnets$^{[1,2]}$, hybrid magnetoresistive nanocomposites$^{[3,4]}$ and multifunctional systems based on LDH and graphene building blocks.  

G. A. thanks the EU for a Marie Curie Fellowship (FP7/2013-IEF-627386).  

References:  

MON 2
Hot carrier relaxation of Dirac fermions in bilayer graphene  
$^1$Department of Engineering, University of Cambridge, United Kingdom  
$^2$Department of Physics, University of Oxford, United Kingdom  
$^3$National Physical Laboratory, Teddington, United Kingdom  
$^4$Department of Microtechnology and Nanoscience, Chalmers University of Technology, Goteborg, Sweden  
$^5$U.S. Naval Research Laboratory, Washington D.C., USA  

Hot carrier dynamics in bilayer graphene has considerable importance for a variety of applications including high power electronics, and quantum Hall metrology. By epitaxial growth on SiC a coverage of 1.5 graphene monolayers was achieved as determined by XPS. Through magnetotransport measurements of epitaxial bilayer graphene devices we reveal the hot-electron energy loss rate which follows a $T^4$ power-law behaviour at carrier temperatures from 1.4-100K due to electron-acoustic
phonon interactions. Additionally we observe a carrier density dependence $n^{-3/2}$, in contrast to the $n^{-1/2}$ dependence for monolayer, such that at low carrier densities the energy loss rates in bilayer graphene exceed those of monolayer graphene. However, in a number of applications the SiC substrate is unsuitable. Therefore, we have performed CVD growth resulting in large area (40µm) individual domains of bilayer graphene. Raman spectroscopy of individual bilayer regions has revealed that a significant proportion are Bernal-stacked, suggesting that large area CVD growth of bilayer graphene is within reach for use in high power applications exploiting the fast hot-electron energy-relaxation.

MON 3
Synthesis of vertically aligned single-walled carbon nanotubes with sub-nanometer-diameter using cobalt-copper binary catalyst

Hua An¹, Kehang Cui¹, Rong Xiang¹, Taiki Inoue¹, Shohei Chiashi¹, Shigeo Maruyama¹
¹Department of Mechanical Engineering, University of Tokyo, Tokyo

Single-walled carbon nanotubes (SWNTs) have been regarded as one of the most attractive materials for electronic devices because of their unique electronic structures and fascinating properties. Since the band gap of a semiconducting SWNT inversely depends on its diameter, small-diameter SWNTs are highly desired in the application. In this study, we used a novel combination of Co/Cu as catalyst to grow small-diameter SWNTs by alcohol catalytic chemical vapor deposition. We characterized the as-grown SWNTs by scanning electron microscopy, Raman spectroscopy, optical absorption spectroscopy and transmission electron microscopy (TEM). Compared with the conventional catalyst Co/Mo¹ and Co/Fe, the combination of Co/Cu can grow sub-nanometer vertically-aligned SWNTs. The diameter and yield of SWNTs can be further tuned by parametric modulation of the growth condition. The possible mechanism through detailed TEM analysis will also be discussed. We also discuss the preliminary result of SWNTs growth from sputtered W/Co binary metal catalysts for chirality controlled synthesis².


MON 4
Monte Carlo simulations of line width dependence of carrier transport properties in graphene nanoribbon interconnects with real space edge roughness

Taichi Misawa¹, Tadashi Sakai², Yuji Awano¹
¹Department of Electronics and Electrical Engineering, Keio University, Yokohama, Japan
²Low-power Electronics Association Project (LEAP)

Because of the high integration of ULSIs, resistivity and reliability problems have become more and more serious in Cu interconnects in recent years. Graphene nanorib-
bons (GNRs) have attracted attention as a promising material for horizontal intercon-
nects to replace Cu, because of their high electron mobility and high electro-migration
tolerance. However, with the minimum feature size getting smaller, manufacturing
variants, such as the edge roughness, cannot be avoided as long as lithography and
dry etching processes are used. Because of the difficulties in experimentally fab-
ricating the controlled edges of GNRs, we developed a novel simulation model for
the GNR interconnects based on a semi-classical Monte Carlo particle method to
investigate electron transport in multi-layered GNRs with edge roughness and the
line width dependence of the transport properties [1]. We discuss the line width
dependency of carrier mobility and the effect of edge roughness scatterings on the
dependency, including the reproducibility of the simulation with a different set of
random numbers.
2014, 4-3 (2014)

MON 5
Spectroscopic metrics to determine monolayer content, mean number of layer
and lateral dimensions of liquid exfoliated transition metal dichalchogenides
Claudia Backes¹, Jonathan N Coleman¹
¹School of Physics and CRANN, Trinity College Dublin, Ireland

Two dimensional nanomaterials beyond graphene such as transition metal dichalco-
genides (TMDs) have received considerable attention the past years because of their
interesting physical properties (such as indirect-direct bandgap transitions) and ap-
plications potential in a number of areas. In order for these materials to be used
in a range of applications, large quantities need to be made available. Even though
exfoliation in suitable liquids has proven to be an important production technique, it
is limited by our inability to easily measure nanosheet sizes, thicknesses and mono-
layer content. As such, understanding of the exfoliation process and size selection
techniques are also limited.

We have recently demonstrated that mean number of layers and lateral dimensions
can simultaneously be obtained from an optical extinction spectrum due to edge and
confinement effects.[1] We have used these metrics to understand and optimise the
exfoliation process[2] and have now developed additional metrics based on the mea-
urement of the Raman and photoluminescence in liquids to quantify the monolayer
content in TMD dispersions.
1. Nature Commun, 5, 4576
2. Chem Mater, 10.1021/cm5044864
MON 6
Optical absorption induced dispersion of carbon nanotubes in a thermoplastic polymer and apparent Raman shifts in nanostructured materials

E Pavlenko\textsuperscript{1}, V Tishkova\textsuperscript{1}, P Puech\textsuperscript{1}, W Bacsa\textsuperscript{1}
\textsuperscript{1}CEMES-CNRS and University of Toulouse, 29 Jeanne Marvig, 31055 Toulouse, France

We find that PEEK, a thermoplast polymer, in the vicinity of carbon nanotubes diffuses spontaneously into CNT agglomerates at the polymer fusion temperature. Enhanced diffusion in the vicinity of polymer molecules has the effect that the tubes disperse spontaneously. We find systematic differences of the dispersion for single, double and multi-wall tubes on a PEEK surface. We will present and discuss electron microscopy and Raman images as well as temperature dependent electric transport measurements. It has been recently shown that non-uniform illumination of the focal spot due to heterogeneity at the nanometer scale can lead to apparent Raman spectral shifts. We find on step edges how the partial illumination of the focal spot can lead to red or blue shifts as large as 1-2 cm\textsuperscript{-1} depending on which side of the focal spot is illuminated. This findings have important consequences when making interpretations of spectral shifts due local strain or doping. The fact that apparent spectral shifts have been overlooked so far, implies that published work on the optical spectroscopy of nano-structure surfaces needs to be reexamined.

MON 7
C60/Collapsed Carbon Nanotube Hybrids - A Variant of Peapods

Hamid Reza Barzegar\textsuperscript{1,2}, Eduardo Gracia-Espino\textsuperscript{1}, Aiming Yan\textsuperscript{2}, Claudia Ojeda-Aristizabal\textsuperscript{2}, Gabriel Dunn\textsuperscript{2}, Thomas Wågberg\textsuperscript{1}, Alex Zettl\textsuperscript{2}
\textsuperscript{1}Department of Physics, Umeå University, 90187 Umeå, Sweden
\textsuperscript{2}Department of Physics, University of California, Berkeley, CA 94720, USA

We examine a variant of so-called carbon nanotube peapods by packing C60 molecules inside the open edge ducts of collapsed carbon nanotubes. C60 insertion is accomplished through a facile single-step solution-based process. Theoretical modeling is used to evaluate favorable low-energy structural configurations. Overfilling of the collapsed tubes allows infiltration of C60 over the full cross-section of the tubes and consequent partial or complete reinflation, yielding few-wall, large diameter cylindrical nanotubes packed with crystalline C60 solid cores.
**MON 8**

**Raman and electron microscopy study of C60 collapse/transformation to nanographene-based disordered carbon phase at high pressure/high temperature**

Vicente Benavides\(^1\), Olga P. Chernogorova\(^2\), Ekaterina I. Drozdova\(^2\), Iraida N. Pota-pova\(^2\), Alexander V. Soldatov\(^1,3\)

\(^1\)Engineering Sciences Mathematics, Lulea university of Technology, SE - 97187, Lulea, Sweden
\(^2\)A.A.Baikov Institute of Metallurgy and Materials Science (IMET), 119991 Moscow, Russia
\(^3\)Department of Physics, Harvard University, Cambridge, MA 02138, USA

Transformation of C60 polymers to superelastic hard carbon phase occurring in metal matrix in temperature interval 1000 K - 1100 K at a pressure of 5 GPa was studied by optical and scanning electron microscopy (SEM) and Raman spectroscopy. Using Raman mapping through T gradient in the sample allowed us to identify different stages of the structural transformation. We demonstrate nucleation character of the buckyballs collapse/formation of nanoclustered graphene phase (NGP) contrary to the recently proposed martensitic mechanism of this transformation [1]. Importantly, SEM and Raman show the NGP nucleation at the defects concentration sites in the parent fullerene structure that supports the proposed phase transition mechanism. The NGP-based composites exhibit further enhancement of the superior mechanical properties of the material synthesized from pure C60 [2] creating better prospective for practical applications.


---

**MON 9**

**Probing electronic excitations in mono- to pentalayer graphene by micro-magneto-Raman spectroscopy**

Stéphane Berciaud\(^1\), Denis M. Basko\(^2\), Marek Potemski\(^3\), Clément Faugeras\(^3\)

\(^1\)IPCMS, Université de Strasbourg and CNRS, France
\(^2\)LPMMC, Université Grenoble 1 and CNRS, France
\(^3\)LNCMI-Grenoble, CNRS/UJF/UPS/INSA, France

We probe electronic excitations between Landau levels in freestanding N-layer graphene over a broad energy range, with unprecedented spectral and spatial resolution, using micro-magneto Raman scattering spectroscopy. A characteristic evolution of electronic bands from two up to five Bernal-stacked graphene layers is evidenced and shown to remarkably follow a simple theoretical approach, based on a one-electron, effective bilayer model [1].

In contrast, in monolayer graphene, the band velocity associated with the Raman active electronic excitations is found to depend on the index of Landau level involved, and to vary as a function of the magnetic field [1,2]. This contradicts the single-particle picture of non-interacting massless Dirac electrons, but is accounted for by
theory when electron-electron interactions are taken into account [2]. Raman active, zero-momentum inter Landau level excitations in monolayer graphene are sensitive to electron-electron interactions, due to the non-applicability of the Kohn theorem in this system, with a clearly non-parabolic dispersion relation.


**MON 10**

**Coulomb-induced Valley Coupling in Transition Metal Dichalcogenides**

Gunnar Berghäuser¹, Anreas Knorr¹, Ermin Malic¹

¹Institut für Theoretische Physik, TU Berlin, Berlin

Within a microscopic model we investigate the impact of Coulomb-induced intervalley coupling on the optical properties of transition metal dichalcogenides (TMDs). Our approach is based on the density matrix formalism and allows an analytical treatment of the excitonic absorption under the influence of intervalley coupling. We find that the strong Coulomb interaction in these atomically thin 2-dimensional materials couples resonant excitonic states in K and K' valleys [1]. This coupling leads to a splitting of excitonic absorption peaks in the range of the trion binding energy. We further investigate the impact of experimentally accessible parameters, such as doping, dielectric environment, and the detuning of resonant states in the K and K' valley, on the intervalley coupling. The gained insights are of crucial importance for the application of TMDs in valleytronics.


**MON 11**

**Functionalization of 2H-MoS₂ with metal acetate salts**

Nina C. Berner¹,², Claudia Backes¹,³, Xin Chen¹,², Paul Lafargue¹,², Pierre LaPlace¹,², Mark Freeley¹,², Conor P. Cullen¹,², Georg S. Duesberg¹,², Jonathan N. Coleman¹,³, Aidan R. McDonald¹,²

¹CRANN and AMBER, Trinity College Dublin
²School of Chemistry, Trinity College Dublin
³School of Physics, Trinity College Dublin

Layered two-dimensional (2D) inorganic transition metal dichalcogenides (TMDs) have recently attracted great research interest due to their potential applications in catalysis, optoelectronics, and medicine. There is a growing need to improve the processing techniques and to find methods to functionalize 2D-TMDs in order to alter their surface chemistry and match it to the requirements of different applications. We have established a facile route towards the functionalization of 2D-MoS₂ which can be applied to both liquid exfoliated MoS₂ nanosheets in solution as well as to vapor-grown MoS₂ thin films and CVD-grown monolayers. We found that the reaction of 2D-MoS₂ with M(OAc)₂ (M=Cu, Ni, Zn; OAc=acetate) salts yielded
functionalized MoS$_2$-M(OC(Ac)$_2$ [1]. Importantly, this method successfully furnished the semiconducting 2H-polytype of MoS$_2$, where all previously reported functionalization methods can only be applied to the metallic and unstable 1T-polytype.


**MON 12**  
**In situ Raman spectroscopy of silica shell formation on colloidal CdSe/CdSe QDs**

Amelie Biermann$^1$, Philipp Baumeister$^1$, Tangi Aubert$^1$, Zeger Hens$^1$, Janina Maultzsch$^1$  
$^1$Institut für Festkörperphysik, TU Berlin, Berlin, Germany  
$^2$Physics and Chemistry of Nanostructures, Ghent University, Ghent, Belgium

In the last decade, colloidal nanocrystals (NC) have attracted a lot of interest because their photoluminescence (PL) in the visible, UV and infrared spectrum. The possibility to synthesize NCs with a precise control over their size, stoichiometry and crystal structure enables the use in systems like LEDs, solar cells and biological sensors and markers. The use as biological marker is of high interest, since the NC are superior in respect to conventionally used dyes in quantum yield, lifetime and narrow PL. Unfortunately most of the materials used for colloidal NC are toxic and thus not ideal for in vivo applications. One solution can be the capping of the NC in a silica shell, which provides both a chemical boundary to the surrounding as well as making the NC soluble in water without decreasing the PL. We discuss the influence of the silica shell on the encapsulated CdSe/CdS NC by Raman spectroscopy and furthermore monitor the synthesis in real time in order to gather insights on the silica growth mechanism. While the optically active CdSe core remains almost unchanged, the CdS shell shows a defined shift, that occurs during the first hours of the experiment.

**MON 13**  
**Aligning graphite platelets in copper to enhance the thermal conductivity**

Andre Boden$^1$, Benji Boerner$^1$, Patryk Kusch$^1$, Izabela Firkowska$^1$, Stephanie Reisch$^1$  
$^1$Institute of Exp. Physics, Free Univ. Berlin, Berlin

Lightweight composites with superior thermal transport properties promise great application as heat sinks for advanced electronic packaging. With the discovery of the extraordinary thermal conductivity of carbon nanotubes and graphene the interest in using these materials for heat dissipation applications has grown strongly. More specifically, using these materials to enhance the thermal properties of conventional materials such as metals or polymers. Here we present a study on refining the thermal properties of Cu by graphite platelet reinforcement. The high aspect ratio of the platelets leads to preferred orientation in the Cu matrix during the fabrication process. The degree of alignment depends on the lateral size of the platelets and
leads to anisotropic thermal conductivity of the composite which is up to 10 times higher along the graphite alignment compared to the perpendicular direction. The correlation between nanoplatelets alignment and their lateral size is quantitatively extracted from polarized Raman measurements. This information is used to derive the thermal interface resistance between Cu and graphite by means of effective medium approximation.

**MON 14**

**Ultrafast electronic readout of diamond nitrogen-vacancy centres coupled to graphene**

Andreas Brenneis\(^1\), Louis Gaudreau\(^3\), Max Seifert\(^1\), Helmut Karl\(^4\), Martin S. Brandt\(^1\), Hans Huebl\(^2\), Jose A. Garrido\(^1\), Frank H. L. Koppens\(^3\), Alexander W. Holleitner\(^1\)

\(^1\)Walter Schottky Institut and Physik-Department, Technische Universität München, Am Coulombwall 4a, 85748 Garching, Germany

\(^2\)Nanosystems Initiative Munich (NIM), Schellingstr. 4, 80799 Munich, Germany

\(^3\)ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain

\(^4\)Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

\(^5\)Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

The near-field interaction between fluorescent emitters and graphene exhibits rich physics associated with local dipole induced electromagnetic fields that are strongly enhanced due to the unique properties of graphene [1]. This interaction can be utilized to explore new limits of light-matter interactions. Recent fluorescent experiments have demonstrated that the fluorescence of nitrogen vacancy (NV) centers in diamond is quenched by the presence of graphene. We apply an ultrafast photocurrent spectroscopy [2,3] to detect the nonradiative energy transfer (NRET) from fluorescent emitters (NV centers) to graphene with a time resolution of picoseconds. Our findings demonstrate that the NRET can be exploited as an ultrafast, electronic read-out process of the electron spin in nitrogen vacancy centers in the diamond nanocrystals [4].

We thank the European Research Council (ERC) for financial support (Grant NanoREAL, No. 306754).


MON 15
Integration of graphene with atomic layer deposited Al2O3 dielectrics for future electronic devices

J. Brndiarova\textsuperscript{1}, M. Hulman\textsuperscript{1}, J. Derer\textsuperscript{1}, K. Fröhlich\textsuperscript{1}, V. Smatko\textsuperscript{1}, P. Siffalovic\textsuperscript{2}

\textsuperscript{1}Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovakia
\textsuperscript{2}Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia

Atomic layer deposition (ALD) emerges as a promising technique for deposition of thin oxide dielectric films on graphene without damage to underlying graphene lattice. However, ALD films do not form a continuous layer on pristine graphene due to the inert nature of the graphene surface. Consequently, additional surface functionalization is necessary to create functional groups for oxide film nucleation. In our contribution, Ni films with a thickness of 300 nm deposited on silicon using vacuum evaporation were used as a substrate. Graphene layers were prepared by chemical vapour deposition from methane atmosphere at a temperature of 1000 °C. Thin Al2O3 films were prepared on top of the graphene films by ALD at temperatures 100 and 200 °C. Properties of graphene films before and after the ALD growth were studied using Raman spectrometry and scanning electron microscopy. Al2O3 films were characterised by capacitance-voltage and current-voltage measurements. Ozone treatment has substantial influence both on graphene and Al2O3 dielectric properties and careful optimization should be performed for obtaining good quality dielectrics without degradation of graphene properties.

MON 16
Switching between different nitrogen forms by annealing/bombardment of CNx nanotubes

Lyubov G Bulusheva\textsuperscript{1}, Mikhail A Kanygin\textsuperscript{1}, Alexander V Okotrub\textsuperscript{1}

\textsuperscript{1}Nikolaev Institute of Inorganic Chemistry, Novosibirsk

As a result of the synthesis, CNx nanotubes usually contain different forms of nitrogen. The most common ones are graphitic nitrogen (direct substitution for carbon atom), pyridinic nitrogen (bonding with two carbon atoms), and pyrrolic nitrogen (location in a pentagonal ring). Here we show that the ratio of these nitrogen forms can be tuned by annealing and bombarding CNx nanotubes in a high vacuum. Aligned CNx nanotubes have been grown vertically on silicon substrates and a post-synthesis treatment was done directly in a chamber of X-ray spectrometer. CNx nanotube arrays were repeatedly bombarded by Ar\textsuperscript{+} ions with a kinetic energy of 0.5 and 1 keV and annealed at temperatures from 600°C to 1100°C. Electronic state of nitrogen in CNx nanotubes before and after the treatment was probed using X-ray photoelectron and X-ray absorption spectroscopy. We found that with the annealing the content of graphitic nitrogen grows while it is impossible removing all pyridinic nitrogen. The final temperature after which the concentration of latter nitrogen form remains constant was determined. Effect of dominant nitrogen form on the field emission property of CNx nanotubes was revealed.
MON 17
Light emitting devices based on organic spintronics

David Carroll

1Physics, Wake Forest University, Winston-Salem

Light emitting devices based on field-induced current injection have been shown to yield high intensity emission with very high power efficiencies. Such devices are typically activated using large AC fields across the nanometer scale thin film emitter organics. Recently, we have correlated the observation of high power efficiencies with the onset of negative magnetoresistance in the organic emitters suggesting that the internally coupled magnetic field of the device is playing a role in spin singlet selection of the injected currents. In this presentation we examine the insertion of 2D quantum dots (nanoplates) into the emitter. We show that the magnetic response of the additional nanophase can result in an additive effect on singlet selection in the emitter yielding a significant enhancement of the singlet to triplet population ratios. We believe such nanophase composites may present a potential route to realizing optical gain in electrically driven organic devices for the first time.

MON 18
Intra-layer potassium intercalation of multiwalled carbon nanotubes


1Experimental Physics, Freie Universität Berlin, Arnimallee 14, Berlin, 14195, Germany
2Faculty of Physics, Budapest University of Technology and Economics, Budafoki ut 8, Budapest, 1111, Hungary
3Department of Physics, Department of Chemistry, Department of Material Science and Engineering and Center for 2-Dimensional and Layered Materials, The Pennsylvania State University, University Park, Pennsylvania 16802, USA
4University of Vienna, Faculty of Physics, Strudlhofgasse 4, Vienna, 1090, Austria

We have obtained highly doped potassium intercalated multiwalled carbon nanotubes (MWNTs). This was only possible by using specific nanotubes uncapped at both ends, with intrinsic axial disruptions, and short length. Our results confirmed a full intercalation depicted by a change in color from black to brown-yellow in the MWNTs. The XRD analyses indicate the presence of K atoms between the layers of the MWNTs. Finally, the Raman spectra revealed a Breit-Wigner-Fano (BWF) line shape in the G-line region additionally to a Cz mode around 500 cm$^{-1}$ and a total vanishing of the 2D-line component.

We have found that the doping mechanism in MWNTs is highly similar to graphite intercalation compounds. Hence, the obtained Raman response is quite the same as in KC$_8$. The BWF Raman line shape and the XRD indicate a possible direct charge transfer mechanism from the intercalant to the rolled graphene layers of the nanotubes, which brings important implications to a potential superconducting phase.
Moreover, a successful complete intercalation in MWNTs will serve as a first step through an effective exfoliation process for bulk graphene nano-ribbon production.

Funding DRS-Fellowship

**MON 19**

**Temperature-dependent NEXAFS and HAXPES: charge carrier localization in the two-dimensional organic conductor (DOEO)$_4$[HgBr$_4$]TCE**

Alisa Chernenkaya$^{1,2}$, K. Medjanik$^{2,3}$, R. Morgunov$^4$, P. Nagel$^5$, M. Merz$^5$, S. Schuppler$^5$, A. Gloskovskii$^6$, E. Yagubskii$^4$, G. Schoenhense$^2$

$^1$Graduate School Materials Science in Mainz, Staudingerweg 9, 55128, Mainz, Germany
$^2$Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, 55128, Mainz, Germany
$^3$Lund University, MAX-lab, 22100 Lund, Sweden
$^4$Institute of Problems of Chemical Physics, Russian Academy of Science, 142432 Chernogolovka, Russia
$^5$Karlsruhe Institute of Technology, Institut für Festkörperphysik, 76344 Eggenstein-Leopoldshafen, Germany
$^6$Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, D-22607 Hamburg, Germany

We investigated (DOEO)$_4$[HgBr$_4$]TCE crystals by near-edge X-ray adsorption fine structure (NEXAFS) and hard X-ray photoelectron spectroscopy (HAXPES). Experiments were performed at the WERA beamline of ANKA, Karlsruhe, and beamline P09 at PETRA III, Hamburg, respectively.

In (DOEO)$_4$[HgBr$_4$]TCE we found evidence of an antiferromagnetic phase existing below 40 K. We characterized occupied and unoccupied electronic states in the crystals. S$_2$s and Cl$_2$p HAXPES spectra were taken at different temperatures. They provide evidence of electron density redistribution in DOEO layers upon cooling and correlations between phase transitions and electronic states in the crystals. Furthermore, the S$_2$p and O$_1$s edges were investigated by NEXAFS, revealing fingerprints of charge carrier redistribution and localization below 50 K. Based on investigations of magnetic susceptibility, transport properties$^1$, electron spin resonance$^2$ and electron density distributions we propose a mechanism of localization with appearance of antiferromagnetic islands in (DOEO)$_4$[HgBr$_4$]TCE.

$^1$ A. Bardin et. al., Coord. Chem., 2006, 32, 88
H-terminated nanoribbons and coronene stacks inside and outside single-walled carbon nanotubes

Alexander I. Chernov\textsuperscript{1,2}, Pavel V. Fedotov\textsuperscript{1}, Vladimir L. Kuznetsov\textsuperscript{3,4}, Elena D. Obraztsova\textsuperscript{1,2}

\textsuperscript{1}Prokhorov General Physics Institute, RAS, 38 Vavilov str., Moscow, 119991, Russia
\textsuperscript{2}National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe hwy. 31, Moscow 115409, Russia
\textsuperscript{3}Boreskov Institute of Catalysis SB RAS, Lavrentieva ave. 5, Novosibirsk, 630090, Russia
\textsuperscript{4}Novosibirsk State University, Pirogova 2, Novosibirsk, 630090, Russia

Diameter of single-walled carbon nanotubes (SWCNTs) determines the possibility to encapsulate molecules and governs the type of structures that can be formed inside the tubes \cite{1,2}. Differences between the encapsulated structures, such as coronene molecules stacks and graphene nanoribbons (GNR), were detected and studied via Raman and photoluminescence (PL) spectroscopies. We show the importance of the PL excitation mapping in a wide spectral range in order to clearly detect the spectral features specific to coronene stacks or GNR inside the nanotubes. We pay particular attention to the by-products that can be formed on the outside surface of nanotubes. Raman spectroscopy was used to study aggregates that were extracted from filled SWCNTs by sonication and density gradient centrifugation processes.

Funding by RFBR grants 13-02-01354, 14-02-00777 and MESRF grants 14.513.12.003, SP-7362.2013.3 is acknowledged.

\cite{1} A.I. Chernov et al., ACS Nano 7, 6346 (2013)
\cite{2} A.I. Chernov et al., Phys. Stat. Sol (b) 251, 2372 (2014)

Magneto-optical response of graphene on boron nitride: Dirac cone replica and Excitonic effects

Larisa Chizhova\textsuperscript{1}, Florian Libisch\textsuperscript{1}, Joachim Burgdörfer\textsuperscript{1}

\textsuperscript{1}Institute for Theoretical Physics, Vienna University of Technology, Vienna

Optical transitions between Landau levels provide precise information on the electronic structure of graphene, as well as substrate and many-body effects. In this work we calculate the magneto-optical response (optical conductivity) of large-size graphene flakes aligned on hexagonal boron nitride (BN) using a tight-binding approach. Recent experiments reveal satellite band gaps in the density of states away from the Dirac point induced by the BN substrate. These structures were interpreted as secondary Dirac cones. However, our calculations suggest that the satellites feature parabolic dispersion and the difference in interpretation arise as an artifact of measuring as a function back gate voltage \cite{1}. We propose magneto-spectroscopy as a way to probe the satellite and Dirac Landau levels in terms of energy. In addition we include the magneto-excitonic correction to the main transition lines in first or-
der perturbation theory. Our approach yields a quantitative explanation of recently observed Landau-level dependent renormalizations of the Fermi velocity.


**MON 22**
**Drawing Circuits with Carbon Nanotubes**

Won Jin Choi¹, Yoon Jang Chung¹, Ki-jeong Kong¹, Hyunju Chang¹, Young Kuk Lee¹, Jeong-Ö Lee¹, Taeil Lee²

¹Korea Research Institute of Chemical Technology, Advanced Materials Division
²Gachon University, College of BioNano Technology

Controlling the orientations of nanomaterials on arbitrary substrates is crucial for the development of practical applications based on such materials. The aligned epitaxial growth of single-walled carbon nanotubes (SWNTs) on specific crystallographic planes in single crystalline sapphire or quartz has been demonstrated; however, these substrates are unsuitable for large scale electronic device applications and tend to be quite expensive. Here, we report a scalable method based on graphoepitaxy for the aligned growth of SWNTs on conventional SiO2/Si substrates. The "scratches" generated by polishing were found to feature altered atomic organizations that are similar to the atomic alignments found in vicinal crystalline substrates. The linear and circular scratch lines could promote the oriented growth of SWNTs through the chemical interactions between the C atoms in SWNT and the Si adatoms in the scratches. The method presented has the potential to be used to prepare complex geometrical patterns of SWNTs by 'drawing' circuits using SWNTs without the need for state-of-the-art equipment or complicated lithographic processes.

**MON 23**
**Non-linear luminescence and four-wave mixing from graphene, probed by femtosecond pulse shaping**

Richard Ciesielski¹, Alberto Comin¹, Matthias Handloser¹, Torben Winzer², Ermin Malic², Andrea C. Ferrari³, Achim Hartshuh¹

¹Department Chemie and CeNS, Ludwig-Maximilians-Universität, München, Germany
²Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany
³Department of Engineering, University of Cambridge, UK

We investigated the non-linear emission of graphene for different layer thickness using confocal microscopy and a 15fs pulsed laser at 1.55eV with a pulse shaper. Ultrafast optical excitation leads to two main non-linear emission signals in the visible. The first contribution is described as incoherent non-linear photoluminescence (NLPL) [1]. Spectrally resolved autocorrelation scans revealed a continuously decreasing decay time of the NLPL from 1.2eV towards 2.8eV. Comparing the dynamics observed for different layers allows us to identify the influence of substrate induced doping.
The second results from near-degenerate four-wave mixing (nd-FWM) which is extraordinarily strong in graphene as compared to other materials. We show that in graphene nd-FWM is spectrally nearly uniform and dispersionless. Finally, we were able to separate a weaker third contribution induced by the microscopic polarization of graphene [2].

Financial support by the DFG through the Nanosystems Initiative Munich (NIM) and the ERC (NEWNANOSPEC) is gratefully acknowledged.


**MON 24**  
**Graphene integrated with silicon waveguides: a route to sensing**

Nick Clark\(^1\), Iain F Crowe\(^2\), Siham Hussein\(^2\), Matthew P Halsall\(^2\), Aravind Vijayaraghavan\(^1\)  
\(^1\)School of Materials, University of Manchester, Manchester, M13 9PL, UK  
\(^2\)School of Electrical and Electronic Engineering, University of Manchester, Manchester, M13 9PL, UK

There are distinct and obvious technological advantages to be gained by the integration of graphene with silicon photonics devices, but understanding the nature of the light-matter interaction in these systems is crucial if this potential is to be realised. Our immediate focus is on trying to understand the limitations on the practical sensitivity of silicon photonic cavities where graphene acts as a sensitization layer with improved reactivity over the bare silicon surface. We examined the near-IR light-matter interaction for graphene integrated cavity ring resonators based on silicon-on-insulator (SOI) race-track waveguides[1]. By measuring the TE mode linear absorption coefficient of graphene and combining this with a model of the variation in coupling strength with the graphene-waveguide separation, we are able to place limits on the graphene cavity length for optical sensing applications.


**MON 25**  
**Electrical tuning of spin-orbit interaction in InAs nanowires**

Zoltan Scherubl\(^1\), Gergo Fulop\(^1\), Balint Fulop\(^1\), Jesper Nygard\(^2\), Szabolcs Csonka\(^1\)  
\(^1\)Department of Physics, Budapest University of Technology and Economics and Condensed Matter Research Group of the Hungarian Academy of Sciences, Budafoki ut 8, H-1111 Budapest, Hungary  
\(^2\)Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

InAs nanowires are a promising platform to fabricate various quantum electronic devices. One of their attractive properties is their strong spin-orbit interaction (SOI). The controlled tuning of the SOI is desired property of spin based quantum devices. In this study we experimentally investigated the possibility of tuning the
SOI by electrostatic field. The sources of the electric field were backgate and two sidegates parallel to the wire axis. The strength of the SOI was analyzed by weak-antilocalization. We demonstrated that the SOI can be strongly tuned, by a factor of 3 with the electric field across the nanowire, while the average electron density in the nanowire was kept constant. Furthermore a simple electrostatic model was introduced to calculate the expected change of SOI and good agreement was found with the experimental results without fitting parameters.

MON 26
Stability analysis and improvement of HNO$_3$-doped graphene

Lorenzo D’Arsié$^1$, Santiago Esconjauregui$^1$, Rob Weatherup$^1$, John Robertson$^1$
$^1$University of Cambridge, Cambridge

Although the charge carrier mobility of pristine graphene is high, its intrinsic charge carrier density is nearly zero. Doping is therefore necessary for industrial applications of graphene as a transparent, flexible conductor. Currently, it is possible to obtain a significant increase in conductivity, using for example nitric acid or iodine treatments, which are, however, not sufficiently stable for industrial applications [1]. A stable increase in conductivity can be obtained by evaporation of high work function oxides [1], but the improvement in conductivity in comparison to acid treatments is more modest. A combination of stable and strong doping is thus still elusive. Here we present a systematic analysis of the doping stability of nitric acid by electrical measurements, X-ray photoemission spectroscopy and Raman spectroscopy, for different treatments and under different environmental conditions. The analysed data is used to develop a procedure to stabilise the acid doping. This improvement in doping stability represents a step towards ITO replacement by graphene.


MON 27
High temperature molecular beam epitaxial growth of graphene on sapphire substrates

Andrew Davies$^{1,2}$, T.S. Cheng$^1$, A. Summerfield$^1$, I. Cebula$^1$, A.N. Khlobystov$^2$, P.H. Beton$^1$, C.T. Foxon$^1$, L. Eaves$^1$, S.V. Novikov$^1$
$^1$School of Physics, University of Nottingham, Nottingham, NG7 2RD, UK
$^2$School of Chemistry, University of Nottingham, Nottingham, NG7 2RD, UK

Here we report the growth of graphene using a custom-designed dual chamber molecular beam epitaxy (MBE) system, based on the GENxplor from Veeco. The standard GENxplor has been specially modified by Veeco to reach growth temperatures of up to 1850$^\circ$C in high vacuum conditions and is capable of growth on substrates up to 3 inches in diameter. Our estimate of the growth temperature is based on a thermocouple reading. In order to calibrate the temperature we have formed graphene on the Si-face of SiC by heating wafers to temperatures above 1400$^\circ$C. To demonstrate
the scalability of the developed process, we have grown graphene on SiC substrate sizes ranging from 10x10 mm$^2$ up to 3-inch diameter.

We have also grown graphene layers on sapphire substrates using a SUKO-63 carbon sublimation source. Growth at substrate temperatures between 1000 and 1650°C have been investigated.

We report the results of a wide range of techniques (reflection high energy electron diffraction (RHEED), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), atomic force microscopy, scanning tunnelling microscopy and sheet resistance measurements) that we have used to characterise these layers.

**MON 28**

**Vibrational properties of cove-shape edged graphene nanoribbons**

Marzio De Corato$^{1,2}$, Deborah Prezzi$^{1,2}$, Alice Ruini$^{1,2}$, Elisa Molinari$^{1,2}$

$^1$University of Modena and Reggio Emilia, Modena, Italy

$^2$CNR-Nanoscience Institute, S3 Center, Modena, Italy

Recently, liquid phase processable graphene nanoribbons (GNR) with atomically precise edges were obtained by bottom up solution-mediated methods [1]. Here we report on ab-initio calculations [2] of the Raman spectrum for such novel structures with cove-shape morphology, where a C ring periodically decorates the zigzag edge. We consider a set of GNRs with different width and edge functionalization, finding very good agreement with experimental results [1]. We find that both the edge geometry and functional groups significantly impact the Radial-Like Breathing Mode (RLBM). The cove-shape morphology of the edge is instead mainly responsible for the activation of the D peak, which is not present in purely zigzag GNRs [3].


**MON 29**

**Light-emitting diodes by bandstructure engineering in van der Waals heterostructures**

F. Withers$^1$, O. Del Pozo-Zamudio$^2$, A. Mishchenko$^1$, A. P. Rooney$^3$, A. Gholina$^3$, K. Watanabe$^4$, T. Taniguchi$^4$, S. J. Haigh$^3$, A. K. Geim$^5$, A. I. Tartakovskii$^2$, K. S. Novoselov$^1$

$^1$School of Physics and Astronomy, University of Manchester, UK

$^2$Physics and Astronomy, University of Sheffield, UK

$^3$School of Materials, University of Manchester, UK

$^4$National Institute for Materials Science, Japan

$^5$Manchester Centre for Mesoscience and Nanotechnology, University of Manchester, UK

The advent of graphene and related 2D materials has recently led to a new technology: heterostructures based on these atomically thin crystals. The paradigm proved itself
extremely versatile and led to rapid demonstration of tunnelling diodes with negative differential resistance, tunnelling transistors, photovoltaic devices, etc. Here we take the complexity and functionality of such van der Waals heterostructures to the next level by introducing quantum wells (QWs) engineered with one atomic plane precision. We describe light emitting diodes (LEDs) made by stacking up metallic graphene, insulating hexagonal boron nitride (hBN) and various semiconducting monolayers into complex but carefully designed sequences. Our first devices already exhibit extrinsic quantum efficiency of nearly 10% and the emission can be tuned over a wide range of frequencies by appropriately choosing and combining 2D semiconductors (monolayers of transition metal dichalcogenides). The range of functionalities for the demonstrated heterostructures is expected to grow further with increasing the number of available 2D crystals and improving their electronic quality.

F. Withers et al. arxiv.1412.762

**MON 30**

**Investigation of contact properties and contact materials for graphene spin valve devices**

Marc Drögeler$^1$, Frank Volmer$^1$, Maik Wolter$^1$, Kenji Watanabe$^2$, Takashi Taniguchi$^2$, Daniel Neumaier$^3$, Christoph Stampfer$^{1,4}$, Bernd Beschoten$^1$

$^1$2nd Institute of Physics A and JARA-FIT, RWTH Aachen University, Aachen

$^2$National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

$^3$Advanced Microelectronic Center Aachen (AMICA), AMO GmbH, Aachen

$^4$Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Jülich

Although millisecond spin lifetimes have been predicted for graphene, the experimentally determined values are usually in the order of several hundred picoseconds in non local spin valve devices at room temperature. Previously, we showed that contact-induced spin dephasing is the main source of spin dephasing in devices where Co/MgO injection and detection electrodes were directly deposited on graphene (1). Here we demonstrate that the spin transport properties can be improved by fabricating Co/MgO electrodes on Si$^{++}$/SiO$_2$ and subsequently transfer the graphene on top of this structure. This reduces the coupling of the graphene to the electrodes and leads to spin lifetimes in the nanosecond range, spin diffusion lengths in the order of 10 $\mu$m as well as mobilities above 20,000 cm$^2$/Vs (2). We present conductive AFM measurements of the Co/MgO interface to get an additional measure of the contact quality. Furthermore, first results using Al$_2$O$_3$ tunnel barriers are shown which are grown by atomic layer deposition.


MON 31
ReS$_2$ interlayer bonding investigated through laser-pump x-ray probe spectroscopy

Ehren Mannebach$^2$, Friederike Ernst$^1$, Tony F. Heinz$^1$, Aaron Lindenberg$^2$
$^1$Columbia University, Department of Physics
$^2$Stanford University, Department of Materials Science and Engineering

ReS$_2$ is a transition metal dichalcogenide (TMDC) for which the Raman and photoluminescence response are similar between monolayer and bulk samples, contrary to the behavior observed in other TMDCs. A DFT study reports a small interlayer coupling strength of 18meV/unit cell, less than 8% of that of MoS$_2$.[1] Weak interlayer coupling may indicate that the individual layers behave like two-dimensional systems without the need for monolayers.

We conduct a laser-pump grazing-incidence x-ray probe study on monolayer-regime samples to investigate the structural changes induced by above band gap laser heating at the picosecond to microsecond scale. Structural changes are observed on two time scales. An initial drop in scattering intensity on the scale of 100ps is followed by a full recovery for laser fluences < 20mJ/cm$^2$ and a partial recovery for fluences > 20mJ/cm$^2$ on the scale of nanoseconds. These time scales support the weak interlayer coupling postulated in the DFT calculations.


MON 32
Doping of Carbon Nanotube Forests Using MoO$_3$

Santiago Esconjauregui$^1$, Lorenzo D’Arsiè$^1$, Yuzheng Guo$^1$, Cinzia Cepek$^1$, John Robertson$^1$
$^1$Department of Engineering, University of Cambridge, Cambridge, UK

Carbon nanotube forests may find applications as interconnects in integrated circuits. However, to outperform the materials currently used in electronics, the tubes need to be grown at low temperatures, on conductive supports, and in the form of high-density forests with all the tubes holding metallic character. As control over structural selectivity has not been achieved yet, the forests show resistivity values orders of magnitude greater than that of Cu, regardless of the fact that nanotubes themselves can sustain much higher current densities. Here, we dope nanotube forests using MoO$_3$ and evaluate the doping stability at different conditions and its impact on the electrical properties of the tubes. By in-situ XPS, we first determine the minimum necessary MoO$_3$ thickness to dope a tube ensemble. We then study the variation of forest resistivity upon annealing in vacuum at various temperatures and times, and find that MoO$_3$-doped forests increase their conductivity at least two orders of magnitude thus reaching values comparable to that of Cu. As MoO$_3$ is CMOS-compatible, this report represents a step towards the use of nanotubes in interconnects of next generation electronics.
**MON 33**

**Scaled Synthesis of Boron Nitride Nanotubes, Nanoribbons, and Nanococonns Using Direct Feedstock Injection into an Extended-Pressure, Inductively-Coupled Thermal Plasma**

Aidin Fathalizadeh$^{1,2}$, Thang Pham$^{1,2,3}$, William Mickelson$^1$, Alex Zettl$^{1,2,4}$

$^1$Department of Physics, University of California at Berkeley, Berkeley, California, United States  
$^2$Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California, United States  
$^3$Department of Materials Science and Engineering, University of California at Berkeley, Berkeley, California, United States  
$^4$Kavli Energy NanoSciences Institute at the University of California at Berkeley and the Lawrence Berkeley National Laboratory, Berkeley, California, United States

Boron nitride nanotubes (BNNTs), which are electrically insulating or semiconducting when properly doped, exhibit excellent thermal conductivity, great chemical inertness, high temperature oxidation resistance, and radiation-absorption properties, making them far superior than their carbon analogues for many applications. Unfortunately, scientific studies and industrial applications of BNNTs and related BN-based nanomaterials have been markedly limited by the lack of availability of synthesized material. Here we demonstrate the successful operation of a high-throughput, scalable BN nanostructures synthesis process whereby precursor materials are directly injected into a high-temperature, variable pressure (up to 10 atm) inductively-coupled thermal plasma system. The system can be operated in a near-continuous fashion and thus far has achieved a record output of over 35 g/h for pure, small diameter, few wall, highly crystalline BNNTs. Under suitable conditions, collapsed BN nanotubes (i.e., nanoribbons), and closed shell BN capsules (i.e., nanococonns) are also obtained. The process is adaptable to a large variety of feedstock materials.

**MON 34**

**Revealing the properties of N-doped carbon nanomaterials synthesized by UHV-CVD**

Filippo Fedi$^1$, Paola Ayala$^1$, Lei Shi$^1$, Aurelio Mateo-Alonso$^{2,3}$, Thomas Pichler$^1$

$^1$Faculty of Physics, University of Vienna, Austria  
$^2$POLYMAT, University of the Basque Country UPV/EHU, Avenida de Tolosa 72, E-20018 Donostia-San Sebastian, Spain  
$^3$Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Herein we present the latest progress in the understanding of the properties and synthesis of Nitrogen doped Single Wall Carbon Nanotube (SWCNT) [1,2] and Graphene [3]. These materials doped with N show new different and interesting electronic properties, like having an n-type or p-type behavior correlated to the structure making them very interesting for several applications. Ultra-High Vacuum Chemical Vapor
Deposition (UHV-CVD) has been used to synthesize the nanomaterials with doping heteroatoms. Using a particular carbon feedstock and a set-up for the furnace it has been possible to achieve high quality nanomaterials. Raman spectra have typical shape of SWCNT with a very narrow diameter distribution. XPS confirmed the Nitrogen percentage and substitutional bonding environment. Using in situ Mass Spectroscopy additional understanding of the mechanism of growth detecting the different species was achieved during the growth. TP acknowledges support from the (FWF Proj.Nr. 1 943-N19), AMA support from DFG (MA 5215/4-1) and the EU (ERA-Chemistry) 


MON 35
Prediction and theoretical investigation of new 2-D and 3-D periodical structures, having graphene-like band structures

Aleksandr Semenovich Fedorov\textsuperscript{1,3}, Maxim Aleksandrovich Visotin\textsuperscript{2}
\textsuperscript{1}Laboratory of physics of the magnetic phenomena, L.V. Kirensky Institute of Physics of RAS, 660036, Krasnoyarsk, Russia
\textsuperscript{2}Siberian Federal University, 660041, Krasnoyarsk, Russia
\textsuperscript{3}Krasnoyarsk Institute of Railway Transport, 660028, Krasnoyarsk, Russia

It is proposed and theoretically investigated the new general family of planar nanostructures having graphene’s electronic band-structure. With help of general theory and using perturbation theory it is shown that the graphene-like planar structure consist of identical nanoparticles having relatively weak contacts should lead to the electronic band structure with the Dirac cones. Within DFT calculations using the VASP program the band structures of two different aforementioned structures consist of silicon nanoparticles having 71 or 114 atoms were calculated. The calculated electron velocity at the Fermi level near the Dirac cones were equal 1.05 \times 10^5 \text{ m/s} and 0.53 \times 10^5 \text{ m/s}, respectively.

Also, by generalizing the theory it is proposed the family of 3-D structures having the band structures with the Dirac cones. As an example, the DFT calculation of a simple cubic lattice consist of identical silicon nanoclusters having 25 atoms shows that the band structure near the special surface of the form \((\cos(k_x) + \cos(k_y) + \cos(k_z)) = 0\) has a feature similar to the Dirac cones.
MON 36
THz-conductivity of CVD graphene on different substrates

Daniel Gabriel\textsuperscript{1}, M. Zahir Iqbal\textsuperscript{1,2}, Jonghwa Eom\textsuperscript{2}, Núria Ferrer-Anglada\textsuperscript{1}
\textsuperscript{1}Applied Physics Dept., Universitat Politècnica de Catalunya, Barcelona
\textsuperscript{2}Dept. of Physics and Graphene Research Institute, Sejong University, Seoul 143-747, South Korea

We analyzed by THz-Time Domain Spectroscopy the conductivity of CVD graphene as grown and p-doped, deposited on different substrates: PET (Polyethylene Terephthalate), PEN (Polyethylene Naphthalate), quartz, glass and silicon, in the range from 0.1 to 2 THz. Graphene shows a superficial conductivity around 10 to 40 times the value of minimum conductivity at frequencies of THz, as previous studies have shown \cite{1}. Our results show a noticeable dependence with the substrate at high frequencies. Flexible substrates like PET and PEN are interesting for applications as flexible electronic devices, including solar cells. We have developed an effective doping method for large area CVD grown graphene by UV-light irradiation under oxygen atmosphere. By Raman spectroscopy we can observe that doping occurs without a noticeable resistance increase and a slight mobility change, and is found to be stable and reversible. Superficial conductivity of p-doped graphene is slightly higher than pristine graphene; p-doped graphene presents an increase of electromagnetic absorption, compared to pristine graphene.


MON 37
Separation of Single-Walled Carbon Nanotubes with a Gel Permeation System

Benjamin S. Flavel\textsuperscript{1}
\textsuperscript{1}Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe

Recently we have shown that by altering the pH of the sodium dodecyl sulfate (SDS) eluent in a Sephacryl gel column that 15 different nanotube (n, m) single-walled carbon nanotubes (SWCNTs) species can be prepared from the HiPco raw material. By changing the pH of the SDS eluent we showed that hydrolysis of SDS leads to small quantities of 1-dodecanol being formed in solution, which become incorporated into the SDS micelle of the SWCNTs and alter the interaction with the gel. We now apply our approach to a gel permeation chromatography (GPC) system. In doing so we gain precise control over the pH of the SDS eluent and can utilize computer-controlled pH-gradients in the separation of (n, m) SWCNT species. This allows us to reproducibly elute different (n, m) species with control over when (time-based) different fractions should be collected. This automated procedure requires no pre-centrifugation, is scalable, and is found to yield monochiral SWCNT fractions of semiconducting SWCNTs with a purity of 61 - 95%.
MON 38
Photoluminescence and Raman spectroscopy of N-layer MoTe$_2$

Guillaume Froehlicher$^1$, Étienne Lorchat$^1$, François Fernique$^1$, Stéphane Berciaud$^1$

$^1$IPCMS, Université de Strasbourg and CNRS, France

Atomically thin transition metal dichalcogenides (TMDs, denoted MX$_2$), exhibit peculiar optical and electronic properties, which may be harnessed in novel optoelectronic devices. As compared to Mo- and W-based TMDs, Te-based TMDs remain less studied. Such compounds are expected to emit in the near-infrared range, thus extending the possible applications of TMDs over a broader spectral window.

Here, we present optical characterizations of N-(tri)layer molybdenum ditelluride (MoTe$_2$), from N=1 to N=10, by means of micro-photoluminescence (PL) and micro-Raman spectroscopy. As for other Mo- and W-based TMDs, a strong PL blueshift and PL enhancement are observed in monolayers, suggesting a transition from an indirect bandgap ($\sim$ 0.94 eV) in the bulk to a direct bangap ($\sim$ 1.10 eV) for N=1.

In addition, the low (breathing and shear modes, in the range 5-40 cm$^{-1}$) and high frequency Raman modes (in the range 150-300 cm$^{-1}$) of N-layer MoTe$_2$ are investigated by means of polarized Raman measurements. The frequencies of the shear and breathing modes are analyzed within a simple model based on a linear chain of oscillators and allow for an accurate determination of N.

MON 39
Investigation of carbon nanotube based field-effect transistors using atomistic quantum transport and numerical device simulation

Florian Fuchs$^{1,2}$, Andreas Zienert$^3$, Jörg Schuster$^1$

$^1$Fraunhofer Institute for Electronic Nano Systems, 09126 Chemnitz, Germany

$^2$now at Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany, and at Center for Advancing Electronics Dresden, Technische Universität Dresden, 01062 Dresden, Germany

$^3$Center for Microtechnologies, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Carbon nanotube based field-effect transistors (CNTFETs) are studied by use of two different approaches: numerical device simulation (NDS) based on the effective mass Schrödinger equation and atomistic quantum transport simulation based on the non-equilibrium Green’s functions formalism (NEGF). The studied CNTFETs consist of n-doped source- and drain-electrodes together with an ideal wrap-around gate.

Using density functional theory, we extracted a parameter set for the NDS model. A band-to-band tunnel current is predicted by the NDS once the valence band edge is shifted to the Fermi energy, which increases the off-current and leads to slight ambipolar behavior. Using the NEGF instead, localized states inside the channel can be observed and the band-to-band tunnel current is suppressed, resulting in a high on/off ratio of about 10$^7$. We illustrate the potential of the studied CNTFET for future applications by varying the channel length and find excellent properties.
for a channel length down to 8 nm. Furthermore, the influence of the gate electrode is investigated, where good transistor behavior is observed even for a small gate of only 0.4 nm length.

**MON 40**  
**Reversible sublattice symmetry breaking in monolayer graphene nanomembranes using tip induced pseudomagnetic fields**

Alexander Georgi$^1$, Peter Nemes-Incze$^1$, Ramon Carillo-Bastos$^2$, Daiara Faria$^2$, Silvia Viola Kusminskiy$^3$, Marco Pratzer$^1$, Nancy Sandler$^2$, Markus Morgenstern$^1$

$^1$RWTH Aachen, II physikalisches Institut B, Aachen  
$^2$Department of Physics and Astronomy, Nanoscale and Quantum Phenomena Institute, Ohio University  
$^3$Dahlem Center for Complex Quantum Systems and Fachbereich Physik, FU Berlin

Strain engineering in graphene might lead to a new generation of electromechanical devices, in particular due to its tunable pseudomagnetic field being a property of the unique sublattice degree of freedom within the honeycomb lattice. However, possibilities to tune the pseudomagnetic field on the nanoscale have not been realized so far. Here, we show that the forces of the tip of a scanning tunneling microscope can be used to switch local fields on and off by applying local strain, as visible by a relative change of the local density of states of the two sublattices up to 30%. Comparison with tight binding simulations reveals that this contrast corresponds to a pseudomagnetic field of up to 500 T. We carefully rule out other possibilities for the apparent sublattice symmetry breaking such as buckling, a local Peierls transition, different lifting forces of the tip above different sublattices, or the correlation of electric and pseudomagnetic fields. Moreover, we show that model calculations of the van-der Waals forces between tip and graphene reproduce the observed effects quantitatively within 50%.

**MON 41**  
**Graphene synthesis of crystalline precursor molecules**

Kati Gharagozloo-Hubmann$^1$, Niclas Müller$^1$, Valerio Oddone$^1$, Stephanie Reich$^1$

$^1$Department of Physics, FU Berlin, Berlin

One of the most promising routes for the synthesis of graphene is the chemical vapor deposition. Common CVD-processes use gas phase carbon sources like methane as a building block. Recent synthesis via molecular building block received graphene from molecular precursor such as benzene or bianthryl, which are liquid and solid. The molecular structure and geometry of the starting compound (molecular precursor) for graphene production is a crucial factor that affects the crystal structure, lateral spreading, and the edges symmetry of resulting graphene. Different precursor molecules with different symmetries were used as starting material for graphene production. Subsequently, the resulting graphene crystals were investigated in respect of their 2-dimensional propagation geometry. We study the influence of the geometry...
and the activity of the precursor molecules on the structure of the resulting graphene layers. The results will affect support the choice of the proper precursor structure for the gas phase production of graphene.

**MON 42**  
**Structure of Double Wall Carbon Nanotubes by combining a robust HRTEM approach and tight binding calculations**  
A. Ghedjatti\(^1\), H. Amara\(^1\), F. Fossard\(^1\), E. Flahaut\(^2\), J.-S. Lauret\(^3\), A. Loiseau\(^1\)  
\(^1\)ONERA-LEM, Châtillon, France  
\(^2\)CIRIMAT, Toulouse, France  
\(^3\)LAC, Orsay, France

Single-walled carbon nanotubes (SWNTs) have shown outstanding capabilities in the realization of new functional devices but are extremely sensitive to any slight changes in their environment, altering their physical properties. A strategy to overcome this difficulty could be to use double-walled carbon nanotubes (DWNTs), consisting of two concentric tubes, provided to know how they interact each other. To this aim, we have developed a systematic and robust procedure using acHR-TEM (aberration corrected Transmitting High Resolution Electron Microscopy) and image simulations to study the atomistic structure of over one hundred CVD made DWNTs. Using these tools, we have established some interesting statistics on helicities and diameters of inner and outer tubes of the DWNTs inspected.

Results reveal the existence of a strong coupling between the two concentric tubes, resulting in favoring high helicity angle configurations for DWNTs with outer diameters below 2 nm. The nature of the coupling and the observed selectivity are discussed with the help of energy calculations based on a tight binding approach.

**MON 43**  
**Assessing and improving the DFT+D3 method for van-der-Waals interaction in layered materials**  
Roland Gillen\(^1\), Janina Maultzsch\(^1\)  
\(^1\)Institut für Festkörperphysik, TU Berlin, Berlin

The novel physics in two-dimensional and/or layered materials gave rise to a recent advent of scientific publications with a variety of proposed applications. One demand on a theoretical study of such materials is the proper interclusion of non-covalent bonding effects between layers and/or adsorbed molecules to obtain the correct geometries and derived physical properties. A flexible description of such van-der-Waals interactions can be achieved by a posteriori corrections of semi-local density functional theory (DFT) in the recently proposed DFT+D3 scheme \([1]\). We have implemented this correction method in the freely available Quantum Espresso computational package and assessed its performance together with the highly accurate Jollet-Torrent-Holzwarth (JTH) set of high-throughout pseudopotentials on a range of layered and non-layered solids. Based on this assessment, we devised a sim-
The functionalization of carbon nanotubes (CNTs) has been widely exploited to attach dyes, switches and other molecules onto CNTs to tailor their optoelectronic properties. The attachment of the functional component can be realized by different approaches, such as non-covalent, covalent and sidewall functionalization, π-π stacking interactions, and endohedral filling. For optoelectronic studies non-covalent functionalization of CNTs had been the most favorable way, since it is a non-invasive and non-perturbing route to attach functional moieties onto CNTs [1,2]. Covalent functionalization on the other hand is known to be a rather harsh treatment, inducing great perturbations to the nanotube structure, resulting in altering the electronic properties of the CNTs. Here we introduce for the first time a non-invasive route to functionalize carbon nanotubes covalently, showing that the characteristic luminescence and Raman spectra remain unchanged upon functionalization.


MON 45
Liquid adhesion and capillary actions at the nanoscopic level: Direct observations of exceptional water-single WS2 nanotube interactions.

Ohad Goldbart¹, Ifat Kaplan-Ashiri², Andrey Enyashin³, Sidney R. Cohen², Reshef Tenne¹, H. Daniel Wagner¹

¹ Materials and interfaces, Weizmann institute of science, Rehovot
² Chemical Research Support, Weizmann Institute of Science, Rehovot 76100, Israel
³ Institute of Solid State Chemistry, 620990 Ekaterinburg, Russia

The use of different nanostructures as fillers in polymer composite materials attracts an ever-growing interest. While the impact of nanoparticles (NP) on composite properties is well studied, the relations between individual NP and the host matrix are yet to be fully understood. In this work, we present a new technique for measurements of individual nanotube-liquid interactions using ESEM and AFM systems. Here the effect of WS2 nanotube morphology and structure on the interaction strength between different liquids and the nanotubes is assessed. These experiments in conjunction

Monday, March 09th

Poster session

with theoretical simulations show that the morphology of the WS2 nanotube has a significant effect on the liquid-NT. The interaction energy of the nanotubes falls off dramatically with the diameter of the nanotubes and then levels off. These differences are currently attributed to the capillary interaction of the small hollow core nanotubes with the water. MD simulations show that the highly confined space results in large interaction energy between the water and the inner core of the nanotubes. These effects and the impact of the nanotubes surface chemistry on the interaction energy are presented and discussed.

**MON 46**

**Studying the interaction of phospholipids with graphene materials using a quartz crystal microbalance**

Stefan Goodwin\(^1,3\), Zachary Coldrick\(^2\), Bruce Grieve\(^3\), Ernie Hill\(^1\), Aravind Vijaayaraghavan\(^1,2\)

\(^1\)Centre for Mesoscience and Nanotechnology, University of Manchester, UK  
\(^2\)School of Materials, University of Manchester, UK  
\(^3\)School of Electrical and Electronic Engineering, University of Manchester, UK

Studying the interaction of phospholipids with surfaces is important for the development of biosensors that accurately mimic or interact with cellular structures. Graphene is a promising material for such sensors due to its high sensitivity. One route to fabricate graphene/phospholipid biomimetic membranes is ‘vesicle fusion’ whereby small lipid liposomes (self-assembled spheres) are fused with a graphene surface to form a membrane. The interaction of liposomes with graphene can be followed in-situ using a quartz crystal microbalance. Using a graphene functionalized quartz crystal microbalance with frequency and dissipation measurements (QCM-D), the adsorption properties of phospholipid liposomes in aqueous solutions to various graphene surfaces is shown. The behavior of liposomes that come in contact with graphene depends strongly on the wettability of graphene to the lipids. Graphene oxide, with its hydrophilic surface, promotes the fusion of lipids whereas hydrophobic graphene causes liposomes to adhere but not fuse. The level of oxidation is important, as a trade-off between the loss of conductivity and stability of the membrane needs to be optimized to create efficient electronic sensors.

**MON 47**

**Multiple subgap states in a superconductor - carbon nanotube hybrid device**

Jörg Gramich\(^1\), Andreas Baumgartner\(^1\), Christian Schönemberger\(^1\)

\(^1\)Department of Physics, University of Basel, Basel, Switzerland

Low-dimensional electronic systems coupled to a superconductor have recently gained much attention due to the search for exotic states like Majorana fermions [1], Cooper pair splitting [2,3], or Andreev bound states [4]. These seemingly different effects have in common that electron transport occurs at energies below the superconducting energy gap, leading to transport resonances where single electron transport should
be suppressed. Here we present detailed transport spectroscopy measurements on a carbon nanotube device contacted by a central superconducting Nb lead and two normal metal contacts. The most striking new features are up to 5 gate-tunable conductance peaks within the large energy gap of $\Delta = 1.2 \text{meV}$. We investigate these subgap states as a function of an external magnetic field and the temperature and interpret our results tentatively as the onset of a fully developed proximity effect of spatially varying strength in the superconductor-carbon nanotube system.


**MON 48**

**Optomechanics with Graphene Mechanical Resonators**

Johannes Guettinger$^1$, Peter Weber$^1$, Adrien Noury$^1$, Ioannis Tsioutios$^1$, Darrick E. Chang$^1$, Adrian Bachtold$^1$

$^1$ICFO-Institute of Photonic Sciences, Barcelona

Graphene and Carbon nanotubes are attractive materials for nanomechanical devices because of their exceptional properties, such as high frequencies, quality factors, and low mass. These properties are employed to push the limits in mass and force sensing. The long lifetimes of excitations in mechanical resonators are also very promising for quantum applications. An outstanding challenge with carbon nanoresonators however, has been to obtain large coupling between the motion and external systems for efficient readout and manipulation. I will present our novel approach, in which we capacitively couple a high-Q graphene mechanical resonator to a superconducting microwave cavity [1]. We are able to use the coupling to measure cryogenic thermal motion and to cool the mechanical resonator. Additionally we strongly tune the mechanical properties by pulling on the resonator with a static electric force. This unique tunability in low-dimensional resonators opens up interesting new possibilities for optomechanical systems.

**MON 49**

**Controlled folding of 2D materials: GraFold Printing**

Toby Hallam\(^1\), Amir Shakouri\(^2\), Emanuele Poliani\(^3\), Aidan P. Rooney\(^4\), Ivan Ivanov\(^5\), Alexis Potie\(^1\), Haydn K. Taylor\(^6\), Mischa Bonn\(^5\), Dmitry Turchinovich\(^5\), Sarah J. Haigh\(^4\), Janina Maultzsch\(^3\), Georg S. Duesberg\(^1,7\)

\(^1\)CRANN & AMBER, Trinity College Dublin, Ireland  
\(^2\)Nanyang Technological University, Singapore  
\(^3\)Institut für Festkörperphysik, Technische Universität Berlin, Germany  
\(^4\)School of Materials, University of Manchester, United Kingdom  
\(^5\)Max Planck Institute for Polymer Research, Mainz, Germany  
\(^6\)Department of Mechanical Engineering, University of California, Berkeley, USA  
\(^7\)School of Chemistry, Trinity College Dublin, Ireland

In the last few years significant inroads have been made into shaping, patterning, doping and processing of graphene to create novel technological applications. However, such approaches have generally ignored the ability of flat 2D materials to fold and crease. In fact, such deformations are typically considered to be undesirable. This is surprising, since the ability to fold is actually one of the properties that are specific to 2D materials.

We have developed a technique (GraFold) that uses elastomeric stamps with periodically varying adhesive properties to introduce structure and print folded graphene films. We report on an investigation of GraFold printed features with scanning probe microscopy, high resolution electron-microscopy and tip-enhanced Raman spectroscopy. The investigation highlights GraFold printing as a new technique which allows for significant modification of the properties of 2D materials without damaging or chemically modifying them. Furthermore, a finite element model is developed to show the fold formation process. Terahertz spectroscopy reveals induced anisotropy of carrier mobility along, and perpendicular to, the graphene folds.

---

**MON 50**

**Improved integration process of individual SWNTs into sensors**

Wei Liu\(^1\), Kiran Chikkadi\(^1\), Christofer Hierold\(^1\), Miroslav Haluska\(^1\)

\(^1\)Micro and Nanosystems, DMAVT ETH Zurich, Zurich, Switzerland

One of the critical issues hindering the application of SWNTs in sensors is related to resist-based lithography applied during SWNT device fabrication. It induces contamination causing poor metal/SWNT electrical contacts [1]. To avoid this contamination we use alumina layer to protect the SWNTs during resist application. Removing alumina by H\(_3\)PO\(_4\) is a residue-free process with no detectable change in the properties of SWNTs as verified by Raman spectroscopy [2]. To avoid resist residue redeposition onto the future contact area, oxygen plasma is introduced prior alumina etch. For a protective layer thicker than 30 nm no changes of nanotube Raman spectra due to the plasma are detected. Incorporating above mentioned processes into the CNFET fabrication, the median on-resistance of CNFETs was reduced by 66%.
and its interquartile dispersion was narrowed by 88%, respectively. The developed process has been extended from chip to wafer level. The median on-resistance of 812 p-type CNFETs fabricated on the wafer was determined to be 64 kΩ for Cr/Pd contacts.


MON 51
Electron optics in suspended and encapsulated graphene

Clevin Handschin1, Balint Fulop2, Peter Makk1, Markus Weiss1, Szabolcs Csonka2, Christian Schönenberger1

1Department of Physics, University of Basel, Switzerland
2Department of Physics, Budapest University of Technology and Economics, Hungary

We present two alternative ways how to fabricate a Veselago lens in graphene [1,2] - in suspended graphene using a resist technique (LOR) [3] and in graphene encapsulated in hexagonal boron nitride (hBN) using a dry-transfer technique [4]. Negative refraction is achieved by electrostatically gating the graphene seamlessly from n- into p-doping (or vice versa) using top-gates. For both techniques, point-contacts as small as 100 nm can be established. While the fabrication of top-gated devices on LOR works in a reproducible manner, the current annealing of multi-terminal devices with large top-gates turned out to be very demanding. On the other hand graphene encapsulated in hBN and contacted with side-contacts allows ballistic transport and high mobilities while allowing for versatile device-geometries. A reversed-order fabrication is introduced which holds the potential of improved side-contacts and at the same time simplifies the fabrication procedure.


MON 52
Electronic noise of carbon nanotube quantum dots

Thomas Hasler1, Minkyung Jung1, Vishal Ranjan1, Gabriel Puebla-Hellmann1,2, Andreas Wallraff2, Christian Schönenberger1

1Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland
2Department of Physics, ETH Zürich, 8093 Zürich, Switzerland

We perform experiments with carbon nanotube quantum dots, which are coupled to an on-chip impedance matching circuit to account for the high device resistances [1]. In order to achieve high quality microwave circuits, we developed a nanotube
stamping technique to transfer them from the growth substrate to the pre-fabricated microwave circuit.

Our high-frequency setup built in a dilution refrigerator enables us to do two kinds of measurements. On one hand, one can measure the reflection coefficient around the resonance frequency of approximately 3 GHz, which is a fast and sensitive way to determine the real and imaginary part of the sample resistance [2]. But our main focus lies on detecting the current noise emitted by the device. In this situation, the impedance matching circuit acts like a band-pass filter with a bandwidth of a few Megahertz.

For the calibration of the setup, we use a noise source with a well-established Fano factor. Our choice is a gold wire in the hot-electron regime with a Fano factor of $\sqrt{3}/4$ [3].


**MON 53**

**Epitaxially driven molecular assemblies: from Kagome lattice to d-wave superconductor**

Abdou Hassanien$^1$, Zhou Biao$^2$, Hisashi Tanaka$^3$, Akira Miyazaki$^4$, Madoka Toku-moto$^5$, Akiko Kobayashi$^2$, Erik Zupanic$^1$, Igor Musevic$^1$

$^1$Jozef Stefan Institute, Department of Condensed Matter, 39 Jamova, Ljubljana Slovenia.

$^2$Nihon University, Sakurajosui, Setagaya-ku, Tokyo 156-8550, Japan

$^3$AIST, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

$^4$Toyama University, 3190 Gofuku,Toyama shi, Toyama 930-8555, Japan

Surface mediated interactions have been utilized to pattern different structural assem-
blies of charge transfer salt such as (BETS)$_2$GaCl$_4$ (where BETS=bis(ethylenedithio) tetraselenafulvalene) on Ag(111). With a low deposition rate of less than 0.05 monolayer per minute, we find that the substrate temperature drive the molecular orientation and their packing geometry into insulating or superconducting phases. Orientation- nal frustration occurs at 125K of deposition temperature, leading to the formation of Kagome lattice with BETS dimers crowding in triangular units. Using in situ STM tip functionalization, we map the spatial variation of the charge density with sub-
molecular resolution on BETS dimers for the first time. When deposited at room temperature, the molecules retain their crystalline superconducting structure with their long molecular axis perpendicular to the substrate. Although the heteroepitaxial process increases the intra dimer separation to about 0.3Å larger than the bulk value, it is remarkable that superconductivity is robust down to a monolayer thickness and still preserves the signature of d-wave symmetry as its bulk counterpart.
MON 54
Controlled nitrogen-doping and carboxyl functionalisation of multi-walled carbon nanotubes

Gergő Péter Szekeres¹, Krisztián Németh¹, Anikó Kinka¹, Melinda Magyar², Balázs Réti¹, Erika Varga³, Zsolt Szegletes¹, András Erdőhelyi³, László Nagy², Klara Hernádi¹
¹Department of Applied and Environmental Chemistry, University of Szeged, Szeged
²Department of Medical Physics and Informatics, University of Szeged, Hungary
³Department of Physical Chemistry and Material Science, University of Szeged, Hungary
4Institute of Biophysics, Biological Research Centre, Hungarian Academy of Sciences, Hungary

Partial N2 doping of MWCNT was performed during CCVD synthesis. A special reactor was created to enable the syntheses with different reaction conditions. Samples were analysed by TEM in order to provide information about the tubular morphology and their deformation gained after reaction conditions were changed. The N2 incorporation was studied by XPS, meanwhile XRD and Raman spectroscopy showed the degree of graphitisation. Samples were then carboxyl functionalised in nitric acid solutions of varied concentration and then RC-26 protein was linked to the carboxyl groups in order to make the functionalisation’s degree and location visible. Protein linked samples were characterized by UV-Vis spectroscopy and AFM. Results indicated that syntheses, carried out in the new reactor, were successful and resulted in CNTs partially doped with N2. TEM studies revealed that the expected deformations are localized only in a defined segment of CNTs. The N2 content in the samples represented in atomic ratios was between 0.9 and 2.9%. The deformations help the functionalisation at that certain area thus the carboxyl groups’ location can be determined.

MON 55
Electrical Properties of Palladium Carbide End-Contacts for Multi-Layered Graphene for Next Generation LSI Interconnects

Takamasa Ogata¹, Kazuyuki Ito¹, Tadashi Sakai², Yuji Awano¹
¹Department of Electronics and Electrical Engineering, Keio University, Yokohama, Japan
²Low-power Electronics Association & Project (LEAP), Tsukuba, Japan

Multi-layered Graphene (MLG) has attracted great attention as a material for future LSI interconnects because of its extremely low resistivity. There have been several reports on the top contact electrode technologies for single-layered graphene FETs. However, a different type of contact configuration must be more suitable for MLG interconnects. An end-contact, in which a metal electrode comes into contact with the edges of the graphene layers, has been proposed, and a significant reduction in contact resistivity (rc) has been demonstrated [1]. For this paper, on the basis of the considerations of carbonization and adhesion strength with nano-carbon materials,
we selected Palladium (Pd) as an end-contact material for MLG. After thermal annealing of 450°C, a 64 % reduction in rc was obtained, and Pd-Carbide was found using XPS measurements. The minimum rc reaches 1.8×10⁻⁷ ohm-cm², which is close to the lowest value ever reported for a pristine MLG [1]. It is worth noting that the rc variation in Pd contacts is much better than that in Titanium contacts, which is probably because Pd is more resistant against oxidation than Ti.

Ref.:

**MON 56**

**Study on Low Temperature CVD Growth Mechanism of Multi-layer Graphene on Single Crystal Ni(111) Wafer and Polycrystalline Ni Thin Film with Artificial Facets**

Takuya Suzuki¹, Yuichi Yamazaki², Masayuki Kitamura², Akihiro Kajita², Tadashi Sakai², Yuji Awano¹

¹Department of Electronics and Electrical Engineering, Keio University, Yokohama, Japan
²Low-power Electronics Association & Project (LEAP), Tsukuba, Japan

To develop graphene interconnect technologies for next generation LSIs, a low temperature (Tg ≤ 600°C) CVD growth mechanism for multi-layer graphene (MLG) is one of the most important subjects relating to high quality material growth under Si-LSI-compatible conditions. Y. Yamazaki et al. reported that graphene growth originates from crystalline facets with specific angles with respect to the crystalline orientation of catalytic metals [1]. To investigate a MLG growth mechanism, we performed MLG growth on a single crystal Ni(111) wafer and on polycrystalline Ni thin film with an etching step at a controlled angle ("artificial facet"). RF-plasma CVD with Tg of 60°C and SEM observations were employed. In the case of MLG growth on a single crystal Ni wafer, by removing the grown MLG with oxygen plasma, we found that connected facets had formed on the Ni surface along a contour of the removed MLG, suggesting the facet growth. From the experiments on MLG growth on artificial facets, we confirmed that MLG grew preferentially from the facets. Moreover, growth extension of MLG by additional CVD process was found after a growth interruption.

Reference:
MON 57
AC Characterization for Organic/Nanotube Thin-Film Transistors using Frequency-Dependent Current Hysteresis Measurements by Applying Sinusoidal Wave Signals

Kazuhiro Watanabe\textsuperscript{1}, Ken Tanoue\textsuperscript{1}, Yasunori Taki\textsuperscript{1}, Kei Noda\textsuperscript{1}, Yuji Awano\textsuperscript{1}
\textsuperscript{1}Department of Electronics and Electrical Engineering, Keio University, Yokohama

Organic/Carbon nanotube thin-film transistors have attracted much attention as light, low cost, flexible, and printable devices in large-area electronics applications. However, their AC characteristics have not yet been well understood, and a measuring method for them has still not been established. Because of their high impedance, the conventional AC characterization methods for inorganic FETs, such as S-parameter extraction, are not suitable for them. The hysteresis effect in the I-V characteristics of OTFTs, which is observed very often and depends on the frequency of the AC applied voltage, should be eliminated for reliable and stable circuit operation even if its mechanism is still unknown. In this paper, we report a new measurement protocol for frequency-dependent current hysteresis phenomena in I-V characteristics by using a sinusoidal wave signal together with a measuring circuit considering the high device impedance. We report current hysteresis changes in Pentacene TFTs depending on the frequency of the sinusoidal wave voltage signal input to the drain and source electrodes.
On your wavelength
08:30 – 09:30 A. Geim, Manchester
*Tutorial: The rise of van der Waals heterostructures*

09:30 – 10:00 T. Müller, Vienna
*Optoelectronics with 2D semiconductors*

10:00 – 10:30 coffee break

10:30 – 11:00 R. Gorbachev, Manchester
*Van der Waals heterostructures composed of thin 2D crystals sensitive to atmospheric exposure.*

11:00 – 11:30 X. Cui, Hong Kong
*Spin-valley Coupling in atomically thin Tungsten Dichalcogenides crystals*

11:30 – 12:00 A. Chernikov, New York
*Excitons and many-body phenomena in atomically thin 2D materials*

12:00 – 17:00 mini workshops

14:00 – 17:00 special workshop
*Nano & Society*

17:00 – 18:30 Dinner

18:30 – 19:00 M. Glazov, St.-Petersburg
*Spin and valley dynamics of excitons in transition metal dichalcogenides*

19:00 – 19:30 J. Appenzeller, West Lafayette
*Two-Dimensional Layered Materials – Physics and Applications*

19:30 – 20:00 G. Duesberg, Dublin
*Vapour phase Synthesis and Functionalisation of 2D Transition Metal Films*

20:00 Poster II
Tuesday, March 10th

Two-dimensional materials and heterostructures
Following the advent of graphene, many other one-atom or one-molecule thick crystals have been isolated. These 2D crystals have become one of the hottest topics in materials science and condensed matter physics. Moreover, isolated atomic planes can now be reassembled into designer structures made layer by layer in a precisely chosen sequence. The first but already remarkably complex heterostructures have recently been fabricated and investigated. I will briefly overview our progress in making such heterostructures with clean and atomically sharp interfaces and then illustrate how exceptionally rich in phenomena the research area is.
Two-dimensional (2D) atomic crystals, such as graphene and layered transition-metal dichalcogenides, are currently receiving a lot of attention for applications in (opto-)electronics. In this talk I will review our research activities on photovoltaic energy conversion and photodetection in 2D semiconductors. In particular, I will present a WSe2 monolayer p-n junction, formed by electrostatic doping using a pair of split gate electrodes, and a MoS2/WSe2 van der Waals type-II heterojunction. Upon optical illumination, conversion of light into electrical energy occurs in both devices. I will present measurements of the electrical characteristics, the photovoltaic properties, and the gate voltage dependence of the photoresponse. In the second part of my talk, I will discuss photoconductivity studies of MoS2 field-effect transistors. We identify photovoltaic and photoconductive effects, which both show strong photoconductive gain. We envision that the efficient photon conversion, combined with the advantages of 2D semiconductors, such as flexibility, high mechanical stability and low costs of production, could lead to new optoelectronic technologies.
10:30
Van der Waals heterostructures composed of thin 2D crystals sensitive to atmospheric exposure.

Roman Gorbachev$^1$, Y. Cao$^1$, K. Khestanova$^1$, A. Rooney$^2$, A. V. Kretinin$^1$, P. Blake$^1$, G. L. Yu$^1$, A. Mishchenko$^1$, S. J. Haigh$^2$, A. K. Geim$^1$

$^1$Physics and Astronomy, University of Manchester, Manchester

$^2$School of Materials, University of Manchester, Manchester M13 9PL, UK

Of the many 2D layered materials known to exist only a precious few are completely stable in the ambient environment. Many more react with oxygen and atmospheric water and only survive due to self-passivation or surface reconstruction, which, in the case of atomically thin films leads to serious structural deterioration. I will describe how to prepare, protect and study these new materials in a specially designed clean argon environment. To demonstrate the technique we studied transport and optical properties of two selected materials: black phosphorus and niobium diselenide. We report, for the first time, transport in single layer black phosphorus. Starting from three layers we see quantum oscillations in magnetic field and determine the effective mass and g-factor. Niobium diselenide crystals in turn demonstrate superconductivity down to a monolayer that also has never been observed before with a relatively high Tc of a few Kelvin.
Spin-valley Coupling in atomically thin Tungsten Dichalcogenides crystals
Xiaodong Cui

The monolayers of group VI transition metal dichalcogenides feature a valence band spin splitting with opposite sign in the two valleys located at corners of 1st Brillouin zone. This spin-valley coupling, particularly pronounced in tungsten dichalcogenides, can benefit potential spintronics and valleytronics with the important consequences of spin-valley interplay and the suppression of spin and valley relaxations. In this talk we discuss the optical studies of WS2 monolayers and multilayers. The polarized resolved photoluminescence spectra reveal a spin-valley coupling of 0.4 eV which suppresses interlayer hopping and manifests as a thickness independent splitting pattern at valence band edge near K valleys. (1) This giant spin-valley coupling, together with the valley dependent physical properties, may lead to rich possibilities for manipulating spin and valley degrees of freedom in these atomically thin 2D materials.

Reference:
11:30
Excitons and many-body phenomena in atomically thin 2D materials
Alexey Chernikov

Department of Physics, Columbia University, New York

Since the discovery of graphene, a single sheet of carbon atoms, research focused on two-dimensional (2D) materials evolved rapidly due to the availability of atomically thin crystals with intriguing physical properties. The 2D materials naturally inherit major traits associated with systems of reduced dimensionality such as strongly enhanced Coulomb interactions and highly efficient light-matter coupling. In particular, in the class of 2D semiconductors this leads to the emergence of strongly bound electron-hole quasi-particles, such as excitons, trions, and biexcitons, with unusually high binding energies and efficient light absorption.

In this talk, I will present a study of the excitonic properties of 2D semiconductors. The observation of exciton binding energies on the order of 0.5 eV and the marked deviation of the exciton Rydberg series from the hydrogenic model will be discussed. The results reflect both strong carrier confinement and the distinctive nature of dielectric screening in atomically thin materials. I will further describe how the presence of high carrier densities can profoundly alter the many-body interactions in these 2D systems.
14:00 - 17:00
Special Workshop (Panel discussion)
Nano and Society

Chair: Siegmar Roth
Panelists: David Carroll (Winston-Salem, USA)
          Hui-Ming Cheng (Shenyang, China)
          Georg Duesberg (Dublin, Ireland)
          Peter Grambow (Nanoinitiative Bayern, Germany)

The goal of this workshop is to develop a feeling on how funding of nanotechnology R&D works in different parts of the world and on how well it works.

During the panel discussion, we may discuss topics like:

1.) Many funding agencies want to shorten the way from research to commercialization. Are there good examples for products having already come out from funded projects?
2.) In European cooperative projects often trans-regional cooperation is a goal by itself. Do you know success stories?
3.) Funding might not have led to a successful project as such, but the fact that companies do engage in attractive research may attract good people, and thus the business of the company might improve. Again, are there good examples?
4.) Do Flagship projects increase the creativity in a country or are they harmful by excluding many creative researchers from the community?
5.) Is it helpful that Europe, America, and China copy each others Flagships, so that the whole world works on the same topics, or would we prefer more global diversity?
6.) Is the ’grasshopper phenomenon’ good or bad? (All scientists worldwide swarming from conductive polymers to superconductors to fullerenes to nanotubes to graphene). A big advantage might be an increased cooperation among scientists. However, does this lead to an "academic monoculture"?

All participants of the Kirchberg winterschool are welcome to attend this special workshop.
Spin and valley dynamics of excitons in transition metal dichalcogenides
Mikhail Glazov\textsuperscript{1,2}

\textsuperscript{1}Ioffe Physical-Technical Institute of the RAS, St.-Petersburg, Russia
\textsuperscript{2}Spin Optics Laboratory of St.-Petersburg State University St.-Petersburg, Russia

The synthesis and studies of graphene, an atom-thick layer of Carbon, has opened up an era of novel truly two-dimensional materials. Such systems combine unusual optical and transport properties and attract a lot of interest nowadays. Monolayers of transition metal dichalcogenides (TMDCs) have, like graphene, hexagonal crystalline lattice, but, unlike graphene, possess direct band gaps (\(\sim 1.7\) eV) at the edges of the Brillouin zone, known as \(K_+\) and \(K_-\) valleys. Extremely strong spin-orbit coupling in TMDCs yields the spin-valley locking: Spin components of individual charge carriers correspond to the given valley of the energy spectrum.

Recent experiments demonstrate valley-selective optical orientation, but the valley/spin polarization decays during several picoseconds. This is, at a first glance, unexpected, since spin-valley locking suppresses spin relaxation of individual electrons and holes. We develop the theory of the neutral exciton fine structure in TMDCs monolayers governed by the long-range exchange interaction between the electron and the hole. We show that this coupling is responsible for the rapid spin/valley depolarization in MoS\(_2\) and WSe\(_2\).
With 2D materials offering unique opportunities for future nano-electronics applications, the quest is to identify their useful properties and potential intrinsic performance benefits. While the most commonly studied 2D system, i.e. graphene, has excited scientists because of high achievable carrier mobilities, the absence of a band gap makes many device related applications very challenging. On the other hand materials as MoS2, WSe2, or WS2, to just name a few, offer sizable band gaps at mobilities that cannot be achieved in bulk materials that are scaled down to similar thicknesses. In my presentation I will discuss the benefits of an ultra-thin body structure for scaled devices. I will also elucidate the critical impact of contacts to benefit from the intrinsic performance of MoS2 based field-effect transistors (FETs). Our study supports the notion that a linear device Id-Vds characteristic is by no means evidence of an ohmic contact and that contacts frequently mask the true mobility specs of novel low-dimensional materials. Moreover, I will present experimental results on the scaling properties of MoS2 FETs and the impact of the layer thickness for device applications.
Vapour phase Synthesis and Functionalisation of 2D Transition Metal Films

Georg S Duesberg¹,²
¹Chemistry, Trinity College Dublin, Dublin 2, Ireland
²Centre for Adaptive Nanostructures and Nanodevices (CRANN) & Advanced Materials BioEngineering Research Centre (AMBER), Trinity College Dublin, Ireland

Transition Metal Dichalcogenides (TMDs) revealed exciting properties which have potential for electronic applications. In order to use TMDs in functional devices, reliable processes for large scale synthesis, functionalisation and integration must be developed. Here we present the thermally assisted conversion of various metal films and scalable CVD growth of TMD layers. Characterization with Raman spectroscopy, photoluminescence, XPS and TEM are presented. We electrically addressed TMDs films to investigate their electrical viability in future electronics. In particular, a large scale p-n photodiode made from a MoS² layer on silicon is presented. Further, we report their on-chip functionalisation. Our approach, which uses large scale synthesis in combination with surface functionalization, is an important step towards integration of novel 2D materials with traditional technology; which may lead to significant advances towards TMD based electronics.

References
TUE 1
Optimizing Spin-transfer Torque in Graphene Spin Devices

Chia-Ching Lin¹, Ashish V. Penumatcha¹, Vinh Quang Diep¹, Joerg Appenzeller¹, Zhihong Chen¹
¹ECE, Purdue University, West Lafayette

Graphene is an ideal channel material due to its long spin diffusion length, gate-tunable carrier density, and high carrier mobility. However, to further develop a graphene-based spin logic, spin transfer torque needs to be demonstrated in graphene devices to show that spin information can be communicated to the outputs. The first experimental measurement of spin transfer torque in graphene lateral non-local spin valve devices has been reported by us. Assisted by an external magnetic field, the magnetization reversal of the ferromagnetic receiving magnet is induced by pure spin diffusion currents from the input magnet. The magnetization switching is reversible between parallel and antiparallel configurations, depending on the applied charge current polarity. In this talk, I will show a new graphene spin device design to improve the spin absorption at the output magnet. The measured nonlocal spin valve signal has lower noise and its magnitude is comparable to a conventional graphene spin device. More importantly, the critical spin torque current density is greatly reduced.

TUE 2
Analysis of the double-resonant 2D Raman mode in bilayer graphene

Felix Herziger¹, Matteo Calandra², Paola Gava², Patrick May¹, Michele Lazzeri², Francesco Mauri², Janina Maultzsch¹
¹Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany
²IMPMC, Université Pierre et Marie Curie, CNRS, Paris, France

We present a two-dimensional calculation of the double-resonant 2D-mode scattering cross-section in bilayer graphene. Based on a first-principles approach, we unravel the dominant contributions to the complex 2D-mode lineshape and demonstrate, in contrast to previous works, that so-called ‘inner’ processes are, by far, the most dominant processes [1]. Moreover, we show that the splitting between the two TO-derived phonon branches in bilayer graphene cannot be neglected for a consistent understanding of the 2D-mode lineshape. Additionally, we investigate the contributions from both TO branches to the symmetric and anti-symmetric scattering processes. Finally, we discuss the effect of the electronic broadening on the observed 2D-mode lineshape. Our results answer the long-standing question regarding the different contributions to the 2D-mode lineshape in bilayer graphene.

**TUE 3**

**Capacitive energy storage properties of large-area sprayed PEDOT:PSS transparent flexible films**

Thomas Higgins¹, Jonathan Coleman¹

¹School of Physics, Trinity College Dublin

To create a fully-integrated transparent/flexible device will also require energy storage and management systems. This role will almost certainly be played by batteries and supercapacitors.

In the absence of underlying current collectors, transparent supercapacitor electrodes based on disordered nanomaterial networks typically suffer from percolation effects, detrimental to both the resulting electrical and capacitive properties. Here we present transparent/flexible supercapacitors using PEDOT:PSS thin films, demonstrating a complete absence of percolation effects for film transmittance as high as T=99%. In doing so, we have achieved the highest energy storage/unit area for technologically relevant transmittance (T greater than 90%).

**TUE 4**

**Fabrication and characterization of thin film transistors based on semi-conductor-enriched carbon nanotubes**

Jun Hirotani¹, Ryotaro Matsui¹, Shigeru Kishimoto¹, Yutaka Ohno¹,²

¹Graduate School of Engineering, Nagoya University, Nagoya, Japan
²EcoTopia Science Institute, Nagoya University, Nagoya, Japan

Carbon nanotubes (CNTs) have been widely recognized as a promising material for various electron device applications due to their remarkable electrical, thermal and mechanical properties. For their thin-film transistor (TFT) applications, the crucial issue is characteristic variation of the CNT thin film. The variation can be predicted to be reduced by increasing number density of CNTs in the channel. In the present work, we have investigated electrical performance and characteristic variation of CNT TFTs as changing number density of CNTs. Semiconductor-enriched (~95%) CNTs were used in this work. The vacuum filtration and transfer method were adopted to fabricate a uniform CNT film. We measured more than a hundred CNT TFTs for each CNT density, and obtained on/off ratio of $10^5 \sim 10^6$, and ON-current variation of ~20% in terms of a standard derivation divided by average ON-current. Our results indicate that as the CNT density increases, the variation in ON-current tends to be eliminated, while the variation is still larger than predicted by simulation.
**TUE 5**

**Towards controlled, integrated manufacturing of 2D materials**

Stephan Hofmann¹, Sabina Caneva¹, Piran Kidambi¹, Robert S Weatherup¹, Andrea Cabrero-Vilatela¹, Bernhard C Bayer¹,², Raoul Blume², Carsten Baecht², Robert Schlögl¹

¹Engineering, University of Cambridge, Cambridge
²Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin
³Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf
⁴Fritz-Haber-Institut der Max-Planck-Gesellschaft
⁵Physics, University of Vienna

The first and foremost challenge for novel 2D materials is to develop integrated manufacturing and processing techniques. Chemical vapor deposition (CVD) has emerged as the most viable route to achieve ‘electronic grade’ 2D materials. Essential to growth control for 2D material CVD is an understanding of the underlying growth mechanisms, specifically the interactions of the precursors and growing 2D structure with the catalyst. [1,2] Here we focus on the growth of hexagonal BN [3,4]. By developing a detailed understanding of element-specific feeding mechanisms for various catalyst systems, we demonstrate the CVD of h-BN single crystals with lateral dimensions of ~0.3 mm as well as continuous h-BN films. Our study of rational catalyst design also includes the effects of oxygen during and after growth. We discuss the implications of these observations in the context of challenges in process integration and hetero-structure CVD.


**TUE 6**

**Solution-processed MoS₂ for broadband ultrafast optical pulse generation at sub-bandgap photon energies**

Richard C. T. Howe¹, Robert I. Woodward², Guohua Hu¹, Felice Torrisi¹, Meng Zhang², Sergei V. Popov², J. Roy Taylor², Edmund J. R. Kelleher², Tawfique Hasan¹

¹Cambridge Graphene Centre, University of Cambridge, Cambridge CB3 0FA, UK
²Femtosecond Optics Group, Blackett Laboratory, Prince Consort Road, Imperial College London, London SW7 2AZ, UK

In fields such as manufacturing, spectroscopy and metrology, there is a considerable demand for wavelength-tunable ultrafast pulsed lasers. Carbon nanotubes and graphene have been used as saturable absorbers to produce such short optical pulses [1]. Here, we demonstrate saturable absorption from liquid phase exfoliated MoS₂. The ~25 µm free-standing MoS₂-polymer composite saturable absorber (SA) shows ~6.3% and ~10.7% modulation depth (change in optical absorption under intense
irradiation) at 1065 and 1565 nm, respectively. The SA is integrated into a fiber laser setup to produce short optical pulses by Q-switching and mode-locking, tunable from 1030 to 1070 nm [2, 3] and 1535 to 1565 nm [4], respectively. We propose that edge-state absorption from the MoS$_2$-nanoflakes could explain the saturable absorption observed at energies below the material bandgap.


**TUE 7**

**Low temperature inks of 2-dimensional crystals for inkjet printing**

Guohua Hu$^1$, Richard Howe$^1$, Zongyin Yang$^1$, Tawfique Hasan$^1$

$^1$Cambridge Graphene Centre, University of Cambridge

Liquid phase exfoliation (LPE) allows production of dispersions of 2-dimensional (2d) crystals, typically in high boiling point solvents, e.g. N-Methyl-2-pyrrolidone (204°C). The dispersions can be formulated into functional inks for inkjet printing, making them promising for large-area, flexible devices. However, difficulties remain in removing the high boiling point solvents and achieving consistent and continuous coating on non-porous substrates.

We demonstrate production of graphene, MoS$_2$, WS$_2$ and MoSe$_2$ by LPE and formulate functional inks with suitable Z values ($\sim$12) for inkjet printing. Z is a figure of merit to characterize the jetting stability of inks with range 1<Z<14 for stable jetting. The inks have low boiling points ($\sim$80°C) and surface tensions ($\sim$28mNm$^{-1}$), making them ideal for a variety of substrates. We demonstrate uniform printed patterns of 2d crystals at high printing resolutions ($\sim$70µm) on flexible glass, SiO$_2$/Si wafer, paper and polymers such as PET and even cling film. Our work promises a wide range of applications, including in photonics, (opto)electronics and sensors.

**TUE 8**

**Efficient one-pot combustion synthesis of graphene sheets**

Andrzej Huczko$^1$, Olga Łabębź$^1$, Agnieszka Dąbrowska$^1$, Michał Soszyński$^1$, Magdalena Kurcz$^1$, Michał Bystrzejewski$^1$, Piotr Baranowski$^1$, Leszek Stobiński$^{2,3,4}$, Artur Małolepszy$^5$, Alexander Okotrub$^6$

$^1$Department of Chemistry, Warsaw University, Warsaw
$^2$Institute of Physical Chemistry, Polish Academy of Sciences, Warsaw, Poland
$^3$University Research Centre "CZMiT", Warsaw University of Technology, Warsaw, Poland
$^4$Nanomaterials Leszek Stobiński, Warsaw, Poland
$^5$Faculty of Materials Science and Engineering, Warsaw University of Technology, Warsaw, Poland
$^6$Nikolaev Institute of Inorganic Chemistry SB RAS, Novosibirsk, Russia
The emerging graphene applications generate a high interest in a search for its large-scale production. Regarding graphene synthesis, thermal or chemical exfoliation of intercalated graphite seems to be the most promising route among various approaches because it enables high-volume production at low-cost, mostly for composite applications. We present here a combustion synthesis approach for the formation of few-layered graphene (FLG). The redox reaction between strong reducers (Mg, Si, Zn, Al) and fluorinated graphite CFx and graphene oxide GO under neutral (Ar, He) and reactive (CO2) atmosphere (at starting pressure 1 MPa) efficiently yields FLG. The products were purified and characterized by XRD, SEM, TEM, and Raman spectroscopy. This environmentally friendly method is simple, fast, economical and suitable for large-scale production of graphene.

Acknowledgement:
This research has been supported by NCN grant No. 2012/05/B/ST5/00709.

TUE 9
Dielectric function and bandgap of graphene oxide

M. Hulman1,2, P. Kotrusz2, V. Vretenár2,3, V. Skákalová2,4
1Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovakia
2Danubia NanoTech, s.r.o., Bratislava, Slovakia
3Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia
4Faculty of Physics, University of Vienna, Vienna, Austria

Optical and electronic properties of graphene oxide (GO) depend on its oxidation state. Based on optical measurements, oxidised graphene is often considered a semiconductor with a wide bandgap of several eV that can be tuned down to almost zero upon reduction. However, this picture is not supported by electrical transport measurements which show rather small bandgaps in order of several tens of meV.

In our contribution, we present results of careful optical measurements of reflectance and transmittance in the visible and near-infrared of GO thin films on sapphire substrates. GO samples with a different level of oxidation were obtained by thermal reduction of a fully oxidised material. From the measurements, we have extracted the dielectric function (DF) in the 0.5 - 5 eV range without taking recourse to any particular model of DF. It has turned out the electronic structure of GO is rather similar to that of amorphous materials with no significant structures in the electronic density of states (DOS) in the energy range investigated. In particular, no sharp band edge in DOS has been found for any GO oxidation level in agreement with electrical conductivity measurements.
TUE 10
Diamond-coated three-dimensional GaN micromembranes

Tibor Izak¹, Gabriel Vanko², Oleg Babchenko¹,², Štefan Potocký¹, Pavlina Choleva⁴, Marian Vojs³, Alexander Kromka¹
¹Institute of Physics AS CR v.v.i., Cukrovarnická 10, 162 00 Prague 6, Czech Republic
²Institute of Electrical Engineering SAV, Dúbravská cesta 9, 841 04 Bratislava, Slovakia
³Institute of Electronics and Photonics, Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, Slovakia
⁴Research Centre for Microtechnology, University of Applied Sciences, Hochschulstrasse 1, 6850 Dornbirn, Austria

In this work, we present technological issues on synthesis of diamond films as a backside heat spreader for AlGaN/GaN heterostructures. First, the AlGaN/GaN circular membrane structures were obtained by a deep reactive ion etching of Si substrate (330 μm thick). The diamond growth was performed complementary in hot filament or microwave plasma CVD system, respectively. We found that standard nucleation techniques (ultrasonic seeding or bias enhanced nucleation) resulted in damaging or cracking of AlGaN/GaN membranes, or low nucleation efficiency in the Z-depth of the structures. Therefore, we implemented a novel nucleation technique with PVA polymer consisting of diamond powder which led to coating of both at bottom and top membrane part, including side walls. Based on FEM simulation, the technological progress will be pointed out as potentially perspective issue for developing high temperature electronic devices working in harsh environments.

This work was supported by the grants 14-16549P and APVV-0455-12.

TUE 11
Theory of coherent light emission in graphene

Roland Jago¹, Torben Winzer¹, Andreas Knorr¹, Ermin Malic¹
¹Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany

Within the density matrix formalism we present a microscopic and full quantized theoretical description of the coupled carrier, phonon and photon dynamics in graphene implemented in a photonic crystal nanocavity. We demonstrate that under strong optical excitation a spectrally broad and long-lived population inversion can be achieved [1]. In the case of free-standing graphene non-radiative Coulomb-induced carrier-recombination on a femtosecond time scale prevents an efficient emission of coherent photons. To partially suppress this ultrafast recombination, we propose to support graphene on a substrate having high-dielectric screening. In this case, our calculations reveal a temporarily extended population inversion, that remains stable up to some tens of picoseconds under realistic conditions. In particular we observe the emission of coherent laser light suggesting graphene as gain medium for lasers [2].
New Directions in Tip-Enhanced Near-Field Optical Microscopy

Julia Janik$^1$, Nina Mauser$^1$, Achim Hartschuh$^1$

$^1$Department Chemie und CENS, Ludwig-Maximilians Universität, München

The characterisation of nanostructures with high spatial resolution and detection sensitivity can be achieved by tip-enhanced near-field optical microscopy (TENOM) [1]. We report on our efforts to extend this method into further directions. One direction is the application of tip-enhancement to photovoltaic and light-emitting devices. We obtained the first high-resolution photocurrent images of carbon nanotube devices using a metal tip to locally enhance optical-to-electrical transduction [2]. We show that the efficiency of the reversed process leading to electroluminescence can be increased as well.

We also implemented tip-enhanced near-field optical microscopy at low temperatures (5 K) and present a new microscope design based on a solid immersion lens configuration providing very high collection angles and efficiencies.

We acknowledge Financial support by DFG, NIM and the ERC (New-NanoSpec).


Binary and Ternary Alloy Nanoparticles Prepared from Apoferritin towards Controlled SWNT Growth

Laura Vera Jenni$^1$, Ruizhong Lin$^1$, Miroslav Haluska$^1$, Tobias Süß$^1$, Yucheng Zhang$^2$, Rolf Erni$^2$, Christofer Hierold$^1$

$^1$Micro and Nanosystems, Department of Mechanical and Process Engineering, ETH Zürich, Switzerland
$^2$Electron Microscopy Center, EMPA, Dübendorf, Switzerland

For controlled single walled carbon nanotube growth the composition, size distribution and density of catalyst particles on a substrate are crucial. It was demonstrated that by using bimetal and novel ternary alloy nanoparticles the yield, the average length as well as the diameter distribution of the grown tubes can be influenced. In this study, the nanoparticles were synthesized inside the protein cage apoferritin [1]. More specifically, Fe-Mo, Fe-Pt, Fe-Ni and Fe-Co as well as Fe-Mo-Pt and Fe-Mo-Ni nanoparticles were produced. For growth with acetylene the average CNT length from Fe-Mo particles could be enhanced by more than 250% in comparison to pure Fe catalysts. Similarly, Fe-Ni and Fe-Pt resulted in a threefold increase in yield. Fe-Mo-Ni displayed some narrowing in the CNT diameter distribution. Using a protein...
cage implies that the elemental composition, size and the deposition density on the growth substrate can be controlled independently. As encouraging results were obtained, this approach is very promising to separately study the factors influencing the growth outcome and to synthesize SWNTs with targeted properties.


**TUE 14**

**Mono- and bi-layer WSe$_2$ as host of localised single – photon emitters**

Artur Kaczmarczyk$^1$, Santosh Kumar$^1$, Brian D. Gerardot$^1$

$^1$Institute of Photonics and Quantum Sciences, SUPA, Heriot-Watt University, Edinburgh EH14 4AS, UK

Semiconducting transition metal dichalcogenides are attracting scientific attention due to its peculiar band structure. Under non-resonant excitation free/charged-exciton peak in monolayer (1L) WSe$_2$ is accompanied by a broad-band emission at lower energies which is associated with defect-bound exciton. Upon cryogenic temperatures $T = 4\text{K}$, the defect band becomes an origin of localised sharp emissions with average linewidth of 130 $\mu\text{eV}$ and obeying single photon statistics (arXiv:1411.2449).

In this work, we show that these lines appear and are localised only in the region where we measure large strain due to wrinkling, abrupt layer termination, or lithographically defined surface modulation. Unlike previous reports, these localised emitters are not only spectrally located in the range of defect-band emission but also extend to much lower energies. In order to characterise the emitters in depth we perform temperature- and polarization- dependent photoluminescence measurements. These findings suggest a promising future for role of strain in quantum optical investigations of spin-valley coherence in WSe$_2$ emitters and their potential for quantum information processing.

**TUE 15**

**Confocal and tip-enhanced Raman spectroscopy on graphene nanoribbons**

Felix Kampmann$^1$, Nils Scheuschner$^1$, Bernat Terrés$^{2,3}$, Danny Jörger$^2$, Christoph Stampfer$^{2,3}$, Janina Maultzsch$^1$

$^1$Institut für Festkörperphysik, TU Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

$^2$JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany

$^3$Peter Grünberg Institute (PGI), Forschungszentrum Jülich, 52425 Jülich, Germany

Lithographic graphene nanoribbons (GNRs) on SiO$_2$ are studied by Raman spectroscopy in order to investigate influences from disorder and charge distributions. The nanoribbon width is obtained from atomic-force microscopy measurements providing a width distribution of each GNR.

The intensities of the defect-induced $D$ and $D'$ modes are compared to the $G$ mode from bulk graphene giving an estimate on the defect concentration. A model, con-
sidering defective and non-defective regions of graphene in a GNR, is developed to quantitatively estimate the size of these regions. Previously used models for GNRs [1,2] and ion bombarded graphene [3] are discussed in comparison. Our findings emphasize the need for nanospectroscopy, such as tip-enhanced Raman spectroscopy (TERS), as a suitable tool to study properties of graphene nanostructures. We present our recent progress in TERS on graphene nanoribbons.


TUE 16
Picosecond photocurrents in single-walled carbon nanotubes

Christoph Karnetzky¹, Alexander W. Holleitner¹
¹Walter-Schottky-Institut and Physik-Department, Technische Universität München, Germany

The exciton dynamics in carbon nanotubes are typically detected in a time-resolved way by optical techniques such as transient absorption and photoluminescence spectroscopy. Many questions remain concerning the separation and transport of photo-generated charge carriers in optoelectronic devices. We address these questions by a novel ultrafast photocurrent spectroscopy, based on an on-chip THz time domain spectroscopy [1]. We find a combination of an optically induced ultra-fast displacement current, transport of photogenerated charge carriers at the Fermi velocity to the electrodes, and interband charge-carrier recombination processes to dominate the ultrafast photocurrent of the single-walled carbon nanotubes [2]. We further discuss optoelectronic effects in the carbon nanotubes which arise from an ultrafast optical excitation with a super-continuous light spectrum [3].

We acknowledge financial support from the ERC-grant "NanoREAL" and the DFG excellence cluster "Nanosystems Initiative Munich" (NIM).


TUE 17
Planar graphene tunnel field-effect transistor

V.L. Katkov¹, V.A. Osipov¹
¹Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna

We propose a concept for a graphene tunnel field-effect transistor. The main idea is based on the use of two graphene electrodes with zigzag termination divided by a narrow gap under the influence of the common gate. Our analysis shows that such device will have a pronounced switching effect at low gate voltage and high on/off current ratio at room temperature.
TUE 18
Electrical property of highly aligned chirality selected single-walled carbon nanotubes assemblies

Hideki Kawai, Kai Hasegawa, Kazuhiro Yanagi

Department of physics, Tokyo Metropolitan University, Tokyo

Conventional Single Wall Carbon Nanotube (SWCNTs) devices have been fabricated as random network where junctions between nanotubes strongly influence their transport property. Such junctions work as scattering centers where carriers are localized [1]. To reduce the presence of such scattering centers is of great importance for improvement of transport characteristics. In this context, development of techniques to produce aligned array or crystal-like assemblies of SWCNTs using the high purity SWCNTs is important. In this study, we report a string-like assembly of aligned SWCNTs, which prepared by controlling temperature of solution where SWCNTs were dispersed using surfactants [2]. In addition, we report production of assemblies of highly aligned chirality selected SWCNTs [3]. In this poster, we discuss the transport characteristics of the aligned assemblies.

Reference:

TUE 19
The effect of annealing on intrinsic defects in zinc oxide nano-crystals

Sevak Khachadorian, Rolland Gillen, Janina Maultzsch, Axel Hoffmann, Sumin Choi, Cuong Ton-That, Matthew R. Phillips

Institut für Festkörperphysik, Technische Universität Berlin, Berlin
School of Physics and Advanced Materials, University of Technology, Sydney, Sydney

The photoluminescence (PL) spectrum of ZnO exhibits a near-band-edge UV emission and generally a broad defect related visible emission. The origin of defect luminescence is still controversial. The optical and vibrational properties of zinc oxide nano-crystals (ZnO NCs), grown by vapor transport method, were investigated after the thermal annealing in oxygen-, argon- and vapor Zn-rich conditions. Raman scattering and other characterization techniques were conducted to show the effect of temperature annealing in various environments on the defect luminescence and local vibrational modes (LVM) of the ZnO NCs. Dramatic changes in the defect-luminescence and Raman LVMs were observed depending on the different annealing treatments. Scanning electron microscopy and X-ray diffraction methods were used to monitor the structural changes induced by the effect of annealing. The experimental results are complemented by density function theory (DFT) calculations using the SIESTA package to get a more detailed understanding of origin of intrinsic defects.
TUE 20
Synthesis and growth properties of inner tubes inside metallocene-filled single-walled carbon nanotubes

Marianna V. Kharlamova¹, Christian Kramberger¹, Hidetsugu Shiozawa¹, Kazuhiro Yanagi², Takeshi Saito³, Thomas Pichler¹
¹Faculty of Physics, University of Vienna, Vienna
²Department of Physics, Tokyo Metropolitan University, Japan
³AIST, National Institute of Advanced Industrial Science and Technology, Japan

The filling of SWCNTs and chemical transformation of encapsulated substances inside their channels are promising approaches to tailor properties of SWCNTs. In present work, we performed the filling of eDIPS SWCNTs of 1.7-nm mean diameter with nickelocene [1], cobaltocene and ferrocene [2] molecules and their further transformation into DWCNTs via thermal annealing in vacuum. Using multifrequency in situ Raman spectroscopy we investigated time-dependent inner tube growth in detail. We calculated growth rates and activation energies of the formation of inner tubes of different chiralities and diameters. We also performed DGU of the filled SWCNTs to study the inner tube growth properties inside metallic and semiconducting SWCNTs of certain chiralities and diameters. These results allowed us to achieve the comprehensive picture of the dependence of the physical properties of metallocene-filled SWCNT hybrids on tube diameter, chiral angle and metallocene type.

M.K. acknowledges the ÖAW for a DOC-fFORTE fellowship.

TUE 21
Probing Electrons in Carbon Nanotubes without Conduction

Ilya Khivrich¹, Shahal Ilani¹
¹Condensed matter physics dept, Weizmann Institute, Rehovot

The recent generation of carbon nanotube devices, which allow to engineer the potential landscape along a pristine one-dimensional system, forms a versatile playground for studying a large variety of correlated electronic ground states. While some of these ground states are conducting, others are fundamentally insulating, thus hindering their measurement via transport. Here we demonstrate a new method that allows us to directly measure these insulating states by probing the interaction between the electrons and the mechanical motion of the nanotube. The key feature of this method is a new capability to control and measure the nanotube’s mechanical motion in the time domain while quickly switching between different electronic configurations. We can thus actuate the mechanical motion, let the electronic system of interest interact with it, and coherently measure the motion after the interaction took place by turning on the conductivity. We will demonstrate how this technique opens a new venue for observing electronic states that were previously impossible to probe.
TUE 22
A novel probe for local imaging of interacting electrons in 1D with minimal invasiveness
Ilanit Shammass\textsuperscript{1}, Sharon Pecker\textsuperscript{1}, Shahal Ilani\textsuperscript{1}
\textsuperscript{1}Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel

Interacting electrons in a one dimensional channel are a unique physical system, which can exhibit a variety of correlated electron phases. Many of these phases, such as the quantum Wigner crystal, have a distinct signature in their real-space electronic structure. Recently, we have developed pristine multi-gate nanotube (NT) devices, which allow for precise engineering of 1D microscopic potentials along the NT, while maintaining strong electron interactions. This makes them ideal for realizing correlated electron phases, and calls for development of a local probe that can resolve their electronic spatial structure, without destroying it due to large potential modulations. For this purpose we created a novel experimental setup, where we use a second NT device as a sensitive charge detector in a scan probe microscope configuration. Its main advantage is that the probe invasiveness can be tuned, and is limited in principle only by the quantum back-action of single electrons in the detector. We will demonstrate how the invasiveness of the probe-NT can be controlled and drastically reduced. In addition, we will present initial results of wavefunction imaging using this platform.

TUE 23
Hydrogen storage in graphene related materials.
Alexey Klechikov\textsuperscript{1}, Guillaume Mercier\textsuperscript{1}, Alexandr Talyzin\textsuperscript{1}
\textsuperscript{1}Physics, Umeå University, Umea

Several studies reported recently that graphene adsorbs 3-10 fold more hydrogen compared to other carbon materials. Graphene powders with broad range of BET surface areas were prepared using thermal exfoliation/activation of Hummers and Brodie graphite oxides. Hydrogen sorption by samples with surface areas in the range 200-2800 m\textsuperscript{2}/g was evaluated using gravimetric and volumetric systems at ambient temperature and 77K. It is found that hydrogen uptake of graphene samples shows precise correlation with surface area both at 295K and 77K, independently on type of GO precursor or activation methods. Maximal hydrogen uptake at 295K and 120 Bar H\textsubscript{2} pressure do not exceed 1 weight percent. Maximal value of H\textsubscript{2} uptake 5.6 weight percent was found for sample with 2800m\textsuperscript{2}/g surface area at 77k. Hydrogen uptake versus surface area trends evaluated in our experiments for graphene are rather similar to those earlier reported for carbon nanotubes, activated carbons and metal organic framework materials. Graphene oxide framework samples synthesized using reaction of graphite oxide with boronic acids also showed no significant deviations from this "standard" trend.
TUE 24
Growth of high-quality monolayer WS$_2$ on graphite
Yu Kobayashi$^{1}$, Shogo Sasaki$^{1}$, Shohei Mori$^{1}$, Hiroki Hibino$^{2}$, Kenji Watanabe$^{3}$, Takashi Taniguchi$^{2}$, Yutaka Maniwa$^{1}$, Yasumitsu Miyata$^{1,4}$
$^{1}$Department of Physics, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan
$^{2}$NTT Basic Research Laboratories, NTT Corporation, Atsugi, Kanagawa 243-0198, Japan
$^{3}$National Institute for Materials Science, Tsukuba, Ibaraki 305-0044, Japan
$^{4}$JST, PRESTO, Kawaguchi, Saitama 332-0012, Japan

Atomic-layer transition metal dichalcogenides (TMDCs) have attracted appreciable interest due to their tunable bandgap, spin-valley physics, and potential device applications. However, the quality of TMDC samples available still poses serious problems, such as inhomogeneous lattice strain, charge doping, and structural defects. Here, we report on the growth of high-quality, monolayer WS$_2$ onto exfoliated graphite by chemical vapor deposition. Unlike commonly-used substrates such as SiO$_2$/Si and sapphire, monolayer WS$_2$ grown on graphite presents a uniform, single excitonic photoluminescence peak with a Lorentzian profile and a very small full-width at half maximum of 21 meV at room temperature and 8 meV at 79 K. Furthermore, no additional peaks are observed for charged and/or bound excitons, even at low temperature. These results indicate that the cleaved graphite surface is an ideal substrate for the growth of high-quality, non-doped TMDCs, and such samples will be essential for revealing intrinsic physical properties and for future applications.

TUE 25
Atomic structure of 2D amorphous carbon membranes
Jani Kotakoski$^{1}$, Giacomo Argentero$^{1}$, Franz Eder$^{1}$, David Lindner$^{1}$, Clemens Mangler$^{1}$, Andrey Turchanin$^{2}$, Jannik Meyer$^{1}$
$^{1}$University of Vienna, Austria
$^{2}$University of Jena, Germany

Since over 80 years, the popular concept of the atomic structure of amorphous materials has been strongly influenced by the drawings of a random network by Zachariasen [1]. However, direct imaging of the atomic structure of a conventional glass has remained impossible. Only very recently, the first possibility to image the complete atomic structure of a disordered material appeared in the form of two-dimensional materials. So far, two different materials have been described: a truly 2D silica glass [2,3] and amorphized graphene [4,5]. Here, via atomic resolution scanning transmission electron microscopy, we compare the atomic arrangements in these materials to two other forms of amorphous 2D carbon: evaporated thin films and disordered membranes created via annealing of organic molecules on a metal substrate.

References:
TUE 26
Low Dose Imaging of Organic Molecules on Graphene
Christian Kramberger1, Jannik Meyer1, Jani Kotakoski1, Clemens Mangler1
1Fakultät für Physik, University of Vienna, Vienna

In conventional STEM beam induced damage is confidently hindering the imaging of small organic molecules with atomic resolution. Graphene is a notable support material that is not suffering beam damage at acceleration voltages as low as 60 kev. We demonstrate by simulations that the full atomic structure of organic molecules can be clearly resolved from large area ultra low dose (virtually dark) exposures on stochastic sub monolayers of organic molecules on a graphene support. By taking into account the full symmetry of the graphene support in a maximal likelyhood image reconstruction even totally asymmetric planar molecules like Guanine can be fully resolved at an exposure as low as $10^{-2}/\text{Å}^2$ or correspondingly 0.5 counts per graphene hexagon.

TUE 27
Correlations of RBM, G line, and D line frequencies of individual SWCNTs grown from carbon:nickel nanocomposite templates
Svetlana Melkhanova1,2, Tim Kunze3, Miro Haluska4, René Hübner1, Adrian Keller5, Sibylle Gemming1,2,6, Matthias Krause1
1Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden
2Technische Universität Dresden, cfaed, D-01062 Dresden, Germany
3Fraunhofer Institute for Material and Beam Technology, 01277 Dresden, Germany
4ETH Zürich, Micro and Nanosystems, CH-8092 Zürich, Switzerland
5University Paderborn, 33098 Paderborn, Germany
6Technische Universität Chemnitz, D-09107 Chemnitz, Germany

Carbon:nickel nanocomposite templates were used for CVD growth of separated, individual single-walled carbon nanotubes (SWCNTs) free of solvents or surfactants. The as-grown carbon nanotubes were characterized by laser-energy dependent Raman spectroscopy and atomic force microscopy. Raman spectra showing a single radial breathing mode (RBM) line were analyzed with respect to correlations of RBM, $G^+$ line and $D$ line frequencies for SWCNT diameters covering the range of 0.8 nm to 1.6 nm. Opposite line shifts were found for RBM and $G^+$ lines of the individual SWCNTs. However, the line shifts of the $G^+$ line are smaller than the standard deviation of the $G^+$ position for SWCNTs with almost the same RBM frequency, i.e. $1 \text{ cm}^{-1}$ compared to $\pm 1 \text{ cm}^{-1}$ for the whole diameter range. The $D$ line often shows
a complex shape including up to three components, which makes the identification of correlations with RBM frequencies possible only in selected cases.

**TUE 28**

**Hydrodynamic Electron Flow in Graphene-Boron Nitride Heterostructures**

Roshan Krishna Kumar\textsuperscript{1,2}, Leonid Ponomarenko\textsuperscript{1,2}, Iacopo Torre\textsuperscript{3}, Greg Auton\textsuperscript{1,4}, Marco Polini\textsuperscript{3}, Andre Geim\textsuperscript{1,4}

\textsuperscript{1}Physics Department, Lancaster University, Lancaster
\textsuperscript{2}School of Physics and Astronomy, University of Manchester, Manchester
\textsuperscript{3}NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Pisa, Italy
\textsuperscript{4}Centre for Mesoscience and Nanotechnology, University of Manchester, Manchester

Electron transport in solid state systems is usually described, depending on sample dimensions and mean free path, by a diffusive or ballistic model where electron interactions are dominated by non-like particle collisions. Intrinsic graphene however has a very low electron-phonon coupling and as a result, at elevated temperatures, transport is dominated by electron-electron collisions where a hydrodynamic description may be more applicable. Theory has already predicted some interesting flow behaviour such as a high viscosity of the electron fluid, owed to the Dirac nature of the electrons. As a result of this viscous flow, whirlpools or vortices may form adjacent to the normal current flow. In this work we have studied high mobility encapsulated graphene and observed such whirlpools by measuring negative four-probe resistance in custom geometries.

**TUE 29**

**Low temperature hydrogenation of diamond nanoparticles using diffuse coplanar surface barrier discharge at atmospheric pressure**

Alexander Kromka\textsuperscript{1}, Jan Čech\textsuperscript{2}, Halyna Kozak\textsuperscript{1}, Anna Artemenko\textsuperscript{1}, Mirko Černá\textsuperscript{k}\textsuperscript{2}

\textsuperscript{1}Institute of Physics, Academy of Sciences of the Czech Republic, Cukrovarnicka 10, 162 00 Prague 6, Czech Republic
\textsuperscript{2}Regional R&D center for low-cost plasma and nanotechnology surface modifications, Masaryk university, Kotlarska 2, 611 37 Brno, Czech Republic

Diamond nanoparticles (DNPs) have attracted an attention of researchers due to their capability for applications as drug delivery, molecule labelling, spintronic, quantum computing. Commonly, high temperature processes (700$^\circ$C) as hot-filament, microwave plasma or annealing in hydrogen gas atmosphere were used to passivate DNPs surfaces with hydrogen that defines the starting point for many functions and chemistries. Yet reliable mass hydrogenation of DNPs is still a challenging task. Here we report on a new approach to plasma assisted DNPs hydrogenation at temperatures below 100$^\circ$C. As received detonation DNPs with size about 5 nm were annealed in air at 450$^\circ$C for 30 min to reduce non-diamond carbon content. Then the annealed DNPs were plasma treated with atmospheric-pressure diffuse coplanar surface barrier discharge in pure hydrogen at power 1.2 W/cm$^2$. While IR spectra
of the annealed DNPs were dominated by oxygen containing functional groups, the hydrogenated DNPs revealed increase of bands of C-H stretching vibrations in the region 2800-3000 cm$^{-1}$ after 5 min plasma treatment. No significant changes in IR spectra were observed for prolonged plasma treatments.

**TUE 30**

**Cavity enhanced light emission from an electrically driven carbon nanotube**

Valentin Fütterling$^1$, Feliks Pyatkov$^1$, Svetlana Khasminskaya$^1$, Frank Hennrich$^1$, Manfred M. Kappes$^{1,3}$, Ralph Krupke$^{1,2}$, Wolfram H.P. Pernice$^1$

$^1$Institute of Nanotechnology, Karlsruhe Institute of Technology

$^2$Department of Materials Science, Technische Universität Darmstadt

$^3$Institute of Physical Chemistry, Karlsruhe Institute of Technology

Nanoscale photonic emitters are essential elements for on-chip networks and optical interconnects. Besides preferred electrical trigger capability, tailored optical properties are highly desirable to engineer application specific light sources. Recently we have shown how light from an electrically-driven carbon nanotube can be coupled directly into a photonic waveguide[1]. Here we demonstrate electrically driven nanoscale emitters with narrow linewidth based on carbon nanotubes embedded into nanophotonic circuits. A particular photonic emission wavelength is realized by engineering the photonic density of states of the dielectric environment of the CNT. Using one-dimensional photonic crystal cavities we spectrally select desired emission wavelengths and couple light into the underlying photonic network with high efficiency and reproducibility. Our approach holds promise for active photonic networks and localized sensing applications in a chip-scale framework.


**TUE 31**

**Raman spectra of hydrocarbons formed in carbon nanotubes - a theoretical study**

Jenő Kürti$^1$, János Koltaí$^1$, Hans Kuzmany$^2$

$^1$Department of Biological Physics, Eötvös University, Budapest

$^2$Elektronische Materialeigenschaften, Universität Wien, 1090 Wien, AT

The origin of several Raman bands which appear in ferrocene filled small diameter carbon nanotubes after annealing at 800 °C is still an open question. The most remarkable observation is the appearance of non-dispersive lines in the D-band region. The experimental details (including Raman- and mass spectra) are presented in the contribution of Kuzmany et al. We performed DFT calculations of structure, HOMO-LUMO transition energy and Raman spectrum with B3LYP functional for a large set of hydrocarbon molecules, including polyenes and polyaromatic hydrocarbons. To follow the effect of deuterization in the Raman spectra we varied the mass of hydrogen atom from 1 to 2 by 0.1 steps. With increasing mass the position of the
lines red shifted as expected. However in some rare occasions the intensity of the red shifted line dramatically decreased and at the same time an originally weak line gained large intensity at a nearby higher frequency. This can be interpreted in an experiment as an apparent blue shift. From a comparison of the calculations with experiments the dimer of the 3,4,9,10-perylenetetracarboxylic dianhydride (PTCDA) is the most likely product of the annealing process.

**TUE 32**
The origin of non-dispersive Raman lines in the D-band region for ferrocene-
@HiPco transformed at high temperatures

H. Kuzmany$^1$, L. Shi$^1$, T. Pichler$^1$, J. Kürti$^2$, J. Koltai$^2$, F. Hof$^3$

$^1$Elektronische Materialeigenschaften, Universität Wien, 1090 Wien, AT
$^2$Department of Biological Physics, Eötvös University, Budapest, HU
$^3$Univ. Erlangen-Nürnberg, Inst Adv Mat & Proc ZMP, D-90762 Fürth, DE

For ferrocene (FeCp2) in HiPco or small diameter DIPs new non-dispersive Raman bands appear in the D-band region after annealing at 800 °C. These bands can be very strong and are resonance enhanced in the red [1]. From Raman mapping a set of at least 6 lines, including a response from a C=C stretch vibration, was identified as belonging to the same source. Mass spectra from cold-trapped evaporation products revealed masses in the range of 450 to 700 Dt with an often observed species at 686 Dt. These values are typical for large hydrocarbon molecules. Isotope labelling of the FeCp2 molecule showed that the new Raman lines originate from reaction products of FeCp2. DFT calculations of Raman spectra were performed for a large set of hydrocarbon molecules, in each case with a stepwise increase of the hydrogen mass from 1 to 2. This allowed for a clear identification of the origin of the lines in hydrogenated and deuterated species. From a comparison of the calculations with experiments the dimer of the 3,4,9,10-perylenetetracarboxylic dianhydride (PTCDA) (652 Dt) was found to give the best agreement.


**TUE 33**
One step production of MWCNT aerogels via catalytic CVD ethylene decomposition.

V. L. Kuznetsov$^{1,2,3}$, D.V. Krasnikov$^{1,2}$, M.A. Kazakova$^{1,2}$, S.I. Moseenkov$^1$, I.O. Dorofeev$^3$, T. E. Smirnova$^3$, V.I. Suslyaev$^3$

$^1$Boreskov Institute of Catalysis, Novosibirsk 630090, Russia
$^2$Novosibirsk State University, Novosibirsk 630090, Russia
$^3$National Tomsk State University, Tomsk 634050, Russia

Carbon nanotube (CNT) aerogels present a new bulk material which integrate unique properties of CNTs and specific properties of aerogels. Here we report one step MWCNT aerogel production by CVD process using preformed catalysts consisting of agglomerates of dispersed support particles with nano-sized oxide precursors of
iron group metal catalyst. In situ activation of the precursors in reaction conditions results in the formation of nano-sized metal particles which in turn provide multi center growth of MWCNTs. Growth of tangled MWCNTs provide the formation sponge structure of aerogel which volume increases a hundred times in comparison with a volume of preformed catalysts. Any form of MWCNT aerogels with density of 0.03-0.08 g/cm³ can be produced using different geometry of preformed catalysts (balls, cubes etc.). Aerogels demonstrate high electrical conductivity (several S cm⁻¹). Measurements of electric and magnetic polarizability in the frequency range of 8-12 GHz using open microwave resonator show that aerogel balls demonstrate electromagnetic properties close to that of metals. That makes them a perspective lightweight material for different EM applications.

**TUE 34**

**Effect of temperature cycling on transconductance fluctuations in graphene**

Dong Su Lee¹

¹Soft Innovative Materials Research Center, Korea Institute of Science and Technology (KIST), Jeonbuk

The charge localization in quantum Hall regime can be captured by a simple measurement of transconductance. Transport measurements normally provide a macroscopic, averaged view of the sample, so that disorder frequently prevents the observation of fragile interaction induced states in the conductance. We demonstrated that these fluctuations reflect processes of charge localization [1]. A systematic study allows observing higher order fractional quantum Hall states. The fluctuations appear when conduction channels are influenced by the compressible quantum dots which form at hills or valleys of disordered potential landscape. The conductance fluctuations are found to be stable for months as long as the sample is kept at cryogenic temperature less than 15 K. However, the fluctuation curve change significantly once the sample is heated up to the temperature higher than 25 K and cooled down again.

**TUE 35**

**Electrical and electromechanical properties of WS\textsubscript{2} nanotubes**

Roi Levi¹, Jonathan Garel¹, David Teich², Gotthard Seifert², Reshef Tenne¹, Ernesto Joselevich¹

¹Materials and Interfaces, Weizmann Institute of Science, Weizmann Institute of Science
²Theoretische Chemie, Technische Universität Dresden, Germany

The electronic properties of dichalcogenide nanotubes (INT) and sheets and their incorporation into nanoelectromechanical systems (NEMS) is the subject of intensive research in recent years. INT-WS\textsubscript{2} possess superior mechanical properties and interesting stick-slip mechanical phenomena [1] and thus are a natural candidate for electro-mechanical devices.
We present here the first significant electro-mechanical response in pure inorganic nanotubes [2], field-effect mobility and surprisingly high current carrying capacity for the INT-WS2 [3]. The INT-WS2 conductivity exhibited a highly repeatable increase in response to strain and torsion. These results are in qualitative agreement with the theoretical torsional calculations presented here and previous theoretical predictions for strain. The high sensitivity to torsion and tension suggests INT-WS2 as promising components in NEMS such as gyroscopes and accelerometers.

References

TUE 36

Size quantization in graphene quantum point contacts

B. Terrés¹,², L. Chizhova³, D. Jörger¹, S. Engels¹,², J. Burgdörfer³, F. Libisch³, C. Stampfer¹,²
¹JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52056 Aachen, Germany
²Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany
³Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria

Quantum point contacts form a cornerstone of mesoscopic physics as central building blocks for quantum electronic devices. Graphene shows a number of exceptional properties but the demonstration of graphene quantum point contacts has proven very challenging. Recent developments in the fabrication of high-mobility graphene-hexagonal boron nitride sandwich structures have improved the chances to observe quantum confinement of Dirac electrons in quasi-one dimensional graphene systems. Here we present joint experimental and theoretical work on ballistic transport of confined Dirac fermions in graphene nanoconstrictions. Reproducible kinks in the conductance are associated with size quantization in the quantum point contact. At high charge carrier densities, measurements agree excellently with theoretical simulations. Deviations from the expected linear behavior at low carrier densities emerge due to localized states at the edges, allowing the direct probing of trap states by transport measurements. Comparing the evolution of the observed kinks with magnetic field to theoretical predictions for one-dimensional confined states in graphene confirms size quantization as their origin.
TUE 37
Optical properties of highly-extended, ultrathin graphene nanoribbons in carbon nanotubes

Hong En Lim\textsuperscript{1}, Yasumitsu Miyata\textsuperscript{2}, Miho Fujihara\textsuperscript{1}, Susumu Okada\textsuperscript{3}, Haruka Omachi\textsuperscript{1}, Ryo Kitaura\textsuperscript{1}, Hisanori Shinohara\textsuperscript{1}
\textsuperscript{1}Department of Chemistry, Nagoya University, Japan
\textsuperscript{2}Department of Physics, Tokyo Metropolitan University, Japan
\textsuperscript{3}Graduate School of Pure and Applied Sciences, University of Tsukuba, Japan

Nano-templated growth of graphene nanoribbons (GNRs) at the interior spaces of the carbon nanotubes (CNTs) \cite{1, 2} allows the possible construction of ultrathin ribbons with defined side edge configuration. However, due to the presence of the template tubes, less is known about the properties of GNRs inside. Herein, we report the optical properties of the extended GNRs, residing in single-wall CNTs. The GNRs were generated using coronene as precursors. Annealing at high temperature results in the extensive polymerization into ribbons of long length, as indicated by the Raman and TEM measurements. Signals generated from the outer CNTs were eliminated by using diazonium-based surface modification \cite{3} to give clear optical absorption of the inner GNRs around 1.5 and 3.4 eV. The values are attributable to the first and second transitions across the energy gaps between the valence and conduction bands, in qualitative agreement with the first principle calculations.

References:
\cite{1} H. E. Lim et al. Nat. Commun. 2013, 4, 2548.
\cite{3} M. S. Strano et al. Science 2003, 301, 1519-1522.

TUE 38
Multiphonon spectral analysis in bulk and monolayer MoS2

Tsachi Livneh\textsuperscript{1}, Jonathan E. Spanier\textsuperscript{2}
\textsuperscript{1}Department of Physics, NRCN, P.O. Box 9001, Beer- Sheva, 84190, Israel.
\textsuperscript{2}Department of Materials Science & Engineering, Drexel University, 3141 Chestnut St., Philadelphia, PA, 19104, USA.

We present a comprehensive multiphonon Raman and complementary infrared analysis for bulk and monolayer MoS2 (1). For the bulk the analysis consists of symmetry assignment from which we obtain a broad set of allowed second-order transitions at the high symmetry M, K and Γ Brillouin zone points. The attribution of about 80 transitions of up to fifth- order processes are proposed in the low temperature resonant (with the A exciton) Raman spectrum. We conclude that the main contributions come from five phonons: A1g (M), and two sets of single degenerate phonons at M with an origin of the two Brillouin zone center E2g phonons. Consistent with the fact that at the M point only combinations with the same inversion symmetry are Raman-allowed, the contribution of combinations with the LA(M) mode is not dominant.
P and T dependent multiphonon Raman spectra will be analyzed in accordance with the above analysis.

For the monolayer MoS2 the second-order phonon processes from the M and Γ Brillouin zone points are also analyzed and are discussed within similar framework to that of the bulk.


**TUE 39**

**Synthesis and Electronic Properties of Li-doped Chemically Exfoliated Graphene**

Bence G. Márikus1, Julio C. Chacon-Torres2, Philipp Vecera3, Jan M. Englert3, Ferenc Simon1, Thomas Pichler4, Andreas Hirsch3

1Department of Physics, Budapest University of Technology and Economics, Budapest

2Institute of Experimental Physics, Freie Universität Berlin

3Department of Chemistry and Pharmacy and Institute of Advanced Materials and Processes (ZMP), University of Erlangen-Nuremberg

4Faculty of Physics, University of Vienna

Alkali atom intercalation of graphene leads to a conducting material which have both compelling fundamental properties and prospective applications. In particular, Li intercalation is expected to lead to a novel energy storage device. In addition, DFT calculations predict that the Li-graphene system is a superconductor with a critical temperature as high as 10 K. We produced Lithium doped Chemically Exfoliated Graphene (CEG/FLG) samples with the liquid ammonia solution method. This method is based on the good solubility of the alkali metal elements in liquid ammonia. The resulting samples were studied by Electron Spin Resonance Spectroscopy (ESR) and Raman spectroscopy. Upon doping, we observe an ESR line which is absent in the undoped samples. The line has a Dysonian lineshape which proves that this signal originates from itinerant electrons which thus come from the charge transferred electrons in graphene. Measurement of the ESR linewidth allows to determine the spin-relaxation time, which is important for prospective spintronics applications of charged graphene.

**TUE 40**

**Theory of anomalous thermal expansion in 2D crystals**

Karl H. Michel1, Sebastian Costamagna1,2, Francois M. Peeters1

1CMT Physics, Universiteit Antwerpen, Antwerpen,Belgium

2Instituto de Fisica, Rosario,Argentina

The thermal expansion ath in layered crystals is a quantity of fundamental and practical interest. As suggested by I.M.Lifshitz 1952 a negative contribution to ath is due to anharmonic couplings between in-plane stretching and out-of plane bending,flexural, modes.Genuine in-plane anharmonicities give a positive contribution to ath.
A change of sign of $\alpha$ as a function of temperature $T$ is a topic of current theoretical and experimental research. Here we present an analytical lattice dynamics approach for a 2D hexagonal crystal. The in-plane and out-of-plane Grüneisen coefficients are calculated. The thermal expansion is studied as function of $T$ and crystal size. The temperature $T_a$ where $\alpha$ changes from negative to positive values decreases with decreasing crystal size. Renormalization of the flexural mode frequency leads to a further decrease of $\alpha$. Numerical examples are given for graphene where the anharmonic couplings are determined from experiments. The theory is applicable to other monolayer crystals wherever the anharmonic couplings are known.

**TUE 41**

**Photo-doping of MoS$_2$ revealed by Inelastic Light Scattering**

Bastian Miller$^1$, Eric Parzinger$^1$, Anna Vernickel$^1$, Alexander W. Holleitner$^1$, Ursula Wurstbauer$^1$

$^1$Walter Schottky Institut and Physik-Department, Technische Universität München, Am Coulombwall 4a, 85748 Garching (Germany)

Two-dimensional layered ‘van-der Waals’ materials are of increasing interest for fundamental research as well as for device applications. For optical and optoelectronic applications as well as for studying fundamental optoelectronic properties, a comprehensive knowledge about the interaction of the 2D materials with light and the dielectric environment such as the substrate is essential.

We utilize inelastic light scattering for studying doping and heating effects of single- and multi-layer MoS$_2$. Using Raman measurements on top-gated field-effect transistor structures we demonstrate that the optoelectronic properties are strongly affected by the substrate. For mono- and bilayer MoS$_2$, we find a laser power induced change of the charge carrier density that is attributed to defects in the SiO$_2$-MoS$_2$ interface serving as trap states for photoexcited holes.

We acknowledge financial support by the DFG excellence cluster ’Nanosystems Initiative Munich’.

**TUE 42**

**Potential of HCCNTs for nano-mechanical mass sensor applications**

Zoran P. Popović$^1$, Saša Dmitrović$^1$, Milan Damnjanović$^1$, Ivanka Milošević$^1$

$^1$Faculty of Physics, University of Belgrade, Serbia

We explore potential of helically coiled carbon nanotubes (HCCNTs) for applications as nano-mechanical resonators in mass and strain sensors. Using symmetry-based atomistic modeling, we consider both bridged and cantilevered configurations and also calculate fundamental frequencies of homogenously deformed HCCNTs taking into account impact of the strain-induced deformations. Finally, we make comparative analysis of the performances of HCCNT-based and SWCNT-based nano-mechanical resonators.
**TUE 43**

High-energy plasmons in graphene and MoS$_2$ heterostructures

Michael Mohn$^1$, Ralf Hambach$^1$, Philipp Wachsmuth$^1$, Ute Kaiser$^1$

$^1$Electron Microscopy Group of Materials Science, Ulm University, Ulm

We investigate high-energy plasmons in layered 2D systems made of graphene and monolayer MoS$_2$. By direct comparison of momentum-resolved electron energy-loss (EEL) spectra and ab initio calculations, we want to gain insight into the influence of interactions between the individual layers.

Our EELS measurements have been performed using the low-voltage "SALVE I" TEM [1] equipped with a monochromator and an in-column energy filter. With simulations based on time-dependent DFT calculations for the graphene and MoS$_2$ layers, we find that regarding the investigated plasmons, only Coulomb interaction between the layers has to be considered. Whereas the spectra of multilayer graphene can be accurately described with homogeneous 2D layers in the layered electron-gas (LEG) model [2], we observe a discrepancy between LEG results and measured spectra of heterostructures involving MoS$_2$ layers. Calculations which account for the finite thickness of the MoS$_2$ layers may resolve this discrepancy, as corresponding calculations for bulk MoS$_2$ suggest.


**TUE 44**

RF NEMS Based on CVD Multilayer Graphene

Clara Fausta Moldovan$^1$, Wolfgang Amadeus Vitale$^1$, Adrian Mihai Ionescu$^1$

$^1$Nanoelectronics Devices Laboratory, NanoLAB, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

Silicon technology is currently dominant in the realization of nanoelectromechanical systems (NEMS), but the growing interest in graphene is paving the way to new devices with improved performance. Graphene is a promising candidate for NEMS applications due to its low mass, high mechanical stiffness, and high strength. For NEM switches, in particular, it brings the advantage of low actuation voltage and fast switching, while its hydrophobic surface avoids the surface stiction problem between the contacts, thus leading to better reliability. We discuss the prospect of graphene as a material for NEMS in the particular case of a NEM capacitive switch. We propose a novel design involving a suspended multilayer CVD-grown graphene membrane, doubly clamped on a coplanar waveguide (CPW). The fabrication consists in suspending the graphene membrane over the signal line of the CPW by etching the underlying sacrificial layer of oxide. We perform a thorough characterization of the NEMS between 1 and 40 GHz and discuss the potential for RF applications. Our results confirm that graphene is a good candidate for the fabrication of suspended membranes for fast-switching RF NEMS devices.
TUE 45
The role of quantum interferences in the plasmon-enhanced Raman scattering in graphene

Niclas Sven Müller¹, Stephanie Reich¹
¹Department of Physics, Freie Universität Berlin

Localized surface plasmon resonances in metal nanostructures can efficiently focus light into nanoscale volumes and generate very intense local fields. The Raman scattering cross section of a molecule in a plasmonic hotspot can be enhanced by several orders of magnitude - an effect that was discovered almost 40 years ago.

We present a new theory of plasmon-enhanced Raman scattering (PERS) that is based on a quantum mechanical description of the plasmonic enhancement. Quantum interference between different scattering channels significantly influences the excitation-energy dependence of the enhanced Raman cross section. Such PERS resonance profiles are explicitly calculated for graphene that is coupled to the plasmonic resonance of a gold nanocavity. Graphene is an ideal material for the investigation of PERS because of its constant Raman cross section. A formalism that is based on the second quantization of the collective electron excitations in the metal nanostructure is employed to calculate all relevant matrix elements. Our calculations explain the excitation-energy dependence of experimental PERS resonance curves, that were recorded with a tunable laser system.

TUE 46
Non-covalent Functionalization of Carbon Nanotubes

Udo Mundloch¹, Sebastian Bosch¹, Erik Weinreich¹, Claudia Backes³, Mario Marcial¹, Simone Berngruber², Susanne Backes², Frank Hauke¹, Andreas Hirsch²
¹Institute of Advanced Materials and Processes, University Erlangen-Nürnberg, Dr.-Mack-Str. 81, 90762 Fürth, Germany
²Department of Chemistry and Pharmacy, University Erlangen-Nürnberg, Henkestr. 42, 91054 Erlangen, Germany
³School of Physics, Trinity College Dublin, Dublin 2, Ireland

Single walled carbon nanotubes (SWNTs) are a material with extraordinary physical, chemical and electronic properties and a variety of possible and already implemented applications. The biggest hurdles one has to address concerning their processability, are their poor solubility and the polydispersity of the pristine material.

Commercially available detergents as well as specially designed surfactants have been extensively examined as means to disperse and even separate different types of SWNTs. However, usually no attention is paid to the effect of the temperature on the resulting dispersions. We demonstrate that the different behavior of detergents above and below their Krafft point is reflected in their selectivity and the dispersion efficiency.
Furthermore, we examine the interaction of tailormade dyes with SWNTs and their capabilities concerning dispersion efficiency and individualization, depending on the size of their aromatic core and other structural motifs.

**TUE 47**

*Synthesis and deposition of individual single-walled carbon nanotubes for applications and fundamental studies*

Kimmo Mustonen\(^1\), Patrik Laiho\(^1\), Antti Kaskela\(^1\), Hua Jiang\(^1\), Esko I. Kauppinen\(^1\)

\(^1\)Department of Applied Physics, Aalto University School of Science, P.O. Box 15100, FI-00076 Aalto, Finland

We present a novel concept for the aerosol synthesis and direct deposition of predominantly individual single-walled carbon nanotubes for electronic applications and fundamental studies. The nanotube synthesis relies on iron catalyst particle generation in the range of 4±3 nm via physical evaporation in a nitrogen driven spark discharge system. The aerosol catalyst particles are mixed with carbon monoxide (CO) and hydrogen and fed to a vertical laminar flow reactor tube held at 880 °C, where the SWNCTs form via catalytic decomposition of CO on the catalyst surface. The as synthesized nanotubes can be deposited on various substrates, including temperature sensitive ones, using a purpose-built thermophoretic precipitator. Based on atomic force and transmission electron microscopy studies, the as deposited SWNTs were up to 80% individual and of high quality and purity. The observed SWCNT mean diameters and lengths were 1.10 nm and 2.97 µm respectively, and based on diffraction studies, 70% are semiconducting and 30% metallic. SWCNT transparent conductive films with sheet resistance of 65 ohms/sqr. @ 90%T and network transistors with On/Off current ratio up to \(10^8\) are presented.

**TUE 48**

*Equilibrium concentration of singlet oxygen in photoreaction of reaction center/carbon nanotube bio-nanocomposites*

Anikó Kinka\(^1\), Kata Hajdu\(^1,3\), Melinda Magyar\(^1\), Klára Hernádi\(^2\), Endre Horváth\(^4\), László Forró\(^4\), László Nagy\(^1\)

\(^1\)Institute of Medical Physics and Informatics, University of Szeged, Szeged\n
\(^2\)Department of Applied and Environmental Chemistry, University of Szeged, Szeged, Hungary\n
\(^3\)Institute of Chemical Engineering Sciences, Foundation of Research and Technology, Patras, Greece\n
\(^4\)Institute of Physics of Condensed Matter Physics, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland

The primary events of photosynthesis take place in the reaction center protein (RC), where the energy of light is converted into chemical potential. When the photochemistry is oversaturated reactive oxygen species (singlet oxygen (1O2), superoxide anion (O2-●), and hydroxyl radicals (●OH), with high cytotoxicity) are formed with
large probability. There is a large interest to reduce the formation of these components because they reduce the efficiency of photochemical energy conversion. The aim of our work is to create a system for efficient light energy conversion. We bind RC, to carbon nanotubes (CNT). 1,3-diphenylisobenzofuran was used to detect the concentration of the 1O2. Although, CNTs are known as sensitizers, under our experimental conditions it is not probable that they play much role in generation of 1O2, indeed, the main 1O2 sensitizers are the RCs. However, CNTs can be sensitized by 1O2 directly depending on the band structure and/or react chemically, typically through cycloaddition reactions. The equilibrium concentration of the 1O2 is a result of the rate of the sensitization and the deactivation determined by the components and functions of the CNT/RC composite.

**TUE 49**  
**Self-assembly of Diamantane Chains inside Carbon Nanotubes from Functionalized Diamantanes**

Yusuke Nakanishi¹, Haruka Omachi¹, Natalie A. Fokina², Ryo Kitaura¹, Peter R. Schreiner², Jeremy E. P. Dahl³, Robert M. K. Carlson³, Hisanori Shinohara¹  
¹Department of Chemistry, Nagoya University, Nagoya 464-8602, Japan  
²Institute of Organic Chemistry, Justus-Liebig University Heinrich-Buff-Ring 58, 35392 Giessen, Germany.  
³Institute for Materials and Energy Science, Stanford University, Stanford, California 94305, United State.

Carbon nanotubes (CNTs), nanoscale cylinders composed of rolled-up graphene sheets, provide an ideal platform to create one-dimensional (1D) nanostructures. Precursor species are first filled into the cavities of CNTs, and then molded into linear structures via thermal annealing. To date, various kinds of 1D nanomaterials have been synthesized, including metal atomic wires, ultrathin boron-nitride nanotubes, and well-defined CNTs, which exhibit different properties from those of their bulk counterparts. As part of our exploring for novel 1D nanomaterials, we have been working on the synthesis of linear forms of crystalline diamond from diamantanes, the molecules in the diamond configuration.

Here we demonstrate that a string of diamantane can self-assemble from a functionalized diamantane within the internal cavities of CNTs. Transmission electron microscopy clearly shows that the diamantane cages are linked together inside CNTs. Using other analytical techniques, we succeeded at revealing the growth mechanism. This new class of diamond materials will offer a new direction for the nanodiamond research as well as a new strategy for the design and synthesis of 1D nanomaterials.
TUE 50
Starting 1985 - Thirty years of Winterschool contributions

Helmut Neugebauer

Linz Institute for Organic Solar Cells (LIOS), Physical Chemistry, Johannes Kepler University, Linz, Austria

According to the 30-years-anniversary of the authors’s participation at the Kirchberg Winterschools, starting already 1985, a retrospective overview on the contributions is presented. In the early years, the work focused on spectroscopic and spectroelectrochemical studies on conjugated polymers, especially on polythiophenes and polyaniline using in-situ FTIR-ATR-spectroscopy. Doping induced infrared responses due to the strong electron-phonon coupling and their relation to structural and electronic properties were investigated. In the nineties and in the following decade, the focus changed to fullerenes, and the work became more device oriented. Especially photovoltaic devices with fullerenes in various molecular arrangements, like "double cable" polymers, molecular donor-acceptor-compounds and energy transfer systems were the main topics. In addition, novel infrared sensing properties and unusual transport phenomena in fullerenes were presented. Studies on oriented paraseiphenyl-needles, ellipsometric surface characterization and recently the presentation of ultrathin and lightweight organic solar cells with high flexibility rounded up the Winterschool contributions.

TUE 51
Contacts and Schottky Barrier Heights in MoS2 and related 2D semiconductors

Yuzheng Guo, John Robertson

Cambridge University, Cambridge, UK

MoS2 and related Transition Metal Dichalcogenides (TMDs) have a band gap and so are suitable as semiconductors in FETs. However, their devices appear to be limited by the resistance of the electrical contacts, and also in the case of MoS2 by the difficulty of making p-type FETs. Thus, a theory of Schottky Barrier Heights (SBH) in TMDs and van der Waals solids is needed. A key parameter is the SB pinning factor S, the rate of change of SBH vs. contact metal work function. A small S indicates many interface states and a pinned SBH, so that the contact resistance can be high. S approaching 1 indicates weak pinning, so that changing metal work functions allows n-FET or p-FET to be easily attained. We show that, against expectations, the standard metal induced gap state (MIGS) model of SBHs does work, despite the vdW bonding gap. The pinning factor S is evaluated as S=0.3. Additional anion vacancy defect states caused additional pinning, lowering S in some cases to S=0.1. Thus, extreme contact metal work function values are needed to scan the gap in MoS2. Analysis finds that WSe2 is better than MoS2 for bipolar devices.
**TUE 52**

Fabrication and optical properties of transition metal dichalcogenide heterostructures

Aurélie Pierret¹, Andreas Stegmaier¹, Janina Maultzsch¹

¹Institut für Festkörperphysik, Technische Universität Berlin, Berlin

Semiconductor transition metal dichalcogenides (TMD) are subject of increasing interest over the last years. In particular single layers of MoS₂ show strong photoluminescence associated with a direct-gap transition, in contrast to bulk. Heterostructures of TMDs will lead to modulations of their individual optical properties. It is expected from calculations that the band alignment of different monolayer TMDs are, for most of them, of type II, leading to spatially indirect excitons. Nevertheless, clear experimental evidence is still missing. It seems that the quality of the interface has a big influence on the results. Therefore, we investigate the fabrication of heterostructures by a dry transfer method, using a polymer stamp as an intermediate substrate, as proposed in Ref. [1].

Here we present, as a first step towards heterostructures, our results on the fabrication and optical properties of stacking of twisted few-layer MoS₂. We analyse the influence of the specific transfer method on the quality of the layers by Raman and photoluminescence spectroscopy.


**TUE 53**

Tip-enhanced Raman spectroscopy of graphene folds

Emanuele Poliani¹, Toby Hallam², Georg S. Duesberg², Janina Maultzsch¹

¹Institut für Festkörperphysik, Technische Universität Berlin, Berlin

²Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) and Advanced Materials BioEngineering Research Centre (AMBER), and School of Chemistry, Trinity College, Dublin 2, Ireland

We studied a single vertically free-standing graphene fold by tip-enhanced Raman and micro-Raman spectroscopy. The folds are produced by GraFold printing [1] on SiO₂ substrate, forming out-of-plane, mono-dimensional deformations of graphene with 10 nm width and macroscopic length. Standard micro-Raman measurement can only give averaged information on the vibrational modes of the fold and of the surrounding area. However, the dependence of the Raman signal on the incoming light polarization shows interesting local anisotropic properties. Exploiting the evanescent field generated by localized surface plasmon polaritons at the apex of a bulk gold AFM tip, we are able to obtain a Raman map with 60 nm spatial resolution. The frequency shift of vibrational modes in relation to the fold morphology is used to calculate local variation maps of strain and doping. The top of the fold shows a variation of $+0.3$ compressive strain and $-10 \cdot 10^{12}$ cm$^{-2}$ hole doping compared to the flat region.

We show measurements of two newly observed first-order Raman modes in few-layer molybdenum disulfide (MoS$_2$) with phonon frequencies of 286 cm$^{-1}$ and 471 cm$^{-1}$. These modes are strongly resonant and appear only at excitation energies above $\approx$ 2.4 eV. At 2.7 eV, in resonance with the $C$ exciton, their intensity is comparable to the second-order Raman modes; their absence thus provides an easy and accurate method to identify single-layer MoS$_2$. At UV excitation, the intensity of the new modes is even larger than the typically examined $A'_1/ A_1g$ and $E'/ E_g$ modes. Using group theory, we provide a systematic analysis of the phonon modes, their symmetries, and their frequencies in few-layer materials, including the newly observed modes.

Raman spectroscopy on cation-exchanged XSe/CdSe (X=Pb, Zn) nanoparticles

Hans Tornatzky$^1$, Cornelia Bothe$^2$, Andreas Kornowski$^2$, Holger Lange$^2$, Horst Weller$^2$, Janina Maultzsch$^1$

$^1$Institute of Solid State Physics, Technische Universität Berlin, Strasse des 17. Juni 135, 10623 Berlin, Germany.
$^2$Institute of Physical Chemistry, University of Hamburg, Grindelallee 117, 20146 Hamburg, Germany.

Colloidal nanoparticles have attracted much interest due to their electronic and optical properties. By controlling size, structure and stoichiometry one can achieve a higher photoluminescence quantum yield and control the fundamental transition energy. Due to these properties colloidal nanoparticles are expected to have a great impact on the development of optoelectronic devices.

XSe (X=Pb, Zn) nanoparticles of different size and shape were synthesized by wet chemical precipitation, a fast, cost-effective and well understood technique. XSe/CdSe composite nanoparticles were created by cation exchange, starting from XSe and exchanging the cation for Cd [1]. The cation exchange is a versatile method enabling the formation of composites which are not liable for direct synthesis. We present Raman measurements giving further insight into the mechanism of the exchange process and provide the possibility to further optimize process parameters to obtain nanostructures with desired properties.

TUE 56
UV Raman spectroscopy of graphene, graphite, and carbon nanotubes
Christoph Tyborski\textsuperscript{1}, Roland Gillen\textsuperscript{1}, Felix Herziger\textsuperscript{1}, Janina Maultzsch\textsuperscript{1}
\textsuperscript{1}Institut für Festkörperphysik, Technische Universität Berlin, Berlin

We present Raman spectra of graphite, graphene, and carbon nanotubes with UV excitation energies. Using excitation energies above 5.0 eV we can observe the vibrational density of states of these carbon materials. We get access to regions of the first Brillouin zone that are not accessible with Raman spectroscopy in the optical visible range. By simulations of the phonon density of states of graphene and graphite, we can assign peaks in the UV Raman spectra to certain phonon branches and high symmetry points in the first Brillouin zone. Tuning the excitation towards lower energies activates double-resonant Raman scattering processes with ultra-short wavevectors. We analyze and explain the origin of the scattering processes by simulating corresponding spectra for various excitation energies.

TUE 57
Defect-induced zone-boundary acoustic phonons in individual carbon nanotubes
Asmus Vierck\textsuperscript{1}, Florentina Gannott\textsuperscript{2}, Manuel Schweiger\textsuperscript{2}, Jana Zaumseil\textsuperscript{3}, Janina Maultzsch\textsuperscript{1}
\textsuperscript{1}Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany
\textsuperscript{2}Institut of Polymer Materials, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
\textsuperscript{3}Lehrstuhl für Angewandte Physikalische Chemie, Ruprecht-Karls-Universität Heidelberg

Raman spectroscopy on single-walled carbon nanotubes is often performed in dispersions or on ensembles of interacting tubes on substrates; such measurements, however, may average out subtle, highly dispersive features present in the spectra of individual tubes. Here, we studied perfectly aligned, mostly individual single walled nanotubes, grown on ST-cut quartz and transferred onto glass. We observe a new Raman mode emerging in the range of 350 cm\textsuperscript{-1} to 500 cm\textsuperscript{-1}, its second order overtone, and combination modes. We assign the new mode to the $ZA$-phonon derived phonon branch. We show that the $ZA$ phonon mode becomes Raman-active due to defect-assisted double resonance close to the $K$-point, similar to the $D$ mode. We present a theoretical evaluation of the diameter and excitation-energy dependence of the $ZA$, $2\cdot ZA$ and $D\pm ZA$ modes, which is in good agreement with our measurements and previous studies of the intermediate frequency region.
08:30 – 09:00  E. Andrei, New Brunswick
Artificial Atoms in Graphene

09:00 – 09:30  M. Bockrath, Riverside
Topological Winding Number Change and Broken Inversion Symmetry in a Hofstadter’s Butterfly

09:30 – 10:00  A. Grüneis, Köln
Electronic properties of functionalized 2D materials: graphene, boron nitride, transition metal dichalcogenides and phosphorene

10:00 – 10:30  coffee break

10:30 – 11:00  R. Saito, Sendai
Raman spectroscopy of graphene and transition metal dichalcogenides

11:00 – 11:30  A. Jorio, Belo Horizonte
Stokes-anti-Stokes correlation in Raman Spectroscopy

11:30 – 12:00  M. Paillet, Montpellier
Combined Raman spectroscopy and reflection/transmission measurements for graphene characterization

12:00 – 17:00  mini workshops

17:00 – 18:30  Dinner

18:30 – 19:00  B. Dora, Budapest
Nematic, topological and Berry phases when a flat and a parabolic band touch

19:00 – 19:30  H. Yeom, Pohang
Soliton and Chiral Soliton of Atomic Wire Charge Density Wave

19:30 – 20:00  S. Berciaud, Strasbourg
Magneto-Raman spectroscopy of suspended graphene layers
Wednesday, March 11th

Graphene spectroscopy, topological materials
Artificial Atoms in Graphene
Yuhang Jiang, Jinhai Mao, Eva Y. Andrei
Department of Physics, Rutgers University, Piscataway, NJ USA

Charged impurities are invisible to graphene’s ultra-relativistic conduction electrons. This makes it difficult to localize and control its charge carriers and poses a problem for realizing graphene’s promise as a building block in electronic applications. We show, using scanning tunneling microscopy and Landau level spectroscopy, that vacancies in graphene can host a so-called super-critical charge that is sufficiently strong to transform the local electronic properties. Such a charge traps electrons in a sequence of quantized states which resemble the bound states in an atom. This transformation is akin to the long sought-after phenomenon of super-criticality in ultra-heavy atoms. But unlike the 3D atom case, where super-criticality unleashes a chain reaction with electrons diving into the nucleus, emitting positrons and ultimately leading to atomic-collapse, we find that the artificial-atom created by a supercritically charged vacancy in graphene is stable and tunable.
**09:00**

**Topological Winding Number Change and Broken Inversion Symmetry in a Hofstadter's Butterfly**

Marc Bockrath$^1$

$^1$University of California, Riverside

Recently several research groups have demonstrated accurate placement of graphene on hexagonal BN (hBN) with crystallographic alignment. Due to the resulting superlattice formed in the graphene/hBN heterostructures, an energy gap, secondary Dirac Points, and Hofstadter quantization in a magnetic field have been observed. Using aligned layer transfer we are able to produce graphene/hBN heterostructures with \( \sim 1 \) degree alignment accuracy, and measure the transport properties of the resulting systems. We observe an additional \( \pi \) Berry’s phase shift in the magneto-oscillations when tuning the Fermi level past the secondary Dirac points, originating from a change in topological winding number from odd to even when the Fermi-surface electron orbit begins to enclose the secondary Dirac points. At large hole doping inversion symmetry breaking generates a distinct hexagonal pattern in the longitudinal resistivity versus magnetic field and charge density. This results from a systematic pattern of replica Dirac points and gaps, reflecting the fractal spectrum of the Hofstadter butterfly.
Ionic functionalization of many layered materials by alkali and alkaline earth metals enables tuning of the charge carrier density into the superconducting regime. We investigate their electron energy band structure and spectral function with high-resolution angle-resolved photoemission spectroscopy (ARPES). For example, for Ca doped graphene this charge transfer can induce relatively large electron-phonon coupling constants of $\sim 0.4$. This provides experimental support for the possibility to achieve superconductivity in graphene monolayers at $\sim 1.5$K. Regarding ionic functionalization of related layered materials, we investigate the interaction of alkali metals with epitaxial monolayer boron nitride and the bulk phosphorene and MoS$_2$ compounds. While boron nitride does not accept electrons, the band gap of the latter two materials is sufficiently small so that a semiconductor to metal transition can be induced by ionic functionalization.
10:30
Raman spectroscopy of graphene and transition metal dichalcogenides
Riichiro Saito¹, Eddwi H. Hasdeo¹, Ahmad R. T. Nugraha¹, Huaihong Guo¹, Teng Yang¹, Syahril Siregar¹
¹Department of Physics, Tohoku University, Sendai

Recent works on Raman spectroscopy of graphene and transition metal dichalcogenides (TMD) in our group are presented. Asymmetric Raman spectra of G band of graphene which is expressed by Breit-Wigner-Fano (BWF) spectra are calculated as a function of the Fermi energy ($E_F$). The asymmetric factor ($1/q$) in the BWF function becomes the maximum at the Dirac point and decreases monotonically with increasing $E_F$. Raman spectra of MoTe$_2$ show some weak Raman spectra which are assigned by double-resonance Raman spectra of the M point phonon in the Brillouin zone. These double resonance peaks appear for other TMD materials, too, which are assigned either the K or the M point phonon. Raman spectra with use of the deep ultraviolet laser (266nm) show the absence of G' band, which is reproduced by calculation.
Stokes-anti-Stokes correlation in Raman Spectroscopy
Ado Jorio

In this talk the correlation between the Stokes and the anti-Stokes processes in the light scattering by phonons will be discussed. This phenomena imposes corrections on the broadly utilized Stokes/anti-Stokes Raman intensity ratio, described theoretically by the boson statistics, and applied experimentally in the measurement of materials temperature. In diamond, the correlation is demonstrated by measuring the field correlation function ($g^2(0)$). Graphene was also explored, indicating that the phenomena can be made many orders of magnitude higher in this low dimensional system by exploring resonance conditions. The power dependence of the Stokes and anti-Stokes inelastic light scattering are theoretically described by an effective Hamiltonian. The photonic and phononic reservoirs are considered by including a lindbladian term in the density operator master equation.
11:30
Combined Raman spectroscopy and reflection/transmission measurements for graphene characterization
Matthieu Paillet
\textsuperscript{1}
\textsuperscript{1}Laboratoire Charles Coulomb, Université Montpellier 2, Montpellier

Raman spectroscopy (RS) of graphene-related materials (GRM) is being considered as a fast, versatile, powerful and non-destructive characterization technique. RS is sensitive to the number of layers, their stacking order, the nature and density of defects, the charge carrier density and in-plane strain variations. However, the positions, linewidths, profiles, intensities of the graphene/multilayer graphene (MLG) Raman bands are not only affected by all these perturbations but also depends on the uniformity across the probed area and on the substrate (through optical interference effects, dielectric screening...). An accurate interpretation of Raman spectra becomes then extremely complex and deserves the combined use of complementary diagnosis. We recently developed a RS set-up allowing to monitor simultaneously the laser power, transmission, reflection and Raman signal. In this contribution, we discuss the application of this tool for counting the number of layers of different kind of graphene/MLG samples with the aim to define standard procedures for GRM characterization on different substrates.
18:30

**Nematic, topological and Berry phases when a flat and a parabolic band touch**

Balazs Dora

Department of Physics, Budapest University of Technology and Economics, Budapest, Hungary

A (single flavor) quadratic band crossing in two dimensions is known to have a generic instability towards a quantum anomalous Hall (QAH) ground state for infinitesimal repulsive interactions. Here we introduce a generalization of a quadratic band crossing which is protected only by rotational symmetry. By focusing on the representative case of a parabolic and flat band touching, which also allows for a straightforward lattice realization, the interaction induced nematic phase is found generally to compete successfully with the QAH insulator, and to become the dominant instability in certain parts of the phase diagram already at weak coupling. The full phase diagram of the model, together with its topological properties, is mapped out using a perturbative renormalization group, strong coupling analysis, the mean-field theory. Interestingly, the Berry flux varies continuously in the single flavour limit with various control parameters.
19:00

**Soliton and Chiral Soliton of Atomic Wire Charge Density Wave**

Han Woong Yeom

1 Center for Artificial Low Dimensional Electronic Systems, Institute for Basic Science, Pohang

2 Department of Physics, POSTECH

Solitons are important in understanding various quantum properties of low dimensional electronic systems. Solitons in charge density waves (CDW’s) have drawn particular interest, since they have fractionalized electrons and are the edge mode of 1D topological insulators. While solitons were investigated for a long time, an individual soliton had not been directly observed until very recently. We review the recent breakthrough in observing directly solitons in commensurate and incommensurate quasi 1D CDW’s with scanning tunnelling microscopy. The newly observed topological solitons in the commensurate CDW of indium atomic wires self assembles on silicon surface are discussed in details. This CDW wire is unique because each wire is composed of two In zigzag chains to yield four degenerate CDW states. This leads to not unique but various distinct solitons. We map this system into two interacting Peierls chains successfully. The topology of this system is unravelled as a rare realization of non-trivial $\mathbb{Z}_4$ with the emergence of ‘chiral’ solitons. The exciting prospect of utilizing solitons and chiral solitons in future subnanometer scale scale electronics will be discussed.
19:30
Probing electronic excitations in mono- to pentalayer graphene by micro-magneto-Raman spectroscopy

Stéphane Berciaud\textsuperscript{1}, Denis M. Basko\textsuperscript{2}, Marek Potemski\textsuperscript{3}, Clément Faugeras\textsuperscript{3}
\textsuperscript{1}IPCMS, Université de Strasbourg and CNRS, France
\textsuperscript{2}LPMMC, Université Grenoble 1 and CNRS, France
\textsuperscript{3}LNCMI-Grenoble, CNRS/UJF/UPS/INSA, France

We probe electronic excitations between Landau levels in freestanding N-layer graphene over a broad energy range, with unprecedented spectral and spatial resolution, using micro-magneto Raman scattering spectroscopy. A characteristic evolution of electronic bands from two up to five Bernal-stacked graphene layers is evidenced and shown to remarkably follow a simple theoretical approach, based on a one-electron, effective bilayer model \cite{1}.

In contrast, in monolayer graphene, the band velocity associated with the Raman active electronic excitations is found to depend on the index of Landau level involved, and to vary as a function of the magnetic field \cite{1,2}. This contradicts the single-particle picture of non-interacting massless Dirac electrons, but is accounted for by theory when electron-electron interactions are taken into account \cite{2}. Raman active, zero-momentum inter Landau level excitations in monolayer graphene are sensitive to electron-electron interactions, due to the non-applicability of the Kohn theorem in this system, with a clearly non-parabolic dispersion relation.

\cite{1} S. Berciaud et al. Nano Letters 14, 4548 (2014)
\cite{2} C. Faugeras et al. arXiv:1412.0115
08:30 – 09:00  M. Prato, Trieste  
*Applications of Functionalized Carbon Nanostructures*

09:00 – 09:30  M. Shaffer, London  
*Versatile and scalable approaches to chemical processing of nanocarbons*

09:30 – 10:00  S. Eigler, Fürth  
*Diversity of Oxo-Functionalized Graphene*

10:00 – 10:30  coffee break

10:30 – 11:00  P. Rudolf, Groningen  
*Graphene growth on metallic and insulating surfaces*

11:00 – 11:30  E. Weig, Konstanz  
*Coherent control of nanomechanical systems*

11:30 – 12:00  G. Steele, Delft  
*Optomechanical coupling of a multilayer graphene resonator to a superconducting microwave cavity*

12:00 – 17:00  mini workshops

17:00 – 18:30  Dinner

18:30 – 19:00  R. Baughman, Richardson  
*Powerful, Giant-Stroke Artificial Muscles From Twisted and Coiled Carbon Nanotube Yarns*

19:00 – 19:30  J. Ahn, Seoul  
*Graphene for Flexible and Wearable Electronics*

20:00  Poster III
08:30
Applications of Functionalized Carbon Nanostructures
Maurizio Prato

Center of Excellence for Nanostructured Materials (CENMAT), INSTM UdR di Trieste, Dipartimento di Scienze Chimiche e Farmaceutiche, University of Trieste, Trieste, Italy

Our group has been involved in the organic functionalization of various types of nanocarbons, including carbon nanotubes, fullerenes and, more recently, graphene. The chemical functionalization represents an important and versatile tool for tuning the chemical and physical properties of the carbon nanostructures (CNS). For example, chemical functionalization can render CNS dispersible in different solvents. During this talk, we will summarize our most recent results in the chemistry and applications of functionalized CNS. In particular, we will focus on the use of carbon nanotubes and graphene as active interfaces in neurosciences and for the splitting of water.
Chemical functionalisation is critical to a wide range of nanotube applications, but needs to be versatile and applicable at scale. Existing approaches rely on liquid phase reactions, often requiring damaging sonication or lengthy work up through filtration or centrifugation. The formation of individualized functionalised single wall nanotubes (SWNTs) is a particular challenge. One approach is to shift the modification reaction into the gas phase. We have developed a generic, scalable furnace treatment, based on the thermochemical activation of the CNTs, followed by reaction with functional organic monomers [1]. This approach allows the introduction of a wide variety of functional groups onto the CNT surface whilst maintaining the excellent properties of the untreated materials. The underlying mechanism of the reaction has been established and the distribution of the functionalised sites studied using tagging experiments. The reaction is extremely versatile and can be carried out with a variety of monomers. The reaction and the subsequent product purification can be carried out entirely in the gas-phase, simplifying work-up and improving scalability; the approach is compatible with the scale and equipment of many industrial CNT synthesis processes, and is applicable to multi-walled CNTs, SWNTs, and other carbon-based materials [6]. The surface properties of these products have been studied by direct wetting experiments on the nanoscale, dispersion studies, and inverse gas chromatography (IGC) [2]. Water dispersible materials with cationic, anionic, and non-ionic surface functionalities provide simple processing routes to a range of applications, and are particularly well suited to studying biological interactions [5,6]. A different approach to CNT processing, relies on reductive charging. Using a liquid ammonia process [3], pure nanotubides can be redissolved, purified, or optionally functionalised without sonication. A key step is to control the ratio of charge to carbons, as it determines the yield and the nature of the dissolved material. The G/D ratios observed during the dissolution sequence, as a function of metal:carbon ratio, demonstrate a new purification method for removing carbonaceous impurities from pristine SWNTs. A similar approach can be applied to graphene nanoplatelets [4]. The resulting nanocarbon ions can be chemically grafted for a variety of applications, depending on the reagent, charge density, and ionic concentration in the reaction medium [9]. The nature of the reactivity of charged graphenides is unusual, due to the continuum density of states of these otherwise molecularly discrete species [10]. The chemical charging agent can be avoided by a pure electrochemical process that yields CNT anions [5] and cations [8], suitable for purification, functionalization, or electrodeposition.

1. Menzel et al, Chem. Sci., 2010, 1, 603-8
   Menzel et al, Carbon, 2012, 134 8302
5. Chen et al, Biomaterials, 2014, 35, 4729
Diversity of Oxo-Functionalized Graphene  
Siegfried Eigler\textsuperscript{1}  
\textsuperscript{1}FAU Erlangen-Nürnberg, Fürth

Graphene (G1), a single layer of graphite is a platform for interdisciplinary research to discover new fascinating properties. However, the wet-chemical synthesis of pure G1 remains challenging because of the polydispersity of flakes of G1. Nevertheless, we synthesized oxo-functionalized graphene (oxo-G1) with a variable amount of functional groups and succeeded in the back-conversion of oxo-G1 to G1 with mobility values of charge carriers up to 1000 cm\textsuperscript{2}/Vs for the best quality of flakes. Furthermore, only recently, we showed an enhanced method minimizing the average density of defects of the carbon framework, which can be as low as 0.04\%. This is an unprecedented low average density of defects for wet-chemically prepared G1. Moreover, the carbon framework of oxo-G1 is thermally stable up to 100 °C and controlled transformations of chemical groups are possible. Thus, azide groups can be introduced or hydroxylated graphene can be prepared, what opens the ability for controlled chemical transformations.
10:30
Graphene growth on metallic and insulating surfaces
Petra Rudolf
\textsuperscript{1}Zernike Institute for Advanced Materials, University of Groningen, Groningen

The epitaxial growth of graphene on catalytically active metallic surfaces via chemical vapour deposition (CVD) is known to be one of the most reliable routes toward high-quality large-area graphene. This CVD-grown graphene is generally coupled to the metal resulting in a modification of its intrinsic properties. Growth on oxides is a promising alternative that can lead to decoupled graphene. Here, I compare graphene on a pure metallic and on an oxidized copper surface, grown by a single step CVD process under similar conditions. Remarkably, growth on copper oxide, a high-k dielectric material, preserves the intrinsic properties of graphene; it is not doped and a linear dispersion is observed close to the Fermi energy. Density functional theory calculations give additional insight into the reaction processes and help explaining the catalytic activity of the copper oxide surface. I shall also present an alternative to CVD growth, namely growth from self-assembled monolayers of 1-1', biphenyl-4 thiol assembled on Cu and copper oxide, which were first polymerized with UV light and then heated to generate graphene. Best quality graphene from this SAM is obtained on copper oxide.
11:00
Coherent control of nanomechanical systems
Eva Weig
Department of Physics, University of Konstanz, Konstanz

Nanomechanical resonators are freely suspended, vibrating bridges with nanoscale diameters. These nanostructures are receiving an increasing amount of attention, both in fundamental experiments addressing the foundations of quantum mechanics and for sensing applications, and show great promise as linking elements in future hybrid nanosystems. In particular, doubly-clamped pre-stressed string resonators are explored as high Q nanomechanical systems. Dielectric transduction by means of electrically induced gradient fields allows to actuate and probe these nanostrings, to tune their eigenfrequencies and to strongly couple their two orthogonal fundamental flexural modes. On resonance, the normal modes are described as a classical nanomechanical two level system, the state of which can be manipulated by radio frequency pulses. Full state control on the Bloch sphere is demonstrated by Rabi, Ramsey and Hahn echo experiments. Moreover, we find that all relaxation times $T_1$, $T_2$ and $T_2^*$ are equal. This indicates that energy relaxation is the dominating source of decoherence, such that not only $T_1$ but also $T_2$ can be increased by engineering larger mechanical quality factors.
11:30

Optomechanical coupling of a multilayer graphene resonator to a superconducting microwave cavity

Vibhor Singh¹, Sal Bosman¹, Ben Schneider¹, Yaroslav Blanter¹, Andres Castellanos-Gomez¹, Gary Steele¹

¹Kavli Institute of Nanoscience, Delft University of Technology, Delft

The combination of low mass density, high frequency, and high quality-factor make graphene mechanical resonators very attractive for many quantum applications. Microwave optomechanics with superconducting cavities offers exquisite position sensitivity and enables the preparation and detection of mechanical systems in the quantum ground state. In this talk, I will present recent work [1] in which we demonstrate coupling between a multilayer graphene resonator and a high-Q superconducting cavity. We achieve a displacement sensitivity of 55 fm/Hz¹/² and measure mechanical quality factors up to 220,000, both significantly better than shown before. Optomechanical coupling is demonstrated by optomechanically induced reflection (OMIR) and absorption (OMIA) of microwave photons, along with signatures of strong optomechanical backaction. We extract the cooperativity C, a characterization of coupling strength, quantitatively from the measurement with no free parameters and find C=8, promising for the quantum regime of graphene motion.

18:30

Powerful, Giant-Stroke Artificial Muscles From Twisted and Coiled Carbon Nanotube Yarns

Ray H. Baughman

Alan G. MacDiarmid NanoTech Institute, the University of Texas at Dallas, Richardson, TX, 75083 USA

Three successive generations of twist-spun artificial muscles are described that provide torsional and tensile actuation (1). Our first generation muscles are electrochemically powered twist-spun carbon nanotube yarns that provide torsional rotation speeds of 590 rpm, and torsional strokes that are 1000 times that for earlier artificial muscles. Our second generation muscles are electrolyte-free, guest-infiltrated carbon nanotube yarns that can torsionally actuate at 11,500 rpm, and deliver 85 times higher contractile power density than natural muscles. Our third generation muscles can rotate at 50,000 rpm, contract by up to 49%, lift 100 times heavier loads than the same size human muscle, or actuate at 7.5 cycles/s for millions of cycles.

(1) Collaboration between The University of Texas at Dallas, The University of Wollongong, The University of British Columbia, Hanyang University, and Namik Kemal University.
With the emergence of unusual format electronics such as flexible and wearable devices, an effort has been made to integrate devices with various functions for providing enhanced convenience for the users. However, it is very difficult to accomplish such electronics with conventional, rigid electronic materials. Graphene has an extremely good mechanical property that should maintain a stable operation under a high strain and also possesses great electronic properties that make it a promising host for device applications. The recent advances in large-scale synthesis and fabrication technique of graphene films are expected to enable various applications for flexible and wearable electronics. In this talk, I present the application possibility of graphene films for flexible and wearable electronics including solid state lighting, strain sensor, transistor and energy harvesting/storage devices.
THU 1

Mechanical stability of empty and filled carbon nanotubes under high pressure

C. A. Kuntscher\textsuperscript{1}, B. Anis\textsuperscript{1}, F. Börrnert\textsuperscript{2}, M. H. Rümmeli\textsuperscript{2}
\textsuperscript{1}Institut für Physik, Universität Augsburg, Augsburg, Germany
\textsuperscript{2}IFW Dresden, P.O. Box 270116, D-01171 Dresden, Germany

The mechanical stability of SWCNTs can be significantly influenced by filling with molecules or with inner tubes: It was shown by high-pressure resonant Raman spectroscopy that filling the SWCNT with another tube (DWCNT) or with argon results in the stabilization of the nanotube, whereas filling with fullerene molecules (peapods) or with iodine leads to the destabilization of the nanotube.

We discuss the mechanical stability of empty SWCNTs, C\textsubscript{60}- and C\textsubscript{70}-peapods, iodine-filled SWCNTs, and DWCNTs based on their optical response under hydrostatic pressure. The synthesis of the materials and their characterization by HRTEM, Raman and optical spectroscopy will be briefly described. The alterations of the electronic properties of the various nanotube materials under pressure were monitored by transmission measurements in the near-infrared and visible frequency range, where the characteristic absorption bands corresponding to optical transitions in the nanotubes can be observed. Anomalies in the pressure-induced shifts of the absorption bands can serve as indications for structural deformations and phase transitions.

THU 2

Raman spectroscopy as probe of nanometer-scale strain variations in graphene

Christoph Neumann\textsuperscript{1,2}, Sven Reichardt\textsuperscript{1}, Marc Drögeler\textsuperscript{1,2}, Takashi Taniguchi\textsuperscript{3}, Kenji Watanabe\textsuperscript{3}, Slava V. Rotkin\textsuperscript{1,4}, Bernd Beschoten\textsuperscript{1,2}, Christoph Stampfer\textsuperscript{1,2}
\textsuperscript{1}JARA-FIT and 2nd Institute of Physics A, RWTH Aachen, 52074 Aachen, Germany, EU
\textsuperscript{2}Peter Grünberg Institut (PGI-8/9), Forschungszentrum Jülich, 52425 Jülich, Germany, EU
\textsuperscript{3}National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan
\textsuperscript{4}Department of Physics and Center for Advanced Materials and Nanotechnology, Lehigh University, Bethlehem, Pennsylvania 18015, USA

Confocal Raman microscopy has become a powerful and widespread tool in graphene research. Amongst other material properties such as carrier doping, short-range disorder and lattice temperature also mechanical strain can be extracted from Raman spectra. The spatial resolution of so-called Raman maps is on the order of the laser spot size, which, for confocal systems and typical laser energies, is usually around 500 nm. The extracted quantities such as doping or strain are in general averaged over the spot size. It is therefore important to distinguish between length scales significantly larger or smaller than the laser spot size. Here, we make use of a magnetic field and doping to control the influence of the electronic system on the line width of the graphene Raman G line. When Landau damping is minimized, we find a linear
dependence of the line widths of the G and 2D line, which reveals that different local strain conditions within the laser spot size make a significant contribution to the line widths (in particular of the 2D line). These nm-scale strain variations are hard to probe with other techniques, but are considered as important scatterers limiting electronic transport.

THU 3
Large-area fabrication and nanomechanical characterisation of suspended graphene membranes

Christian Nikolaus\(^1\), Nicholas Clark\(^1\), Aravind Vijayaraghavan\(^1\)
\(^1\)School of Materials, University of Manchester, Manchester

Nanoelectromechanical systems (NEMS) aim to explore the behavior and performance of mechanical devices in the nanometer regime. By reducing device dimensions, these systems demonstrate increased resonance frequencies and lower bending stiffness, thereby improving force and mass sensitivity. Graphene, the thinnest, stiffest, and strongest material known to date, has great potential for NEMS applications. Moreover, graphene is remarkably versatile in its processability. It can be grown over large areas, transferred onto arbitrary substrates and patterned by standard photolithography processes. However, the fabrication of suspended graphene membrane devices with minimal contamination and high yield over large areas remains a challenging issue. In this work we present a fabrication method that allows the construction of arrays of micrometer scale suspended graphene membranes over entire wafers. Furthermore, by either applying an electric field or a differential pressure across these suspended structures, whilst taking AFM measurements, we can study the electromechanical characteristics of graphene-NEMS devices.

THU 4
Coherent and squeezed states of phonons in single wall carbon nanotubes

A. R. T. Nugraha\(^1\), E. H. Hasdeo\(^1\), R. Saito\(^1\)
\(^1\)Department of Physics, Tohoku University, Sendai

In quantum mechanics, coherent states are known as a quantum state whose amplitude-phase uncertainty reach its minimum value. Moreover, we may generally increase the uncertainty in the amplitude and at the same time decrease the uncertainty in the phase, or vice versa, while still holding the minimum uncertainty principle. These states are the so-called squeezed states. Recently, there is a possibility to generate squeezed states of phonons in single wall carbon nanotubes (SWNTs) via ultrafast spectroscopy using less than 10 femtosecond pulses, in which the coherent oscillations of G’ bands involving two-phonon process may be relevant as a particular example. In this work, we calculate the squeezed phonon amplitude of the G’ band for a given SWNT and compare it with the coherent phonon amplitude of the G band. We find that the ratio between the G’ band and G band intensities in ultrafast spectroscopy depend on the laser energy, laser pulse width, and SWNT chirality.

138
(electron-phonon coupling). This result is useful for understanding the coherent control of phonon excitations, i.e. we may be able to selectively excite a certain phonon mode by adjusting some physical parameters.

**THU 5**

**Chemical Vapour Deposition of MoS$_2$ and WS$_2$ via Close Proximity Precursor Supply**

Maria O’Brien$^{1,2}$, Niall McEvoy$^{1,2}$, Toby Hallam$^{1,2}$, Hye-Young Kim$^{1,2}$, Nina C. Berner$^{1,2}$, Damien Hanlon$^{2,3}$, Kangho Lee$^{1,2}$, Jonathan N. Coleman$^{2,3}$, Georg S. Duesberg$^{1,2}$

$^1$School of Chemistry, Trinity College Dublin, Dublin 2, Ireland

$^2$Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN) and Advanced Materials and BioEngineering Research (AMBER) Centre, Trinity College Dublin, Dublin 2, Ireland

$^3$School of Physics, Trinity College Dublin, Dublin 2, Ireland

Reliable chemical vapour deposition (CVD) of transition metal dichalcogenides (TMDs) is a highly pressing research field, as numerous potential applications rely on the production of high quality films on a macroscopic scale. Here, we show the use of liquid phase exfoliated and sputtered metal oxide precursor layers as solid precursors for CVD in a microreactor setup[1]. MoS$_2$ and WS$_2$ monolayers have both been synthesised in this way. Raman spectroscopy, photoluminescence, XPS, AFM, TEM, SEM and electrical transport measurements over large areas reveal the high quality of the TMD samples produced, with mobilities of up to 1.15 cm$^2$ V$^{-1}$ s$^{-1}$. This shows that large area CVD grown MoS$_2$ is potentially viable for electronic devices despite the presence of grain boundaries. Furthermore, through patterning of the precursor supply, we achieve patterned growth of monolayer TMDs in defined locations, which could be adapted for the facile production of electronic device components.


**THU 6**

**HRTEM and Optical Investigations of Ultrathin Graphene Nanoribbons Formed from Coronenes**

Elena D. Obraztsova$^1$, Andrey L. Chuvilin$^2$, Alexander I. Chernov$^1$, Pavel V. Fedotov$^1$, Ekaterina A. Obraztsova$^1$, Vladimir L. Kuznetsov$^3$, Andrew Fairbrother$^4$, Roman Fasel$^4$

$^1$A.M. Prokhorov General Physics Institute, RAS, Moscow

$^2$CIC nanoGUNE Consolider, San Sebastian, Spain

$^3$Boreskov Institute of Catalysis, SB RAS, Russia

$^4$Swiss Federal Laboratories for Materials Science and Technology (Empa), Switzerland

Flat one-dimensional graphene nanoribbons are interesting due to their band gap be-
ing inversely proportional to the ribbon width. One of the most reliable technique to form nanoribbons is to fill the nanotubes with coronene molecules and to treat them thermally [1]. A mechanism of transformation of coronene chain into nanoribbon has been theoretically modeled and then monitored by a high resolution transmission electron microscopy (HRTEM), Raman scattering and Photoluminescence techniques. A comparison of Raman spectra for the graphene nanoribbons inside single-wall carbon nanotubes and for the armchair graphene nanoribbons grown on metal surfaces [2] has been made.

The work was supported by RFBR-13-02-01354 project.


**THU 7**

The Aharonov-Bohm effect in a graphene ring encapsulated in hexagonal boron nitride

Martin Oellers¹, Jan Dauber¹,², Alexander Epping¹,², Kenji Watanabe³, Takashi Taniguchi³, Fabian Hassler⁴, Christoph Stampfer¹,²

¹JARA-FIT and 2nd Institute of Physics , RWTH Aachen, 52074 Aachen, Germany
²Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany
³National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan
⁴JARA-Institute for Quantum Information at RWTH Aachen University, 52074 Aachen, Germany

Recent developments in the fabrication of graphene-hexagonal boron nitride (hBN) heterostructures enable nowadays graphene devices on substrate with outstanding electronic properties. In state-of-the-art graphene devices mean free paths in the range of several micrometers as well as long phase coherence times are reported. The latter is an important quantity responsible for numerous mesoscopic phenomena such as the Aharonov-Bohm (AB) effect. Here we present low-temperature magnetotransport measurements on a high mobility graphene ring encapsulated in hBN. We show the existence of AB oscillations with high visibility as well as their dependence on charge carrier density. For low magnetic fields we observe focusing of charge carriers within the ring, where the cyclotron radius matches distinct sample-related length scales. From the crossover between quasi-ballistic transport and quantum hall effect (QHE) we extract relevant length-scales of our structure, consistently with the sample geometry. Finally, we report on the investigation of the AB effect in the crossover regime of emerging QHE at magnetic fields of a few Tesla and show qualitative agreement with earlier theoretical work.
THU 8
Biosensor applications of carbon nanotube thin film

Nguyen Xuan Viet\textsuperscript{1}, Shigeru Kishimoto\textsuperscript{1}, Yutaka Ohno\textsuperscript{1,2}
\textsuperscript{1}Graduate School of Engineering, Nagoya University, Nagoya
\textsuperscript{2}EcoTopia Science Institute, Nagoya University, Nagoya

CNT have shown promising properties as electrochemical electrodes such as rapid electron transfer kinetics, wide potential window, biocompatibility, and manufacturing versatility. In this study, we demonstrate high-performance flexible microelectrodes based on a CNT thin film for electrochemical biosensor applications. The CNT microelectrodes were fabricated on a PEN film by the dry transfer method based on floating-catalyst CVD and standard microfabrication process. To minimize the process-originated contamination of CNT surface, the CNT surface was covered with an oxide film during the fabrication process. The electrochemical properties of flexible CNT microelectrodes were characterized by cyclic voltammetry with K\textsubscript{4}[Fe(CN)\textsubscript{6}]. The results showed that the fabricated CNT microelectrodes have high electron transfer rate. Electrochemical deposition of gold nanoparticles on electrode confirmed the excellent uniformity in electrochemical activity of the CNT film. We also demonstrate high sensitivity in detection of dopamine.

THU 9
Bottom-up assembly of suspended nanocarbon devices by dielectrophoresis

Antonios Oikonomou\textsuperscript{1}, Nick Clark\textsuperscript{2}, Sebastian Heeg\textsuperscript{2}, Andrey Kretinin\textsuperscript{3}, Aravind Vijayaraghavan\textsuperscript{2}
\textsuperscript{1}National Graphene Institute, The University of Manchester, UK
\textsuperscript{2}School of Materials, The University of Manchester, UK
\textsuperscript{3}School of Physics and Astronomy, The University of Manchester, UK

Over the past few years, we have demonstrated that bottom-up device assembly of nanocarbons using dielectrophoresis (DEP) can achieve ultra-high integration densities, excellent FET device performance and can be combined with sorting to even produce single-chirality SWCNT device arrays. Recently, we have achieved the large-scale assembly of suspended single-walled carbon nanotube (SWCNT) and few-layer graphene (FLG) devices by bottom-up DEP assembly. Suspended device fabrication is associated with a range of new technological challenges which we have overcome. These devices are ideally suited for sensors and resonator applications. Our fabrication strategy resulted in ultra-flat devices and then to high-yield suspended structures as confirmed by atomic force microscopy (AFM) and scanning electron microscopy (SEM). Raman spectroscopy measurements highlighted the non-destructive nature of the fabrication process. These results further demonstrate the versatility of the DEP assembly technique for nanocarbon device fabrication and argue about the need of high quality materials dispersions in order to establish itself as an attractive device integration method.
THU 10

Electronic structure and optical properties of $\text{C}_2\text{Fx}$ graphites

Alexander Okotrub$^1$, Lyubov Bulusheva$^1$, Dmitrii Pinakov$^1$, Igor Asanov$^1$, Galina Chekhova$^1$, Andrey Chuvilin$^2$

$^1$Nikolaev Institute of Inorganic Chemistry, Novosibirsk, Russia
$^2$CIC nanoGUNE Consolider, San Sebastian, Spain

Interaction of graphite with a mixture of $\text{BrF}_3$ and $\text{Br}_2$ at room temperature produces bromine intercalated graphite fluoride with a composition of $\text{C}_2\text{Fx}0.13\text{Br}_2$, where $x$ is less 1. The hosted bromine molecules are easily replaced by another intercalant. Optical spectra of absorption and luminescence were measured for samples with different fluorine contents. Obtained compounds can be considered as a stack of the fluorinated graphenes (FG). These FGs are large in area making it possible to study how the conjugated system is distributed on the basal plane. It was shown that fluorine atoms form short chains, while non-fluorinated carbon atoms are organized in very narrow ribbons and aromatic areas with a size smaller than 3 nm. These nanochains and nanoislands preserved after the fluorination process are likely responsible for the value of the energy gap of the compound of $\sim$2.5 eV. Variation in the size and the shape of pi electron regions within the fluorinated graphene layers could be a way for tuning the electronic and optical characteristics of the graphene-based materials.

THU 11

Quantum Transport in Two-dimensional Transition Metal Dichalcogenides

Michal Papaj$^1$, Liang Fu$^2$

$^1$Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland
$^2$Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Quantum spin Hall effect (QSHE) is a phenomenon which shows a great promise for quantum electronics. However, the materials that feature this effect do not live up to theoretical predictions and thus their applicability is limited. Recently, QSHE was proposed in 2D transition metal dichalcogenides [1]. This work is devoted to numerical quantum transport simulations in $\text{WTe}_2$. Without strain, it is a semimetal with 0.1 eV band overlap, but if small strain is applied, the overlap can be removed. We prepared a tight-binding model in order to recreate low-energy band structure obtained from first principles calculations. It is used to study properties of the edge states, which reveals features such as a short decay length (about 5 nm). Quantum transport simulations for both free and strained material were performed and displayed the topological protection of the edge states from disorder, which results in quantized conductance for a broad range of disorder magnitudes, confirming the viability of this material in device application.

Reference:
THU 12
Photocatalytic stability of single- and few-layer MoS$_2$ edge sites

Eric Parzinger$^1$, Bastian Miller$^1$, Joel W. Ager$^2$, Alexander Holleitner$^1$, Ursula Wurstbauer$^1$

$^1$Walter-Schottky Institut and Physik Department, TU Munich, Garching, Germany
$^2$Joint Center for Artificial Photosynthesis, Lawrence Berkeley National Laboratory, Berkeley, USA

MoS$_2$ is a promising two-dimensional "van der Waals" material with outstanding electronic, optical and catalytic properties that offers potential for many applications. The formation of a direct band gap in the visible range, together with a high catalytic activity makes single-layer MoS$_2$ a very promising material for solar energy conversion by photocatalytic hydrogen evolution.

In order to probe the photocatalytic stability, we perform spatially resolved $\mu$-Raman spectroscopy of single- and few-layer MoS$_2$ in liquid environments. We find a significantly lower stability of edge sites compared to terrace sites. The decomposition on edge and defect sites can only be observed for excitations energies larger than the band gap energies, pointing towards the important role of photoexcited charge carriers. We discuss the increased stability in the single-layer case, the dependence on laser excitation power as well as preliminary results on electrochemically driven decomposition of single-layer MoS$_2$.

We acknowledge the financial support by the DFG excellence cluster "Nanosystems Initiative Munich" (NIM) and BaCaTec.

THU 13
Tailoring the interaction of separated SWCNT with NO$_2$ by advanced filling reactions

Thomas Pichler$^1$, Filippo Fedi$^1$, Oleg Domano$^1$, Hidetsugo Shiozawa$^1$, Kazuhiro Yanagi$^2$, Andrea Goldoni$^3$, Paola Lacovic$^3$, Silvano Lizzit$^3$, Paola Ayala$^1$

$^1$Faculty of Physics, University of Vienna, AT
$^2$Tokyo Metropolitan University, J
$^3$Elettra, Trieste, IT

Our recent work on the interaction of ultrapure metallicity sorted SWCNT with NO$_2$ using a combination of high resolution XPS and XAS revealed a physisorption mechanism and a weak chemisorption with defects at 100 K [1]. Here we report on new experiments at the SUPERESCA beamline in ELETTRA showing how to tailor this interaction with NO$_2$ by advanced filling reactions using metalacetylacetonates containing Ni and Fe, We find a weak chemisorption at room temperature which is reversible after annealing at 150 C. We also were able to further fine tune the interaction by converting the filled molecules to Fe and Ni nanoclusters getting a fully reversible gas adsorption mechanism with a significant change in the density of states at the Fermi level at room temperature. The new results pave the way to get utmost sensitivity and selectivity for gas sensing at room temperature.
Work supported by the FWF and EU.

THU 14
Microscopic study of laser welded amorphous material
Wirginia Pilarczyk¹, Adam Pilarczyk²
¹Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
²Institute of Spawalnictwa, Gliwice, Poland

The presented tests comprise bulk metallic glasses (BMG) with ferrous matrix characterized by two important properties—mostly very good magnetically soft ones and wear resistance. Because of their structure and properties metallic glasses can be used as monitoring equipment sensors or microelectromechanic systems. At present the elements made of BMG have small dimensions. The use of laser-beam fusion welding process will enable the increase of elements’ diameter together with the enhancement of application abilities of new materials. To get exceptional properties of the material after welding process, its structure in the heat affected zone (HAZ), fusion zone (FZ) and parent material (PM) should be controlled. Because of the amorphous character of the welded material and small dimensions of particular fusion weld zones, TITAN 80-300 HRTEM and Hysitron TI950 Triboindenter nanoindenter equipped with QScope 250 microscopic attachment with Q-WM190 scanning probe were used for structure analysis. Probably in the presented work the atomic force microscope was used for the first time to examine the amorphous material after laser-beam welding process.

THU 15
Nanoindentation characteristic of Fe-based bulk metallic glass laser weld
Wirginia Pilarczyk¹, Oliwia Starczewska², Dariusz Łukowiec¹
¹Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
²Institute of Materials Science, University of Silesia, Chorzów, Poland

Fe-based bulk metallic glasses are characterized by good magnetic properties, high mechanical strength and corrosion resistance. Although, despite these properties, their using is limited because of small sample thickness that could be achieved by rapid solidifications. Therefore, one of the most prominent and promising process engineering which can be used for extending amorphous materials applications is laser beam welding. In this experiment, amorphous alloy of desired composition was prepared by melting high purity constituents. Fully amorphous plate was achieved by die pressure casting method. Next, the laser welding process was carried out by the use of TruLaser Station 5004.

In the present study, the influence of laser beam on the topography on the parent material, heat affected zone and fusion zone was investigated. Nanohardness and reduced Young’s modulus of particular amorphous material fusion weld zones were examined with the use of Hysitron TI950 Triboindenter nanoindenter and with the
use of Berkovich’s indenter. Examination of the nanostructure of particular weld zones by the use of TITIAN 80-300 high-resolution electron transmission microscope were carried done.

**THU 16**

**Electron-phonon scattering and electron mobility in semi-conducting HCCNTs**

Zoran P. Popović¹, Tatjana Vuković¹, Bozidar Nikolić¹, Milan Damnjanović¹, Ivanka Milošević¹

¹Faculty of Physics, University of Belgrade, Serbia

We consider model of helically coiled carbon nanotubes (HCCNTs) where pentagonal and heptagonal carbon rings are regularly incorporated into hexagonal carbon net [1]. Electron-phonon scattering rates are calculated out of electron and phonon dispersion relations [2,1], applying deformation potential approximation and evaluating electron-phonon matrix elements by means of extended tight-binding model based on density functional theory [3]. Electron drift velocities are obtained from one-particle Monte Carlo simulations where their motion is simulated as series of free flights interrupted by instantaneous electron-phonon scattering events.


**THU 17**

**Controllable fabrication of diamond thin films with active and inactive Si-related color centers**

Štěpán Potocký¹, Tibor Izak¹, Marian Varga¹, Alexander Kromka¹

¹Institute of Physics AS CR, v.v.i., Cukrovarnická 10, 162 00 Praha 6, Czech Republic

In this paper we investigated the reproducible fabrication of Si-related color centers (Si-V) with a strong and homogeneous photoluminescence (PL) at 738 nm in diamond films deposited by microwave plasma enhanced CVD. The influence of process parameters (gas composition and concentrations of H₂/CH₄/CO₂/N₂ and substrate temperature) on the optical activity of Si color centers is studied. The activity of Si-V zero phonon line (ZPL) center is found similar for a broad substrate temperature range from 450 °C to 1100 °C with a FWHM of ~6 nm. For the lowest substrate temperature 350 °C the photoluminescence intensity decreased and the FWHM increased to 10 nm. For diamond films deposited at 5 % of methane in hydrogen, Si-V activity was still measurable for adding up to 0.5 % CO₂ or 1 % of N₂ to the hydrogen rich gas mixture while no shift of ZPL peak position of Si-V was observed. By the confocal PL setup we have measured about 10 000 Si-V centers in the focal spot. The comparison with monocrystalline diamond with ion implanted centers gives us
THU 18

Novel Functionalities in Electric Double Layer Transistors of CVD-grown Transition Metal Dichalcogenides

Jiang Pu\textsuperscript{1}, Lain-Jong Li\textsuperscript{2}, Tomo Sakanoue\textsuperscript{1}, Taishi Takenobu\textsuperscript{1,3}

\textsuperscript{1}Advanced Science and Engineering, Waseda University, Tokyo
\textsuperscript{2}Physical Sciences and Engineering Division, KAUST, Saudi Arabia
\textsuperscript{3}Kagami Memorial Laboratory, Waseda University, Japan

Monolayer transition metal dichalcogenides have emerged as potential candidates for electronics and optoelectronics \cite{1}. In particular, the combination of CVD-grown large-area samples and electric double layer transistors (EDLTs) leads to variety of functionalities due to extremely high carrier density accumulated at the electric double layer interface. In this paper, we fabricate EDLTs with various CVD-grown monolayers, such as $\text{MoS}_2$, $\text{MoSe}_2$, $\text{WS}_2$, and $\text{WSe}_2$. As a result, we realized significant four functionalities of these devices, as shown in following list. (i) High mobility transistors and high-gain complementary inverters \cite{2,3}. (ii) Highly flexible and fully stretchable transistors \cite{4-6}. (iii) Novel light-emitting devices which can inject high current density at room temperature. (iv) Unique thermoelectric properties under continuous band filling.

\begin{thebibliography}{9}
\bibitem{2}J. K. Huang, J. Pu, et al. ACS Nano. 8, 923 (2014).
\end{thebibliography}

THU 19

Impact of differently long polyynes on the inner tube photoluminescence of double-walled carbon nanotubes

Philip Alexander Rohringer\textsuperscript{1}, Lei Shi\textsuperscript{1}, Thomas Pichler\textsuperscript{1}

\textsuperscript{1}Faculty of Physics, University of Vienna, Vienna

Long linear carbon chains (lcc) can be grown inside the inner tubes of double-walled carbon nanotubes (DWCNT) by post-synthesis annealing of as-grown DWCNT in high vacuum. Growth yield and length distribution of the obtained polyynes depend sensitively on the growth temperature, with the longest chains being grown at 1460°C. The lcc alter the optical properties of the DWCNT: Photoluminescence (PL) of filled DWCNT is enhanced, depending on the inner tube diameter similar to the effect of filling SWCNT with ferrocene \cite{1}. The optimum diameter for PL enhancement shifts towards smaller diameters when increasing the growth temperature which is linked to the thermal stability of long lcc. The physical process behind the
PL enhancement of the inner tube can be explained by a charge transfer between the excess charges located on the lcc ends and the nanotube. The amplitude of these excess charges varies with the lcc length which consequently leads to an optimum in the lcc length distribution for the PL emission intensity. We acknowledge the support of the FWF project P21333-N20.


THU 20
Resist-free contacting and AFM nanolithography of graphene and transition metal dichalcogenides

Alice Sackville Hamilton

1 London Centre for Nanotechnology, London

Contacting graphene and 2D layered transition metal dichalcogenides (TMDs) using conventional lithography techniques results in a poor quality device due to the difficulty in removing the resist after processing. The resist residue has an adverse effect on the electron mobility as well as further experimentation such as scanning tunnelling microscopy and atomic force microscope lithography (AFML). Here we present a shadow mask evaporation technique used to contact samples without a resist, resulting in a cleaner, better quality device. Shadow masks for 2, 3 and 4-terminal devices of various geometries were designed and made from thin Si wafers using deep reactive ion etching. The masks were used to fabricate devices for bulk and few layer graphene and TMDs, including MoS$_2$ and NbSe$_2$.

The absence of a resist residue allowed AFML to be performed on these devices to investigate local oxidation and hydrogenation. As in the literature, graphene was found to oxidise much more readily than to hydrogenate. Bulk MoS$_2$, previously unexplored in this area, behaved very differently from graphene, but the oxidation was still noticeably more reliable than the hydrogenation.

THU 21
Direct TEM observation on phase transition of aqueous solution sandwiched by graphene layers

Yuki Sasaki, Ryo Kitaura, Hisanori Shinohara

1 Chemistry, Nagoya university, Nagoya

High-resolution transmission electron microscopy (HRTEM) provides real-time atomic-level structural information on nanomaterials. If HRTEM is applied to observation of liquids, nanostructures of liquids can directly be observed, which leads to a great impact on physical chemistry of liquids. One of the biggest problems for the realization of HRTEM observations of liquids is that samples have to be placed under a high vacuum condition, where almost all of liquids spontaneously vaporize. In our previous work, we have developed an HRTEM observation method of liquids, which incorporates encapsulation of liquids in graphene-sandwiched-type environmental cell. Using the graphene cell, we have found that water molecules encap-
sulminated inside the graphene cell formed hexagonal ice at room temperature in high vacuum. In this work, we have applied the method to observe various solvents and solution of simple ions. We have observed the dynamics of various solutions by using graphene-sandwiched cell. At the graphene pockets, it can be seen the crystallization of solvent or hydrate salt. In this poster, details of sample preparation and results of TEM observations are addressed.

**THU 22**

**A spectroscopic study of Ni clusters encapsulated in single-walled carbon nanotubes**

Markus Sauer¹, Hidetsugu Shiozawa¹, Antonio Briones Leon¹, Kazuhiro Yanagi², Takeshi Saito³, Karina Schulte⁴, Thomas Pichler¹

¹Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria
²Department of Physics, Tokyo Metropolitan University, 1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan
³Nanotube Research Center, AIST, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568 Japan
⁴Lund University, MAX IV Laboratory, P.O Box 118, SE-221 00 Lund, Sweden

Investigating the electronic properties of metal clusters often poses several difficulties. To make their characteristics visible by spectroscopic methods environments are needed where clusters are protected from external influences.

Therefore, we filled ultra-clean SWCNT with Ni-acetylacetonate molecules and subsequently converted them to Ni clusters by high-temperature annealing where the cluster size is controlled directly by temperature and annealing time. X-ray absorption and (resonant) photoemission spectroscopy (RESPES) have been combined with X-ray diffraction and Raman analysis, where cluster sizes between 2 nm and 10 nm have been investigated. While higher annealing temperatures lead to formation of larger clusters it also reduces the Ni content in the SWCNT system. Smaller clusters show higher reactivity and therefore provide larger n-type doping to the SWCNT. RESPES shows the changes in the density of states of these Ni clusters, thereby providing insight into the effects caused by changing cluster size and doping.

In addition, this study provides another method to alter the properties of SWCNT in a precise and reproducible way.

We acknowledge funding by the FWF.

**THU 23**

**Simultaneous, spatially-resolved optical and electrical measurements on mono- and few-layer MoS₂**

Sebastian Schäfer¹, Holger Lange¹

¹Department of Physical Chemistry, University of Hamburg and Hamburg Centre for Ultrafast Imaging (CUI), Hamburg, Germany

MoS₂ exhibits unique optical and electrical properties such as the transition from an indirect band gap to a direct band gap material for few and single layer nanosheets.
Due to their 2-dimensional structure paired with a direct band gap they are of great interest as a future material in solar cells. Despite recent success of using MoS$_2$ nanosheets in optoelectronic devices there is still a lack in the understanding of the interplay between the optical and electrical properties. Here, combined optical and electrical measurements can be helpful to further understand these interactions and improve future devices.

We present a novel method combining AFM and KPFM on one hand combined with scanning photocurrent and optical measurements on the other hand. Measurements were carried out simultaneously on single, free standing nanosheets as well as on contacted nanosheets. We investigate the effect of a local laser illumination on the charge state of individual nanosheets. Furthermore we correlate the local photocurrent with the local electronic properties as measured by scanning probe microscopy techniques.

**THU 24**

**Orthogonal sorting of single-walled carbon nanotubes by ultracentrifugation**

Linda Scharfenberg$^1$, Michael Mertig$^{1,2}$

$^1$Professur für Physikalische Chemie, Mess- und Sensortechnik, Technische Universität Dresden, 01062 Dresden, Germany

$^2$Kurt-Schwabe-Institut für Mess- und Sensortechnik e.V. Meinsberg, Kurt-Schwabe-Strasse 4, 04736 Waldheim, Germany

The application of single-walled carbon nanotubes (SWCNTs) as source-drain channels in field-effect transistors requires semiconducting (sc) tubes with defined parameters. We present an orthogonal sorting method to separate SWCNTs according to electronic type and subsequently according to length by applying ultracentrifugation in a density medium. During the ultracentrifugation in a linear density gradient and in combination with different anionic surfactants, SWCNTs are sorted according to electronic type. We achieve an enrichment of sc-SWCNTs up to a content of 98% in two sorting steps. Afterwards these enriched sc-SWCNTs are separated according to length by performing ultracentrifugation without a density gradient. The challenge is to find appropriate anionic surfactants and conditions to combine successive the different sorting mechanisms. We use UV-Vis spectroscopy to measure the differences in the content of metallic and sc-SWCNTs between different samples and AFM to characterize the tube lengths.
**THU 25**  
**Covalent functionalization of single-walled carbon nanotubes with diazonium salts**

**Milan Schirowski**¹, **Ferdinand Hof**¹, **Frank Hauke**¹, **Andreas Hirsch**²  
¹Institute of Advanced Materials and Processes, University Erlangen-Nürnberg, Dr.-Mack-Str. 81, 90762 Fürth, Germany  
²Department of Chemistry and Pharmacy, University Erlangen-Nürnberg, Henkestr. 42, 91054 Erlangen, Germany

Various routes of the covalent functionalization of SWCNTs were explored in the recent past. Diazonium cations react with nanotubes without previous activation by a radical chain mechanism, theoretically leading to a carbon species with an attached moiety and a positive charge. However, the latter has not been proven or investigated yet. We use analytical methods such as inert statistical raman spectroscopy and thermogravimetical analysis coupled with mass spectrometry and gas chromatography (TGA-MS or TGA-GC-MS) to examine the existence and the reactivity of these intermediately formed positively charged SWCNTs. These analytical methods are also used to characterize the products of further novel reaction pathways, like the reaction of brominated SWCNTs with nucleophiles and the reaction of potassium nanotubides with iodonium salts.

**THU 26**  
**Unraveling doping effects on SWNT light-absorption and emission by stationary and time-resolved spectroelectrochemistry**

**Friedrich Schöppler**¹, **Holger Hartleb**¹, **Daniel Schilling**¹, **Klaus Eckstein**¹, **Florian Späth**¹, **Tobias Hertel**¹  
¹Institute for Physical and Theoretical Chemistry, Julius Maximilian University Würzburg, Würzburg

We have studied spectroelectrochemical properties of highly enriched semiconducting (6,5) single-wall carbon nanotubes (SWNTs) in organic suspensions using a home built setup. The experiment allows for quasi-simultaneous absorption and photoluminescence spectroscopy of SWNTs under potentiostatic control. We find that the absorption strength of the first and second excitonic transitions, as well as the photoluminescence intensity exhibit a strong but distinct dependence on the doping level. However, the overall oscillator strength in the VIS and NIR regions remains constant. The decrease of first and second subband exciton oscillator strengths is compensated by the development of new absorption features. Global analysis of our data identifies one of the features as a trion state, whereas a second feature appears to be due to light absorption by the well-screened free-carrier continuum. Preliminary transient absorption measurements of SWNTs under potentiostatic control corroborate and complement the results from stationary absorption spectroscopy. Depending on the doping level we find a decreasing photobleach and vanishing photoabsorption signal in the first exciton subband range.
THU 27
Strong exciton-photon coupling in two-dimensional heterostructures

Stefan Schwarz\textsuperscript{1}, Scott Dufferwiel\textsuperscript{1}, Freddie Withers\textsuperscript{2}, Aurelien A. P. Trichet\textsuperscript{3}, Feng Li\textsuperscript{1}, Maksym Sich\textsuperscript{1}, Osvaldo Del Pozo-Zamudio\textsuperscript{1}, Caspar Clark\textsuperscript{4}, Konstantin S. Novoselov\textsuperscript{2}, Jason M. Smith\textsuperscript{3}, Maurice S. Skolnick\textsuperscript{1}, Dmitry N. Krizhanovskii\textsuperscript{1}, Alexander I. Tartakovskii\textsuperscript{1}

\textsuperscript{1}Physics and Astronomy, University of Sheffield, Sheffield
\textsuperscript{2}School of Physics and Astronomy, University of Manchester, Manchester
\textsuperscript{3}Department of Materials, University of Oxford, Oxford
\textsuperscript{4}Helia Photonics, Livingston

Monolayer films of transition metal dichalcogenides (TMDCs) are direct band gap semiconductors with large exciton binding energies and small Bohr radii, indicating great potential for development of novel optoelectronic devices. In this work we report strong exciton-photon coupling with these materials using a tunable open-access microcavity. TMDCs are embedded into the cavity via standard transfer methods of monolayer sheets of molybdenum diselenide (MoSe\textsubscript{2}), placed on hexagonal boron nitride (hBN) at the planar DBR surface. A double quantum well (QW) heterostructure is produced by placing a second monolayer of MoSe\textsubscript{2}, separated by 3nm thick hBN, on top of the first monolayer sheet. We observe a characteristic anticrossing between the tunable cavity mode resonances with the neutral exciton energy for the single and double QW showing a vacuum Rabi splitting of 20 meV and 29 meV respectively, displaying the expected dependence on the number of QWs. This work opens a new avenue in the field of polaritonics in a new material system of van der Waal crystals.


THU 28
Bottom Surface States in Topological Insulators: AFM defined low-dimensional circuits

Christoph Kastl\textsuperscript{1}, Paul Seifert\textsuperscript{1}, Xiaoyue He\textsuperscript{2}, Kehui Wu\textsuperscript{2}, Yongqing Li\textsuperscript{2}, Alexander Holleitner\textsuperscript{1}

\textsuperscript{1}Walter-Schottky-Institut and Physik-Department, Technische Universität München, Am Coulombwall 4a, 85748 Garching, Germany
\textsuperscript{2}Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

We optoelectronically investigate the bottom surface states in thin films of the topological insulator (Bi\textsubscript{0.5}Sb\textsubscript{0.5})\textsubscript{2}Te\textsubscript{3} on SrTiO\textsubscript{3}-substrates. In contrast to the top surfaces of the films, these buried topological states are encapsulated from environmental conditions. We introduce a dynamic plowing lithography based on an atomic force microscope to demonstrate that the bottom surface states are independent from the top surface morphology. We further verify a distinct optoelectronic response at the lateral edges of the circuits and in nano-plowed constrictions. We discuss photo-
THU 29  
**An interaction of lithium with fluorinated graphite via X-ray photoelectron and absorption spectroscopy**

Boris Senkovskiy\textsuperscript{1}, Lyubov Bulusheva\textsuperscript{2}, Denis Vyalikh\textsuperscript{1}, Alexander Okotrub\textsuperscript{2}  
\textsuperscript{1}Institute of Solid State Physics, Dresden University of Technology, Dresden, Germany  
\textsuperscript{2}Nikolaev Institute of Inorganic Chemistry, SB RAS, Novosibirsk, Russia  

To achieve the greatest efficiency of lithium batteries, it is necessary to get insight into the process of interaction of novel cathode materials with lithium. Here, we investigate the interaction of Li with originally fluorinated highly ordered pyrolytic graphite. The experiment was carried out in situ in perfect vacuum conditions for deeper understanding of the process. First time the breaking of the C-F bonds through LiF formation was directly observed in a process of Li penetration into the depth of fluorinated graphite by means of angle-resolved near-edge X-ray absorption spectroscopy (NEXAFS) of the C and F K-edge. Depth profiled information on elemental composition was derived by means of X-ray photoelectron spectroscopy (XPS) with different photon energies. During the Li intercalation into the material the layered structure is preserved, fluorinated carbon atoms with sp\textsuperscript{3} hybridization turn into the sp\textsuperscript{2}-bonded ones and C-layers become conducting. We found also that the amount of the intercalated Li depends on the fluorine content. This result is important for finding the optimal composition of the fluorinated graphite as electrode material for primary lithium batteries.

THU 30  
**Effect of the close gold nanoparticles-carbon nanotubes proximity**

Antonio Setaro\textsuperscript{1}, Stephanie Reich\textsuperscript{1}, Patryk Kusch\textsuperscript{1}, Mareen Gläske\textsuperscript{1}  
\textsuperscript{1}Physics, Freie Universität Berlin, Berlin  

Recently, we have introduced a new class of nanohybrid systems obtained by encaging within the same micelle carbon nanotubes and gold nanoparticles to ensure their close proximity. The yielded hybrids exhibit enhancement of their linear and nonlinear optical response. Here we will show the effect of different coupling geometries onto the performances of the yielded hybrid systems; in particular, we will show the different approaches needed to couple the semiconducting carbon nanotubes with the near and the far field of the metallic particles.
THU 31  
**Fabrication of 2-D transition metal dichalcogenides using Atomic Layer Deposition**

Akhil Sharma¹, N. Thissen¹, J.W. Weber¹, W.M.M. Kessels¹, A.A. Bol¹  
¹Dept. of Applied Physics, Eindhoven University of Technology, The Netherlands

Two-dimensional transition metal dichalcogenides (2D-TMDs) are an exciting class of new materials. Their ultrathin body, optical band gap and unusual spin and valley polarization physics make them very promising candidates for a vast new range of (opto-)electronic applications. So far, most experimental work on 2D-TMDs has been performed on mechanically exfoliated flakes made by the ‘Scotch tape’ technique. The major next challenge is the high quality and large-area synthesis of 2D-TMDs by a technique that ultimately can be used for commercial device fabrication.

In this contribution, a novel scalable process for the fabrication of 2D-TMDs using atomic layer deposition (ALD) has been explored. Ultra-thin films of HfO2 and MoO3 were deposited by ALD on SiO2/Si substrates followed by thermal sulfurization at 1000° C. The formed nano-sheets were characterized by means of XPS, SEM, HRTEM, Raman spectroscopy and photoluminescence spectroscopy.

---

THU 32  
**Confined linear carbon chains: A route to bulk carbyne**

Lei Shi¹, Philip Rohringer¹, Kazu Suenaga², Yoshiko Niimi², Jani Kotakoski¹, Jannik C. Meyer¹, Herwig Peterlik¹, Marius Wanko³, Seymour Cahangirov³, Angel Rubio³,⁴, Kazuhiro Yanagi⁵, Paola Ayala¹, Thomas Pichler¹  
¹University of Vienna, Faculty of Physics, Strudlhofgasse 4, A-1090 Vienna, Austria  
²AIST, Nanotube Research Center, Tsukuba 305-8562, Japan  
³Nano-BioSpectroscopy Group & European Theoretical Spectroscopy Facility (ETSF), Universidad del País Vasco, CFM CSIC-UPV/EHU-MPC & DIPC, 20018 San Sebastian, Spain  
⁴Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany  
⁵Department of Physics, Tokyo Metropolitan University, 1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan

The extreme instability and strong chemical activity of carbyne, the infinite sp³ hybridized carbon chain, are responsible for its low possibility to survive at ambient conditions. We successfully synthesized extremely long linear carbon chains inside thin double walled carbon nanotubes (as nanoreactor and protector). Their existence, structure, lengths and yield have been proved by Raman, HRTEM, STEM and XRD. The results show that the single-triple bonded LLCCs including hundreds of carbon atoms have at least six new Raman lines, some of which are even stronger than the G-band. The optimum growth conditions, for example, diameter of the host tubes, annealing temperatures and time were carefully studied. The interaction and charge transfer between the LLCCs and their host nanotubes were explored using resonance
THU 33
Reduced graphene oxide/polyaniline composites for energy storage devices
Claudio H. B. Silva\textsuperscript{1,2}, Maria Iliut\textsuperscript{1}, Vera R. L. Constantino\textsuperscript{2}, Marcia L. A. Temperini\textsuperscript{2}, Aravind Vijayaraghavan\textsuperscript{1}
\textsuperscript{1}School of Materials, The University of Manchester, Manchester, United Kingdom
\textsuperscript{2}Institute of Chemistry, University of Sao Paulo, Sao Paulo, Brazil

Reduced graphene oxide/polyaniline (rGO/PANI) composites were prepared by simply mixing the dispersions of graphene oxide (GO) and polyaniline (PANI), followed by in situ chemical reduction of GO. Here we report the morphological and spectroscopic characterizations of the rGO/PANI composites, and their electrochemical performance. The obtained results are promising for development of energy storage devices such as batteries and supercapacitors. Optical images combined with atomic force microscopy and Raman spectroscopy clearly show that GO nanosheets are uniformly dispersed in the composite matrix. This can be associated to the good stability of the individual components and the electrostatic interaction (positively charged polymer chains and negatively charged GO nanosheets). Raman spectra show an increase of the relative intensity of the D band, which confirms the in situ reduction of GO in the composite. Moreover, they confirm that PANI remains doped in the rGO/PANI composite. Electrochemical performances of the composites are being assessed by cyclic voltammetry and galvanostatic charge/discharge cycles, and will be correlated to their structural and morphological aspects.

THU 34
Optically detected magnetic resonance in single-wall carbon nanotubes
Ferenc Simon\textsuperscript{1,2}, Milán Negyedi\textsuperscript{1}, Philip Rohringer\textsuperscript{2}, Thomas Pichler\textsuperscript{2}
\textsuperscript{1}Department of Physics, TU-Budapest, Budapest
\textsuperscript{2}University of Vienna, Faculty of Physics, Austria

Understanding the photophysics of SWCNTs is important for potential applications in light-harvesting and light-generation. Excited states of SWCNTs are known to form bound electron-hole pairs, excitons. Only excitons with a singlet spin state can be excited optically but they can form triplet excitons with a low probability in a process known as intersystem crossing. The triplet excitons decay to the ground state with a long relaxation time as the spin conservation is again violated in this process. Understanding the details of the singlet-triplet excited state energy levels and the excitation and decay dynamics is of great importance for the potential applications. We present optically detected magnetic resonance (ODMR) on SWCNTs at 77 K.
and 9 GHz. We developed a unique ODMR spectrometer for this: light source is a tunable laser, detection is in the NIR in a spectrally resolved manner. Usual ODMR instruments operate in the visible range with a single laser source and without spectral resolution of the emitted light. We identify light emission from the triplet states and determine the triplet binding energy.

Supported by the ERC-259374 and the Austrian Science Fund grants.

**THU 35**  
**Raman spectrum of two-dimensional silica glass on graphene**  
Viera Skákalová\textsuperscript{1,2}, Torbjörn Björkman\textsuperscript{3}, Arkady V. Krasheninnikov\textsuperscript{3}, Simon Kurasch\textsuperscript{4}, Jurgen Smet\textsuperscript{2}, Ute Kaiser\textsuperscript{4}, Jannik C. Meyer\textsuperscript{1}  
\textsuperscript{1}Physics of Nanostructured Materials, University of Vienna, Vienna  
\textsuperscript{2}Max Planck Institute for Solid State Research, Stuttgart, Germany  
\textsuperscript{3}Department of Applied Physics, Aalto University, Aalto, Finland  
\textsuperscript{4}Electron Microscopy Group of Materials Science, University of Ulm, Ulm, Germany  

A two-dimensional (2D) silica glass was synthesized on top of graphene during the CVD process. With help of atomic-resolution transmission electron microscopy, the 2D nature of the new structure is visualized in its amorphous as well as crystalline forms with the crystalline lattice constant 5.3 Å, roughly 2.14 times that of graphene and it was identified as a bilayer of SiO₂. Ab-initio calculations indicate that van der Waals interaction with graphene energetically favors the 2D structure against the bulk SiO₂. Raman spectrum acquired from 2D silica glass shows a specific very narrow peak at 1050 cm\textsuperscript{-1}. The calculation of the phonon spectrum indicates that the mode at 1050 cm\textsuperscript{-1} originates from antisymmetric stretching displacements. These results demonstrate a new class of 2D structures that, in principle, can be produced and applied in layered graphene devices.

**THU 36**  
**Calculating core level binding energies for graphene and azafullerenes**  
Toma Susi\textsuperscript{1}, Duncan Mowbray\textsuperscript{2,3}, Mathias P. Ljungberg\textsuperscript{3,4}, Dogan Erbahar\textsuperscript{5,6}, Xavier Rocquefelte\textsuperscript{7}, Carla Bittencourt\textsuperscript{8}, Mattia Scardamaglia\textsuperscript{8}, Peter Guttmann\textsuperscript{9}, Georgias Rotas\textsuperscript{10}, Nikos Tagmatarchis\textsuperscript{10}, Xiaohui Zhu\textsuperscript{11}, Adam Hitchcock\textsuperscript{11}, Christopher P. Ewels\textsuperscript{5}, Paola Ayala\textsuperscript{1}  
\textsuperscript{1}Faculty of Physics, University of Vienna, Austria  
\textsuperscript{2}Departamento de Fisica de Materiales, Universidad del Pais Vasco, San Sebastian, Spain  
\textsuperscript{3}Donostia International Physics Center, San Sebastian, Spain  
\textsuperscript{4}Deparment of Physics, Phillips-University Marburg, Germany  
\textsuperscript{5}Institut des Matériaux Jean Rouxel, Université de Nantes, France  
\textsuperscript{6}Physics Department, Gebze Institute of Technology, Turkey  
\textsuperscript{7}Institut des Sciences Chimiques de Rennes, Université de Rennes 1, France  
\textsuperscript{8}Chemistry of Interaction Plasma-Surface, University of Mons, Belgium
X-ray photoelectron spectroscopy (XPS) combined with first principles modeling is a powerful tool for determining the chemical composition of novel materials. We have calculated the carbon 1s core level binding energy of pristine graphene [1] using two methods based on density functional theory total energy differences: a delta Kohn-Sham calculation with a frozen core-hole (KS) [2], and a novel all-electron extension of the delta self-consistent field (SCF) method. Although the binding energy depends on the chosen exchange correlation functional, using the Perdew-Burke-Ernzerhof functional we find a value remarkably close to what has been measured for graphite. As a first application, we have analyzed XPS measurements of free-standing powders of C$_{60}$ and C$_{59}$N fullerenes using such core-level calculations [3]. This has allowed us to propose a model for oxygen impurities and to quantify the effect of C$_{59}$N dimerization on its N 1s core-level shift (-0.4 eV), with implications for interpreting measurements of other nitrogen-doped systems.


THU 37
Generating photocurrent by nanocomposites based on photosynthetic reaction center protein
Tibor Szabó$^1$, Emil Nyerki$^1$, Tünde Tóth$^1$, Melinda Magyar$^1$, Endre Horváth$^2$, Klára Hernádi$^3$, László Forró$^2$, László Nagy$^1$

$^1$Dept. of Medical Physics and Medical Informatics, University of Szeged, Szeged
$^2$Institute of Physics of Complex Matter, Ecole Polytechnique Federale de Lausanne, Lausanne
$^3$Department of Applied and Environmental Chemistry, University of Szeged, Szeged

There is a large interest these days in binding photosynthetic proteins purified from plants (PS-I and PS-II) and from purple bacteria to nanostructures while their functional activity is largely retained. Current researches are focussing on finding the best bio-nanocomposite sample preparations and experimental conditions for efficient energy conversion and for the stability of the systems. Photosynthetic reaction center protein (RC) purified from purple bacterium Rhodobacter sphaeroides was bound successfully to functionalized multiwalled carbon nanotubes (MWCNTs) then this complex was immobilized onto the surface of indium tin oxide (ITO) by using specific silane crosslinker and conducting polymer. Structural and functional measurements have shown that RCs were bound effectively to the functionalized carbon nanotubes. The complex has high stability and generates photocurrent in wet and
dried condition as well. Several hundreds of nA photocurrent was measured with fully active RCs when the RC turnover was reconstituted by the electron acceptor quinones. The study of possibility for generating photocurrent in organic solar cell based on RC protein is also under process.

THU 38
Structure of graphene oxide membranes in solvents and solutions.
Alexandr Talyzin¹, Alexey Klechikov¹
¹Department of Physics, Umea University, Umea

Structural modification of graphite/graphene oxide (GO) under conditions of hydration/solvation is the key parameter for understanding of GO membrane permeation and filtration properties. It is believed that solvent and solute molecules travel through the network of interlayers between graphene oxide sheets of GO membranes in process of permeation. In situ synchrotron X-ray diffraction study demonstrated that GO membranes exhibit expansion (swelling) swelling properties which are distinctly different compared to precursor graphite oxide powder samples. Intercalation of several liquid solvents into GO membrane structure occurs with maximum one monolayer insertion (Type I), in contrast with insertion of 2-3 layers of these solvents into graphite oxide structure. However, examples of GO membrane structure expansion similar to precursor graphite oxide are also found (Type II). It can be anticipated that Type II solvents will permeate GO membranes significantly faster compared to Type I solvents. It is found that inter-layer distance of GO structure can be modified in a broad range of values up to several nanometers due to intercalation and chemical modification of the membranes.

THU 39
Separation of Metal and Semiconducting Single-Wall Carbon Nanotubes using Automatic Gradient Elution-Gel Filtration
Boanerges Thendie¹, Haruka Omachi¹, Ryo Kitaura¹, Yasumitsu Miyata², Hisanori Shinohara¹
¹Chemistry, Nagoya University, Nagoya
²Physics, Tokyo Metropolitan University, Tokyo

Single-wall carbon nanotubes (SWCNT) are excellent materials for electronic devices. However, due to the varying properties from metallic (m-SWCNT) to semiconductor (s-SWCNT), conventional as-grown SWCNT have limited uses for electronic devices. Obtaining single type of either m-SWCNT or s-SWCNT therefore is essential to optimally utilize SWCNT as electronic device materials. Our work focused on separation of m-SWCNT and s-SWCNT by a simple gel filtration. For elution of SWCNT, we chose two surfactants as eluent: sodium dodecyl sulfate (SDS) and sodium cholate (SC). Metallic SWCNT are collected during first elution with SDS solution while semiconductor SWCNT are collected during second elution with SC solution. Fractionation during SC elution helps improving the pu-
rity of the collected s-SWCNT. Finally, we developed an automatic gradient elution (AGE) system which change the eluent composition from SDS to SC over time. By utilizing AGE system, further purity improvement of s-SWCNT is obtained. Furthermore, diameter-based separation and length-based separation of SWCNT have also been achieved simultaneously by the optimized AGE system.

THU 40
Carbon nanotube thin films from liquid crystal phase polyelectrolytes
Daniel Tune¹, Benjamin Flavel¹
¹Institut für Nanotechnologie, Karlsruher Institut für Technologie, Karlsruhe

Thin films of carbon nanotubes have been widely reported and the potential applications of such films are numerous and varied. However the commonly used preparation methods of spray deposition or vacuum filtration from surfactant stabilised suspensions produce either sparse ‘spiderwebs’ with poor homogeneity and large void spaces on the nanoscale, or extremely rough and opaque films. As well, the extended ultrasonication required invariably shortens the nanotubes and introduces defects into the sidewalls which irreparably alters the electronic and optical properties of the pristine material. An area of recent research interest in the nanotube community is in the production of thin films in which the nanotubes are very highly aligned in one direction parallel to the surface and it is expected that such films will exhibit much improved properties compared to their randomly aligned counterparts. A new method to fabricate such films will be presented, based on the deposition of nanotubes from polyelectrolyte inks having a liquid crystal phase, and measurements of the films and from some devices which use them will clearly demonstrate their superiority.

THU 41
Synthesis and characterization of TiO2/C nano-materials: Applications in water treatment
Drissa Bamba¹,²,³, Krisztina Vajda⁴, András Dombi⁴, Klára Hernádi⁵, Gábor Kovács², Carmen I. Fort², Mariame Coulibaly¹,⁶, Cosmin L. Cotet², Zsolt Pap², Elogne G. Zoro¹, N. Alfred Yao⁶, Virginia Danciu², Didier Robert³
¹Laboratoire de Chimie des Eaux (LCE) - Ecole Normale Supérieure d’Abidjan 08 P 10 Abidjan 08, Côte d’Ivoire
²Laboratory for Electrochemical Research (LER) - Université Babé-Bolyai de Cluj-Napoca 400028 Cluj-Napoca, Roumanie
³Institut de Chimie et Procédés pour l’Energie, l’Environnement et la Santé (ICPEES), CNRS University of Strasbourg, Saint-Avold Antenna, Université de Lorraine rue Victor Demange, 57500 Saint-Avold, France.
⁴Research Group of Environmental Chemistry - University of Szeged, HU-6720 Szeged, Hungary
⁵Department of Applied and Environmental Chemistry - University of Szeged, HU-6720 Szeged, Hungary
The TiO\textsubscript{2} deposition on high surface possessing supports can increase the photocatalytic efficiency of the semiconductor. This effect has been resulted the high adsorption capacity of the support which can help to enrich organic substrate around the catalyst, promoting the charge transfer process between the pollutants and the photocatalysts. In this study the synthesis of TiO\textsubscript{2}-carbon composite photocatalytic materials have been investigated. Titanium tetrachloride (TiCl\textsubscript{4}) was used as the precursor, while graphite, activated carbon and carbon aerogels were chosen as carbon supports. These have different surface properties and various surface textures, thus obviously can lead to distinct photocatalytic performances. An optimization of the synthesis method was proposed by varying the molar ratio titanium / carbon (Ti/C). The obtained materials were characterized by XRD and DRS. The specific surface area, pore volume and pore size distribution were evaluated by nitrogen adsorption/desorption. The photocatalytic activity was investigated by the photodegradation of Diuron which was a model pollutant.

**THU 42**

**Raman analysis of strain in $^{12}$C graphene/fullerenes/$^{13}$C graphene system**

Václav Valeš\textsuperscript{1}, Tim Verhagen\textsuperscript{2}, Jana Vejpravová\textsuperscript{2}, Martin Kalbáč\textsuperscript{1}

\textsuperscript{1}Department of Low-dimensional Systems, J. Heyrovsky Institute of Physical Chemistry, ASCR, Praha

\textsuperscript{2}Institute of Physics of the ASCR, v.v.i., Na Slovance 2, 182 21 Praha 8, Czech Republic

Strain engineering has been proposed as a powerful technique for modifying the electronic properties of graphene [1]. It has been shown recently that strain and doping in graphene cause different shift of G and 2D Raman bands [2]. Therefore it is possible to separate both effects by a correlation analysis of G and 2D positions.

In our work we sandwiched fullerenes in between two layers of graphene in order to induce strain in graphene. Isotope labelling [3] was used to distinguish the top and the bottom graphene layers in the measured Raman spectra. We analysed the Raman maps of isotopically labelled graphene-fullerene sandwiches and estimated the effect of the fullerenes on graphene layers. The results were compared to the AFM images of the surface topography.


(3) O. Frank, L. Kavan, M. Kalbac, Carbon isotope labelling in graphene research, Nanoscale 6 (2014) 6363.
THU 43
Quartz crystal microbalance gas sensor with nanocrystalline diamond sensitive layer

Marian Varga\textsuperscript{1}, Alexander Laposa\textsuperscript{2}, Pavel Kulha\textsuperscript{2}, Jiri Kroutil\textsuperscript{2}, Miroslav Husak\textsuperscript{2}, Alexander Kromka\textsuperscript{1}

\textsuperscript{1}Institute of Physics ASCR, Cukrovarnicka 10, 162 00 Prague 6, Czech Republic
\textsuperscript{2}Czech Technical University, Technicka 2, 16627 Prague, Czech Republic

In this contribution we present a gas sensor for ammonia (NH\textsubscript{3}) detection at room temperature. The sensor is based on a bulk acoustic quartz crystal microbalance (QCM) piezoelectric device coated with nanocrystalline diamond (NCD) as a sensitive layer. Diamond film was directly grown on the QCM by pulsed linear antenna MWCVD process from the H\textsubscript{2}/CH\textsubscript{4}/CO\textsubscript{2} gas mixture at the deposition temperature lower than 400 °C. The QCM coated with the NCD showed a twofold increase in the frequency shift compared to virgin QCM sensor for the NH\textsubscript{3} gas detection. The frequency shift for 50 ppm NH\textsubscript{3} at room temperature was about 10 Hz. Due to the NCD large surface area the response time was very fast (5 s). Further, it was found that the response and recovery times were varied with the NH\textsubscript{3} concentration (10 and 50 ppm) as well as for different detection/purging times. Moreover, the sensor showed a good selectivity to NH\textsubscript{3} gas over CO\textsubscript{2} (2500 ppm) and promising response for the relative humidity detection at room temperature. In summary, such QCM/NCD platform provides a promising gas sensor with good response, reasonable selectivity, high stability and promising repeatability at room temperature.

THU 44
Wet Chemical Exfoliation of Graphene: The Solvent Effect

Philipp Vecera\textsuperscript{1}, Julio C. Chacon-Torres\textsuperscript{2}, Thomas Pichler\textsuperscript{3}, Frank Hauke\textsuperscript{1}, Stephanie Reich\textsuperscript{2}, Andreas Hirsch\textsuperscript{1}

\textsuperscript{1}FAU Erlangen-Nürnberg, Institute of Advanced Materials and Processes, Dr. Mack Strasse 81, Fuerth, Germany
\textsuperscript{2}Institut für Experimental Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany
\textsuperscript{3}Faculty of Physics, University of Vienna, Strudlhofgasse 4, A-1090 Vienna, Austria

The covalent functionalization of graphene represents a main topic in the growing field of nano materials. Since the pioneering work of Pénicaud and Drummond, graphite intercalation compounds (GICs) have been exploited as highly activated species for a subsequent covalent functionalization of the individualized carbon layers. Intercalation of alkali metals in graphite has shown to be a controllable procedure which can be monitored in situ by Raman spectroscopy. For the exfoliation of high quality graphene, absolute and inert solvents are required for a defect-free stabilization of the intermediated charged layers.

Under high vacuum conditions, stage 1 GICs were exposed to various common solvents via vapor pressure control. In order to observe the interaction of the inter-
calation compound, four common solvents were investigated: 1,2 dimethoxyethane, tetrahydrofurane, dimethyl sulfoxide and acetonitrile. Applying in situ Raman spectroscopy to the air sensitive ternary system GIC-solvent, a detailed study of these solvents let us conclude about the quality of each solvent by the spectroscopic signatures in situ prior to the exposure to air.

**THU 45**

*Low temperature induced uniaxial and biaxial strain in CVD grown monolayer graphene*

Tim Verhagen\(^1\), Vaclav Valeš\(^2\), Martin Kalbáč\(^2\), Jana Vejpravová\(^1\)

\(^1\)Institute of Physics of the ASCR, v.v.i., Na Slovance 2, 182 21 Praha 8, Czech Republic

\(^2\)J. Heyrovsky Institute of Physical Chemistry of the AS CR, v.v.i, Dolejskova 3, 182 23 Praha 8, Czech Republic

Using strain engineering, the range of remarkable properties of graphene can be further extended. To observe these predictions experimentally, a well-defined strain direction and a rather large magnitude of the strain is needed, which are not straightforward to realize.

Different thermal expansion coefficients of graphene and its supporting substrate result in the introduction of strain when heating or cooling the sample. Although a relatively large strain is needed to observe changes in the band structure of graphene, it is important to understand the type and magnitude of the strain which is induced in graphene due to thermal cycling.

Here, we study how strain is induced in CVD grown graphene, transfered on a Si/SiO\(_2\) substrate, by varying the temperature between 300 K and 4 K. As Raman spectral mapping is used, we follow an area on the CVD grown graphene sheet where growth induced ripples are clearly present. In this way, we can follow how graphene and the ripples behave when the temperature is varied. Using the correlation analysis, we clearly see a difference between the uniaxial strain in the ripples and biaxial strain in graphene.
THU 46
Large-scale multiplex functionalization of graphene using dip-pen nanolithography

Andrea Francesco Verre\textsuperscript{1}, Michael Hirtz\textsuperscript{2}, Antonios Oikonomou\textsuperscript{1}, Nick Clark\textsuperscript{1}, Sarah Varey\textsuperscript{1}, Aravind Vijayaraghavan\textsuperscript{1}
\textsuperscript{1}School of Materials, University of Manchester, Manchester
\textsuperscript{2}Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Karlsruhe, Germany

The application of graphene for sensors relies on engineering selectivity and sensitivity through chemical modification of graphene. Non-covalent chemical modification allows efficient charge-transfer interaction between molecules and graphene as well as not significantly disturbing the electronic structure of graphene. Recently, we have shown that dip-pen nanolithography (DPN) can be used to pattern self-assembled phospholipid membranes on graphene, which mimic biological membranes\cite{1}.

Here we present further developments to this work. Firstly, we demonstrate how single-pen DPN can be scaled up to multi-pen DPN, where a 1-dimensional array of cantilevers can be used to simultaneously write arrays of lipid patches on graphene. Each probe can carry a different lipid mixture, allowing multiplex functionalization. This can then be extended to simultaneous writing over a 2-d surface using a 2-d array of polymer probes, using a technique called polymer-pen nanolithography (PPN).

Secondly we demonstrate how proteins can be incorporated into the graphene supported biomimetic membranes for biosensing applications.

1. Hirtz, M.; et al; Nature Communications, 2013, 4, 2591

THU 47
Bottom-up assembly of 2-dimensional materials devices

Antonios Oikonomou\textsuperscript{1}, Aravind Vijayaraghavan\textsuperscript{1}
\textsuperscript{1}School of Materials, The University of Manchester, Manchester

We have previously demonstrated that dielectrophoresis (DEP) can be used to assemble carbon nanotubes and graphene into large-scale integrated device arrays. This approach is compatible with sorted materials such as single-chirality SWCNTs, resulting in single-chirality device arrays. Such devices are ideal for certain applications like sensor arrays. In this work, we extend this approach to a variety of other 2-dimensional materials. 2-d materials can be produced by ultrasonic exfoliation in a variety of solvents including water and NMP. We show that MoS\textsubscript{2}, WS\textsubscript{2}, MoTe\textsubscript{2}, MoSe\textsubscript{2} and phosphorene can be assembled from their respective dispersions into functional devices using bottom-up DEP. The assembly of individual flakes can be confirmed by scanning electron microscopy with EDX, scanning probe microscopy and Raman spectroscopy measurements. As previously observed with graphene, we obtain predominantly few-layer devices due to the nature of the starting dispersions which contain a majority of few-layer flakes. The devices are shown to be functional.
using electronic transport measurements and compared to devices produced by other methods.

**THU 48**

**Nanostructures of Bismuth Chalcogenide Topological Insulators: A Computational Study**

Naunidh Virk¹, Gabriel Autès¹, Oleg V. Yazyev¹

¹Institute of Theoretical Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

Surface states of three-dimensional $\mathbb{Z}_2$ topological insulators (TIs), such as the layered bismuth chalcogenides $\text{Bi}_2\text{Se}_3$ and $\text{Bi}_2\text{Te}_3$, are defined by a Dirac cone band dispersion with a helical spin texture. Low-dimensional nanostructures of TIs represent a promising avenue for exploring and harnessing the topological protection of these surface states due to the increased surface-to-volume ratio. Aside from the much explored low energy (0001) surface, bismuth chalcogenide nanostructures possess other higher energy facets. A systematic ab initio investigation of these facets was performed. Calculations find several stable surfaces and, depending on the chemical potential value, allow the prediction of conditions favouring nanoplate and nanowire morphologies. Surface orientation is found to significantly affect the band dispersion and spin polarization of the topological surface states. Furthermore, 1D nanowires and nanoribbons of $\text{Bi}_2\text{Se}_3$ were constructed and investigated using a tight-binding model. The band dispersion and spin texture of the surface states, stemming from their circumferential confinement in 1D nanostructures, is discussed.

**THU 49**

**Electrochemical Degradation of Legal and Illegal Drugs in Waste Water by Boron Doped Diamond Electrode**

Marian Vojs¹, Tomáš Mackuľák², Andrea Vojs Staňová³, Marian Marton¹, Miroslav Behúl¹, Roman Grabič⁴

¹Institute of Electronics and Photonics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Ilkovičova 3, 812 37 Bratislava, Slovak Republic
²Department of Environmental Engineering, Faculty of Chemical and Food Technology, Slovak University of Technology, Radlinského 9, 812 37 Bratislava, Slovak Republic
³Department of Analytical Chemistry, Faculty of Natural Science, Comenius University in Bratislava, Mlynská dolina CH-2, Mlynská dolina CH-2, 842 15 Bratislava, Slovak Republic
⁴Faculty of Fisheries and Protection of Waters, University of South Bohemia in Ceske Budejovice, Zatusi 728/II, 389 25 Vodnany, Czech Republic

Water is a crucial resource for human beings and the environment. Conventional waste water treatment plants cannot degrade the majority of new types of pollu-
tants. Hence the powerful methods for the decontamination of drugs, psychoactive substances and antibiotics waste have received increasing attention over the past decade. The Boron doped diamond (BDD) anode is the best electrode with low adsorption properties, remarkable corrosion stability even in strongly acidic media and extremely high O2 evolution overvoltage. In this study, we investigate the application of polycrystalline BDD thin films in the field of water micropollutants degradation. Extreme effective degradation process of the most "popular" legal and illegal drugs in water (Methamphetamine, Cocaine, Cotinine, Tramadol, Diclofenac, etc.) is presented. We compare the efficiency of BDD and Fenton system degradation techniques analyzed by LC-MS/MS in waste water from the input of a sewage treatment plant on Danube River in Bratislava.

This work was financially supported by the grants of No. 1/0785/14, Slovak Research and Development Agency under the contract No. APVV-0365-12.

THU 50
Nanostructured boron doped diamond films for detection of erythromycin in water samples

Andrea Vojs Staňová1, Monika Radičová1, Lenka Leštinská1, Miroslav Behúl2, Pavol Michniak2, Marian Vojs2
1Department of Analytical Chemistry, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina CH-2, SK-842 15 Bratislava, Slovakia
2Institute of Electronics and Photonics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, Ilkovičova 3, SK-812 19 Bratislava, Slovakia

Nowadays, many studies are focusing on various pollutants emerging in the environment, including in waste-waters and in drinking water, whose presence is continuously increasing. These pollutants include different chemical species such as drugs, personal care products, endocrine disruptors and many other chemicals that are used daily worldwide. Risk assessment of these chemicals and of new products in the environment requires a comprehensive understanding of their degradation behavior and persistence, respectively, which is becoming a field of increasing interest. It is known that the important degradation paths of xenobiotics in the environment usually involve a redox reaction mechanism. In our experimental work we were concerned with optimization of electrochemical conditions for analysis of erythromycin in water samples. We used square wave voltammetry (SW) for analysis. Our BDD electrodes provided oxidation peak at potential 0.87 V at trace concentration level (umol/L). Commercial glassy carbon paste electrode provided no signal in this concentration range.

This work was financially supported by the grant of the Slovak Research and Development Agency (APVV-0365-12).
**THU 51**

**Highly conductive carbon nanotube fibers**

Jinquan Wei\(^1\), Fengmei Guo\(^1\), Can Li\(^1\), Xian Cui\(^1\), Ruiqiao Xu\(^1\)

\(^1\)School of Materials Science and Engineering, Tsinghua University, Beijing

Carbon nanotubes (CNTs) exhibit metallic or semiconducting properties, depending on their chirality and diameter. In generally, the electrical conductivity of the macroscopic fibers without doping is only 103~105 S/m, which is 2-4 order in magnitude lower than that of the individual tubes. Here, we demonstrate our recent advance in preparing highly conductive CNT fibers from controlling growth of metallic CNTs to making near ideal fibers. We first prepare CNT fibers with conductivity higher than stainless steel from macroscopic and semiconducting-rich CNT films by using industrial wire-drawing method. The curving CNT bundles are straightened and aligned along the fiber axis under tension, which reduce inter-tube contact resistance and cross-sectional area of the fibers. The fiber has an electrical conductivity of 1.5×10\(^6\) S/m which is one fold higher than that of the fibers without drawing. By controlling the catalyst and gas, we can increase the content of metallic CNTs in the samples. The metallic-rich CNT fibers have electrical conductivity above 6×10\(^6\) S/m. The highly conductive CNT fibers have great potential applications in replacing copper wires in the future.

**THU 52**

**In situ Study of Metal Induced Crystallization Processes for Low-Dimensional Materials Synthesis**

Robert Wenisch\(^1\), René Heller\(^1\), Daniel Hanf\(^1\), René Hübner\(^1\), Frank Lungwitz\(^1\), Erik Schumann\(^1\), Sibylle Gemming\(^1,2\), Matthias Krause\(^1\)

\(^1\)Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany
\(^2\)Technische Universität Chemnitz, Reichenhainer Strasse 70, 09126 Chemnitz, Germany

Metal induced crystallization (MIC) is a promising technique for thin film transistor fabrication and graphene synthesis. In MIC, a transition metal catalyzes the crystallization of the amorphous phase of a group IV element by bond screening near the interface and facilitation of nucleation. So far, in situ studies have been performed using X-ray diffraction which is sensitive to the degree of crystallinity. However this technique lacks depth resolution and is therefore unable to track diffusion and layer exchange.

Here, the Si/Ag and C/Ni bilayer systems are studied. The samples are annealed at temperatures of up to 750°C. Simultaneously, depth profiles of the elements are investigated by in situ Rutherford backscattering spectroscopy revealing the diffusion kinetics. The changes in the phase structure are explored by in situ Raman spectroscopy. Both the quick initial nucleation and ensuing growth processes are in-
vestigated. Scanning electron microscopy provides insight to the surface morphology.

**THU 53**

**Catalyst-free growth of nanographene on oxides by various CVD methods**

Guofang Zhong\(^1\), Xingyi Wu\(^1\), Junwei Yang\(^1\), Lorenzo D’Arsie\(^1\), John Robertson\(^1\)

\(^1\)Department of Engineering, University of Cambridge, Cambridge CB3 0FA, UK

Since its first isolation by mechanical exfoliation, graphene has been attracting broad interest due to its outstanding physical properties.[1] In recent years, great progress has been made on catalyzed CVD growth of graphene.[2] To make use of this kind of graphene, the important issue is that a transfer process is needed, which dramatically degrades graphene.[3] Therefore, there is an increasing demand to growth graphene on dielectric substrates - normally oxides such as SiO\(_2\), especially under a low temperature by remote plasma CVD. [4, 5]

In this study, we demonstrate the growth of nanographene on oxides by various CVD methods including thermal CVD (quartz tube style furnace), modified microwave-plasma assisted CVD and modified DC-plasma assisted CVD. These successful approaches also promote our understanding of the catalyst-free growth mechanism of nanographene.


**THU 54**

**Fabrication of Thermoelectric Devices using Precisely Fermi Level Tuned Single Wall Carbon Nanotubes by Electric Double Layer Carrier Injections**

Yuki Oshima\(^1\), Yoshimasa Kitamura\(^1\), Hideki Kawai\(^1\), Kazuhiro Yanagi\(^1\)

\(^1\)Department of Physics, Tokyo Metropolitan University, Tokyo

Thermoelectrics are a very important technology for efficiently converting waste heat into electric power. Hicks and Dresselhaus proposed two important approaches to innovate the performance of thermoelectric devices. One approach involves using low-dimensional materials, and the other approach involves properly tuning the Fermi level because the Seebeck coefficient strongly depends on the Fermi Level. Here we report across-bandgap p-type and n-type control over the Seebeck coefficients of semiconducting single wall carbon nanotube (SWCNT) networks through an electric double layer transistor setup using an ionic liquid as the electrolyte. All-around gating characteristics by electric double layer formation upon the surface of the nanotubes enabled the tuning of the Seebeck coefficient of the nanotube networks by the shift in gate voltage, opening the path to Fermi-level-controlled three dimensional thermoelectric devices composed of one-dimensional nanomaterials. Moreover, by
freezing the motion of the ionic liquids, we fabricated thermoelectric devices using the precisely p-type and n-type tuned semiconducting SWCNTs.

THU 55
Magneto transport properties of three-dimensional flexible and conductive interconnected graphene networks

Xixiang Zhang¹
¹Division od Physical Science and Engineering, King Abdullah University of Science & Technology, Thuwal

In this work we present the study of magneto-transport properties of the three-dimensional flexible and conductive interconnected graphene networks. The magnetoresistance (MR) as a function of applied magnetic field was measured in different configurations: a) magnetic field being perpendicular to both the foam plane and the current; b) magnetic field being parallel the foam plane and the current; and c) magnetic field being perpendicular to the current, but angle between the magnetic field and normal direction of the foam plane being changed. As large as 300 percent of magnetoresistance was observed in two both configurations of (a) and (b). More importantly, the observed MR is not only very large, but also nearly temperature independent over the whole temperature range. This characteristics of the MR qualifies the graphene foam as a potential material candidate for the field sensors operating in both wide temperature range and with magnetic field range. Another very interesting observation is that an anisotropic MR was observed in the third configuration, which was not expected for three dimensional nature of the material.

THU 56
Few-layer-thin Two-dimensional Metallic Niobium Disulfide Nanosheets: Preparation, Optical Characterization and Transport Properties

Sihan Zhao¹, Takato Hotta¹, Takumi Sawazaki¹, Mitsuhiro Okada¹, Hisanori Shinohara¹, Ryo Kitaura¹
¹Department of Chemistry, Nagoya University, Nagoya

The semiconducting two-dimensional (2D) transition-metal dichalcogenides (TMDs), such as MoS2, WS2 etc., have recently been studied intensively, however, research work on 2D metallic TMDs, such as NbS2, NbSe2 etc., which show superconductivity and charge-density-wave (CDW) states in bulk, has been limited. In this contribution, we report a direct chemical vapor deposition (CVD) growth of ultrathin 3R-NbS2 nanosheets down to 3 layers on the exfoliated hexagonal boron nitride (hBN) flakes. AFM data show that most of NbS2 samples grown are very thin with an average lateral size of ca. 2~3 µm. Detailed Raman spectroscopy studies on layer number-identified NbS2 samples reveal a systematic shift of out-of-plane vibration mode (A1g), which offers a reliable and rapid optical method for layer number identification. Two-terminal devices on thin-layered NbS2 were also fabricated and show
a metallic transport behavior as predicted by DFT calculations. The metallic nature of thin-layered NbS2 has also been supported by absence of PL peaks regardless of number of layers. Exploration of 2D superconductivity and CDW states in this system is an on-going work.
08:30 – 09:00  F. Mauri, Paris  
*Superconductivity in flatland: universal enhancement in 2D semiconductors at low doping*

09:00 – 09:30  J. Hoffman, Cambridge  
*High $T_c$ superconductivity in a single atomic layer of FeSe*

09:30 – 10:00  B. Beschoten, Aachen  
*Nanosecond spin lifetimes in graphene-based spin-valves at room temperature*

10:00 – 10:30  coffee break

10:30 – 11:00  J. Fabian, Regensburg  
*Spin phenomena in graphene materials*

11:00 – 11:30  B. Özyilmaz, Singapore  
*Transport Studies in Black Phosphorus Field Effect Transistors*

11:30 – 12:00  R. Martel, Montréal  
*Photo-Oxidation Promoted by Electronic Confinement in Exfoliated Black Phosphorus*

12:00 – 17:00  mini workshops

17:00 – 17:30  F. Kreupl, München  
*High Performance X-ray Transmission Windows Based on Graphenic Carbon*

17:30 – 18:00  S. Garaj, Singapore  
*Ion selectivity and water flow in graphene-derived membranes*

18:00 – 18:30  C. Stampfer, Aachen  
*IWEPNM 2015 Conference Summary*

18:30 – 20:00  break

20:00  Bauernbuffet – Farewell
08:30
Superconductivity in flatland: universal enhancement in 2D semiconductors at low doping
Francesco Mauri\textsuperscript{1}, Matteo Calandra\textsuperscript{1}, Paolo Zoccante\textsuperscript{1}
\textsuperscript{1}Université Pierre et Marie Curie / CNRS, Paris

The occurrence of superconductivity has been reported in several two-dimensional (2D) semiconductors, such as transition metal dichalcogenides or cloronitriles (ZrNCl, HfNCl). In these systems, a metallic state can be achieved and controlled by intercalation or by gating in a field-effect transistors. Unexpectedly, in the layer compound Li\textsubscript{x}ZrNCl, the superconducting transition temperature (T\textsubscript{c}) increases by decreasing the doping (x), reaching a maximum of 15 K at the metal-insulator transition. In 2D multivalley semiconductors, at low doping, the electron-electron interaction enhances the response to any perturbation inducing a valley polarization. If the valley polarization is due to the electron-phonon coupling, the electron-electron interaction results in an enhancement of the superconducting critical temperature. By performing first principles calculations beyond DFT, we prove that this effect accounts for the unconventional doping-dependence of T\textsubscript{c} and of the magnetic susceptibility measured in Li\textsubscript{x}ZrNCl. Finally we discuss what are the conditions for a maximal T\textsubscript{c} enhancement in weakly doped 2-dimensional semiconductors.
Work to be published in PRL, arxiv:1408.6502
09:00
High $T_c$ superconductivity in a single atomic layer of FeSe
Jennifer Hoffman\textsuperscript{1}
\textsuperscript{1}Physics, Harvard University, Cambridge

The remarkable discovery of superconductivity above 100 K in a single atomic layer of FeSe (compared to the relatively mundane $T_c = 8$ K in bulk FeSe) prompts tremendous excitement and numerous pressing questions. What is the mechanism of the order-of-magnitude $T_c$ enhancement in FeSe? What is the pairing symmetry? Could FeSe be a topological superconductor? What applications might one envision with such a 2D superconductor? I will review current experimental progress towards addressing these questions, then discuss our own growth (via molecular beam epitaxy) and imaging (via scanning tunneling microscopy) of single layer FeSe. We use quasiparticle interference imaging to access the band structure of filled and empty states, and to explore the pairing symmetry.
09:30
Nanosecond spin lifetimes in graphene-based spin-valves at room temperature
Bernd Beschoten
12nd Institute of Physics, RWTH Aachen University, Aachen, Germany

By successive oxygen treatments of graphene nonlocal spin-valve devices we achieve a gradual increase of the contact-resistance–area products $R_c A$ of Co/MgO spin injection and detection electrodes. With this manipulation of the contacts, the spin lifetime can be increased by a factor of seven in the same device reaching values larger than 1 ns at 300 K. This demonstrates that contact-induced spin dephasing is the bottleneck for spin transport in devices with small $R_c A$ values [1].

Spin transport properties can further be enhanced by improving both the electrode-to-graphene and graphene-to-substrate interface. In these devices, Co/MgO spin injection electrodes are first fabricated onto Si$^{++}$/SiO$_2$. Thereafter, a graphene–hBN heterostructure is mechanically transferred onto these prepatterned electrodes. Room temperature spin transport in single-, bi-, and trilayer graphene devices exhibit spin lifetimes of several ns with spin diffusion lengths reaching 10$\mu$m combined with carrier mobilities exceeding 20,000 cm$^2$/V s)[2].

Intrinsic spin-orbit coupling in graphene is relatively weak, some tens of micro eVs. On one hand, this is nice, as the projected intrinsic spin relaxation is also slow, on the order of microseconds. On the other hand, a greater value for the spin-orbit interaction is desired for spin manipulation and spin-orbit induced phenomena, such as the (quantum) spin Hall effect. In this talk I will review basics of the spin-orbit physics in graphene and show how to effectively increase the value of the spin-orbit interaction by adding adatoms. Examples will be hydrogen, fluorine, and copper adatoms. I will present first-principles results as well as phenomenological model Hamiltonians which are useful to study model spin transport and spin relaxation. I will also discuss the spin relaxation problem in graphene: experiments get the spin relaxation times of 100 ps, orders of magnitude below what is theoretically expected. The cause appears to be extrinsic, due to impurities. I will argue that the mechanism is resonant scattering by a small concentration of magnetic moments (wherever they come from). I will also present graphene-TMC heterolayers as promising systems for spin optoelectronics.
11:00
Transport Studies in Black Phosphorus Field Effect Transistors
Barbaros Özyilmaz\textsuperscript{1,2}
\textsuperscript{1}Physics, National University of Singapore, Singapore 117546
\textsuperscript{2}Centre for Advanced 2D Materials, National University of Singapore, Singapore 117546

Unlike graphene, Ultrathin black phosphorus (BP), is a semiconductor with a sizeable band gap that allows both high carrier mobility and large on/off ratios. Its excellent electronic properties make it attractive for applications in transistor, logic, and optoelectronic devices. However, it is also the first widely investigated two dimensional electronic material to undergo degradation upon exposure to ambient air. Therefore a passivation method is required to study the intrinsic material properties, understand how oxidation affects the physical transport properties and to enable future application of phosphorene. I will show that atomically thin graphene and hexagonal boron nitride crystals can be used for passivation of ultrathin black phosphorus. I will also discuss experiments where we characterize few-layer black phosphorus field effect transistors on hexagonal boron nitride (BN) and compare with results obtained with BP fully encapsulated with BN.
Exfoliated Black phosphorus (P(black)), a lamellar crystal of P atoms that can be exfoliated down to few layer 2D-phosphane (also called phosphorene), has recently been highlighted for their 2D semiconducting properties, such as tunable bandgap with thickness and high carrier mobility. Device fabrication with mono- and bi- and other multi-layer 2D-phosphane has however been challenging due to a ubiquitous degradation of the layer in air. Here we report on results on this chemistry, which was investigated using in-situ Raman and TEM-EELS. A photo-oxidation initiated by charge transfer to adsorbed oxygen in water is found to be at the origin of the degradation. The oxidation rate is thickness dependent and increases with photon flux and oxygen concentration. Finally, different ways to prevent degradation were used to acquire Raman measurements on mono-, bi- and other multilayer 2D-phosphane in their pristine states. These results as well as signatures of degradation in Raman were determined and they will be discussed here using symmetry analysis. A trend in the intensity ratio of A1g and A2g Raman modes emerges from our data as a useful parameter to assess the oxidation level.
A novel x-ray transmission window based on graphenic carbon (GC) has been developed and integrated into a silicon drift detector (SDD) with much better performance than beryllium transmission windows that are currently used in the field [1]. GC integrated on a silicon frame allows for a 7 mm wide window which does not use a mechanical support grid or additional light blocking layers. Compared to beryllium, the novel GC window exhibits an improved x-ray transmission in the important low energy region (0.1 keV - 3 keV) enabling the detection of C and F while demonstrating excellent mechanical stability, as well as light and vacuum tightness. Be-windows with an opening diameter of 7 mm are specified to withstand a differential pressure of 2 bar. The GC window with a thickness of 1 micrometer exceed this requirement. Pressure cycle fatigue for Be-windows is specified to ∼20k cycles, while GC has already demonstrated more than 4 million pressure cycles without damage. Therefore, the newly established GC window, can replace beryllium in x-ray transmission windows with a nontoxic and abundant material.

[1] S. Huebner et al., accepted for publication in IEEE Trans. on Nuclear Science
17:30
Ion selectivity and water flow in graphene-derived membranes
Slaven Garaj$^{1,2}$

$^1$Department of Physics, National University of Singapore, Singapore
$^1$Centre for Advanced 2D Materials, National University of Singapore, Singapore

Graphene’s unique interaction with water, ions and molecules - with implied superior performance in diverse fields such as next-generation DNA sequencing or water desalination - has attracted a lot of attention from research groups and industrial champions.

We have previously shown that the monoatomic, crystalline graphene membrane in its pristine form is impermeable to water and ions[1]. If modified, graphene membrane could become an effective ionic and molecular sieve, while retaining ultra-high water flux. Two strategies have been applied to that end: (a) perforating graphene with sub-nanometer sized pores[1,2]; and (b) layering graphene-oxide crystallites into a thin laminated membrane[3]. With careful investigation of the ionic flow in graphene-derived membranes, for a range of ionic species, we identified basic mechanisms governing ion-graphene interaction. This insight opens us a new venue for developing desalination membranes with unmatched performance.


18:00
IWEPNM 2015 Conference Summary

C. Stampfer$^{1,2}$

$^1$JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52056 Aachen, Germany, EU
$^2$Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany, EU
Authors

Özyılmaz, B. , 176
Čech, J. , 96
Černák, M. , 96
Łabębź, O. , 85
Łukowiec, D. , 144

Abellán, G. , 37
Adeli, M. , 61
Ager, J. W. , 143
Ahn, J. , 136
Alexander-Webber, J. A. , 37
Amara, H. , 60
Amsharov, K. , 22
An, H. , 38
Andrei, E. Y. , 117
Anis, B. , 137
Appenzeller, J. , 80, 82
Argentero, G. , 94
Artemenko, A. , 96
Asanov, I. , 142
Aubert, T. , 43
Autès, G. , 163
Auton, G. , 96
Awano, Y. , 38, 67, 69
Ayala, P. , 55, 143, 153, 155

Börrnert, F. , 137
Babchenko, O. , 87
Bachtold, A. , 63
Backes, C. , 39, 42, 105
Backes, S. , 105
Bacsà, W. , 40
Bachtz, C. , 84
Bamba, D. , 158
Baranowski, P. , 85
Barzegar, H. R. , 40
Basko, D. M. , 41, 125
Baughman, R. H. , 135
Baumeister, P. , 43
Baumgartner, A. , 62
Bayer, B. C. , 84
Behül, M. , 163, 164
Benavides, V. , 41
Berciaud, S. , 41, 58, 125
Berghäuser, G. , 42
Berner, N. C. , 42, 139
Bergneruber, S. , 105
Beschoten, B. , 53, 137, 174
Beton, P. , 51
Biao, Z. , 66
Biermann, A. , 43
Bittencourt, C. , 155
Björkman, T. , 155
Blake, P. , 75
Bланter, Y. , 134
Blume, R. , 84
Bockrath, M. , 118
Boden, A. , 43
Boerner, B. , 43
Boh, A. , 153
Bonn, M. , 64
Bosch, S. , 105
Bosman, S. , 134
Bothe, C. , 110
Bouchiat, H. , 19
Braeuninger, P. , 37
Brandt, M. S. , 44
Brenneis, A. , 44
Brndiarova, J. , 45
Bulusheva, L. G. , 45, 142, 152

181
<table>
<thead>
<tr>
<th>Name</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgdörfer, J.</td>
<td>48, 100</td>
</tr>
<tr>
<td>Bystrzejewski, M.</td>
<td>85</td>
</tr>
<tr>
<td>Cabrero-Vilatela, A.</td>
<td>84</td>
</tr>
<tr>
<td>Cahangirov, S.</td>
<td>153</td>
</tr>
<tr>
<td>Calandra, M.</td>
<td>82, 172</td>
</tr>
<tr>
<td>Caneva, S.</td>
<td>84</td>
</tr>
<tr>
<td>Cao, Y.</td>
<td>75</td>
</tr>
<tr>
<td>Carillo-Bastos, R.</td>
<td>59</td>
</tr>
<tr>
<td>Carlson, R. M. K.</td>
<td>107</td>
</tr>
<tr>
<td>Carroll, D.</td>
<td>46</td>
</tr>
<tr>
<td>Castellanos-Gomez, A.</td>
<td>134</td>
</tr>
<tr>
<td>Cebula, I.</td>
<td>51</td>
</tr>
<tr>
<td>Cepek, C.</td>
<td>54</td>
</tr>
<tr>
<td>Chacon-Torres, J. C.</td>
<td>46, 102, 160</td>
</tr>
<tr>
<td>Chang, D. E.</td>
<td>63</td>
</tr>
<tr>
<td>Chang, H.</td>
<td>49</td>
</tr>
<tr>
<td>Chekhova, G.</td>
<td>142</td>
</tr>
<tr>
<td>Chen, X.</td>
<td>33, 42</td>
</tr>
<tr>
<td>Chen, Z.</td>
<td>82</td>
</tr>
<tr>
<td>Cheng, T.</td>
<td>61</td>
</tr>
<tr>
<td>Chernenkaya, A.</td>
<td>47</td>
</tr>
<tr>
<td>Chernikov, A.</td>
<td>77</td>
</tr>
<tr>
<td>Chernogorova, O. P.</td>
<td>11</td>
</tr>
<tr>
<td>Chernov, A. I.</td>
<td>48, 139</td>
</tr>
<tr>
<td>Chiashi, S.</td>
<td>33, 38</td>
</tr>
<tr>
<td>Chiba, T.</td>
<td>33</td>
</tr>
<tr>
<td>Chikkadi, K.</td>
<td>64</td>
</tr>
<tr>
<td>Chizhova, L.</td>
<td>48, 100</td>
</tr>
<tr>
<td>Choi, S.</td>
<td>91</td>
</tr>
<tr>
<td>Choi, W. J.</td>
<td>49</td>
</tr>
<tr>
<td>Choleva, P.</td>
<td>87</td>
</tr>
<tr>
<td>Chung, Y. J.</td>
<td>49</td>
</tr>
<tr>
<td>Chuvilin, A. L.</td>
<td>139, 142</td>
</tr>
<tr>
<td>Ciesielski, R.</td>
<td>49</td>
</tr>
<tr>
<td>Clark, C.</td>
<td>151</td>
</tr>
<tr>
<td>Clark, N.</td>
<td>31, 50, 138, 141, 162</td>
</tr>
<tr>
<td>Cohen, S. R.</td>
<td>61</td>
</tr>
<tr>
<td>Coldrick, Z.</td>
<td>62</td>
</tr>
<tr>
<td>Coleman, J. N.</td>
<td>39, 42, 83, 139</td>
</tr>
<tr>
<td>Comin, A.</td>
<td>49</td>
</tr>
<tr>
<td>Constantino, V. R. L.</td>
<td>154</td>
</tr>
<tr>
<td>Corato, M. D.</td>
<td>52</td>
</tr>
<tr>
<td>Coronado, E.</td>
<td>37</td>
</tr>
<tr>
<td>Costamagna, S.</td>
<td>102</td>
</tr>
<tr>
<td>Cotet, C. L.</td>
<td>158</td>
</tr>
<tr>
<td>Coulibaly, M.</td>
<td>138</td>
</tr>
<tr>
<td>Crowe, I. F.</td>
<td>50</td>
</tr>
<tr>
<td>Csonka, S.</td>
<td>50, 65</td>
</tr>
<tr>
<td>Cui, K.</td>
<td>33, 38</td>
</tr>
<tr>
<td>Cui, X.</td>
<td>76, 165</td>
</tr>
<tr>
<td>Cullen, C. P.</td>
<td>42</td>
</tr>
<tr>
<td>D’Arsié, L.</td>
<td>51, 54, 166</td>
</tr>
<tr>
<td>Dąbrowska, A.</td>
<td>85</td>
</tr>
<tr>
<td>Dahl, J. E. P.</td>
<td>107</td>
</tr>
<tr>
<td>Damnjanović, M.</td>
<td>103, 145</td>
</tr>
<tr>
<td>Danciu, V.</td>
<td>158</td>
</tr>
<tr>
<td>Dauber, J.</td>
<td>140</td>
</tr>
<tr>
<td>Davies, A.</td>
<td>51</td>
</tr>
<tr>
<td>Deblock, R.</td>
<td>19</td>
</tr>
<tr>
<td>Delagrange, R.</td>
<td>19</td>
</tr>
<tr>
<td>Derer, J.</td>
<td>45</td>
</tr>
<tr>
<td>Diep, V. Q.</td>
<td>82</td>
</tr>
<tr>
<td>Dmitrović, S.</td>
<td>103</td>
</tr>
<tr>
<td>Domanov, O.</td>
<td>143</td>
</tr>
<tr>
<td>Dombi, A.</td>
<td>158</td>
</tr>
<tr>
<td>Dora, B.</td>
<td>123</td>
</tr>
<tr>
<td>Dorofeev, I.</td>
<td>98</td>
</tr>
<tr>
<td>Drögeler, M.</td>
<td>53, 137</td>
</tr>
<tr>
<td>Drozdova, E. I.</td>
<td>41</td>
</tr>
<tr>
<td>Duesberg, G. S.</td>
<td>42, 64, 81, 109, 139</td>
</tr>
<tr>
<td>Dufferwiel, S.</td>
<td>151</td>
</tr>
<tr>
<td>Dunn, G.</td>
<td>40</td>
</tr>
<tr>
<td>Dzsaber, S.</td>
<td>46</td>
</tr>
<tr>
<td>Eaves, L.</td>
<td>51</td>
</tr>
<tr>
<td>Eckstein, K.</td>
<td>150</td>
</tr>
<tr>
<td>Eder, F.</td>
<td>94</td>
</tr>
<tr>
<td>Eigler, S.</td>
<td>131</td>
</tr>
<tr>
<td>Engels, S.</td>
<td>100</td>
</tr>
<tr>
<td>Englert, J. M.</td>
<td>102</td>
</tr>
<tr>
<td>Enyashin, A.</td>
<td>61</td>
</tr>
<tr>
<td>Eom, J.</td>
<td>57</td>
</tr>
<tr>
<td>Epping, A.</td>
<td>140</td>
</tr>
<tr>
<td>Erbahar, D.</td>
<td>155</td>
</tr>
<tr>
<td>Erdőhelyi, A.</td>
<td>64</td>
</tr>
<tr>
<td>Erni, R.</td>
<td>88</td>
</tr>
<tr>
<td>Ernst, F.</td>
<td>54</td>
</tr>
</tbody>
</table>
Index

Esconjauregui, S., 51, 54
Ewels, C. P., 155
Fütterling, V., 97
Fabian, J., 175
Fairbrother, A., 139
Faria, D., 59
Fasel, R., 139
Fathalizadeh, A., 55
Faugeras, C., 41, 125
Favron, A., 177
Fedi, F., 55, 143
Fedorov, A. S., 96
Fedotov, P. V., 48, 139
Fernique, F., 58
Ferrari, A. C., 49
Ferrer-Anglada, N., 57
Firchowska, I., 43
Fischer, F., 23
Flahaut, E., 60
Flavel, B. S., 57, 158
Fokina, N. A., 107
Forró, L., 106, 156
Fort, C. I., 158
Fossard, F., 60, 177
Frohlick, K., 45
Fracoeur, S., 177
Freeley, M., 42
Froehlicher, G., 58
Fu, L., 142
Fuchs, F., 58
Fujihara, M., 101
Fujii, S., 17
Fulop, B., 50, 65
Fulop, G., 50
Gabriel, D., 57
Gannott, F., 111
Garaj, S., 179
Garcia de Abajo, J., 30
Garel, J., 99
Garrido, J. A., 44
Gaskill, D. K., 37
Gaudreau, L., 44
Gaufres, E., 177
Gava, P., 82
Geim, A. K., 36, 52, 73, 75, 96
Gemming, S., 95, 165
Georgi, A., 59
Gerardot, B. D., 89
Gharagazloo-Hubmann, K., 59
Ghedjatti, A., 60
Gholinia, A., 52
Gillen, R., 60, 91, 110, 111
Glänske, M., 61, 152
Glazov, M., 79
Gloskovskii, A., 47
Goldbart, O., 61
Goldoni, A., 143
Goodwin, S., 62
Gorbachev, R., 36, 75
Grüneis, A., 119
Grabič, R., 163
Gracia-Espino, E., 40
Gramich, J., 62
Grieve, B., 62
Guettlinger, J., 63
Guo, F., 165
Guo, H., 120
Guo, Y., 54, 108
Guttman, P., 135
Hübner, R., 95, 165
Haag, R., 61
Haigh, S. J., 36, 52, 64, 75
Hajdu, K., 106
Hallam, T., 64, 109, 139
Halsall, M. P., 50
Haluska, M., 64, 88, 95
Hambach, R., 104
Hamilton, A. S., 147
Handloser, M., 49
Handschin, C., 65
Hanf, D., 165
Hanlon, D., 139
Hartleb, H., 150
Hartschuh, A., 49, 88
Hasan, T., 84, 85
Index

Hasdeo, E. H. , 120 138
Hasegawa, K. , 91
Hasler, T. , 65
Hasanien, A. , 66
Hassler, F. , 140
Hauke, F. , 105 150 160
He, X. , 151
Heeg, S. , 31 141
Heinz, T. F. , 54
Heller, R. , 165
Henrich, F. , 97
Hens, Z. , 43
Hernádi, K. , 67 106 156 158
Hertel, T. , 150
Herziger, F. , 82 111
Hibino, H. , 94
Hierold, C. , 64 88
Higgins, T. , 83
Hill, E. , 62
Hirano, A. , 17
Hirotani, J. , 83
Hirsch, A. , 37 102 105 150 160
Hirtz, M. , 162
Hitchcock, A. , 155
Hof, F. , 98 150
Hoffman, J. , 173
Hoffmann, A. , 91
Hoffmann, S. , 37 84
Holleitner, A. W. , 32 44 90 103 143 151
Horváth, E. , 106 156
Hotta, T. , 167
Howe, R. C. T. , 84 85
Hu, G. , 84 85
Huang, J. , 87
Huczko, A. , 85
Huebl, H. , 44
Huebner, S. , 178
Hulman, M. , 45 86
Husak, M. , 160
Hussein, S. , 50
Ilani, S. , 20 92 93
Iliut, M. , 154
Inoue, T. , 38
Ionescu, A. M. , 104
Iqbal, M. Z. , 57
Ito, K. , 67
Ivanov, I. , 64
Izak, T. , 87 145
Jörger, D. , 89 100
Jago, R. , 87
Janik, J. , 88
Janssen, T. J. B. M. , 37
Jenni, L. V. , 88
Jiang, H. , 106
Jiang, Y. , 117
Jorio, A. , 121
Joselevich, E. , 99
Jung, M. , 65
Kürti, J. , 97 98
Kaczmarczyk, A. , 89
Kaiser, U. , 34 104 155
Kajita, A. , 68
Kalbáč, M. , 159 161
Kampmann, F. , 89
Kanygin, M. A. , 45
Kaplan-Ashiri, I. , 61
Kappes, M. M. , 97
Karl, H. , 14
Karnetzky, C. , 90
Kaskela, A. , 106
Kastl, C. , 151
Kasumov, A. , 19
Kataura, H. , 17
Katkov, V.L. , 90
Kauppinen, E. I. , 106
Kawai, H. , 91 166
Kazakova, , 98
Kelleher, E. J. R. , 84
Keller, A. , 95
Kessels, W. , 153
Khachadorian, S. , 91
Kharlamova, M. V. , 92
Khasminskaya, S. , 97
Khestanova, K. , 75
Khivrich, I. , 92
Khlobystov, A. , 51
Kidambi, P. , 84
Kim, H. , 139
Kinka, A. , 67, 106
Kishimoto, S. , 83, 141
Kitamura, M. , 68
Kitamura, Y. , 166
Kitaura, R. , 101, 107, 147, 157, 167
Klechikov, A. , 93, 157
Knorr, A. , 42, 87
Kobayashi, A. , 66
Kobayashi, Y. , 94
Koltai, J. , 97, 98
Kong, K. , 49
Kono, J. , 18
Koppens, F. H. L. , 44
Kornowski, A. , 110
Kotakoski, J. , 94, 95, 153
Kotrusz, P. , 86
Kovács, G. , 138
Kozak, H. , 96
Kramberger, C. , 92, 95
Krasheninnikov, A. V. , 155
Krasnikov, , 98
Krause, M. , 95, 165
Kretinin, A. V. , 75, 141
Kreipl, F. , 178
Krizhanovskii, D. N. , 151
Kromka, A. , 87, 96, 145, 160
Kroun, J. , 160
Krupke, R. , 97
Kurasch, S. , 155
Kubatkin, S. , 37
Kulha, P. , 160
Kumar, R. K. , 96
Kumar, S. , 89
Kuntscher, C. A. , 137
Kunze, T. , 95
Kurcz, M. , 85
Kusch, P. , 31, 43, 152
Kusminskiy, S. V. , 59
Kuzmany, H. , 97, 98
Kuznetsov, V. L. , 48, 98, 139
Lacovic, P. , 143
Lafargue, P. , 42
Laiho, P. , 106
Lange, H. , 110, 148
LaPlace, P. , 42
Laposa, A. , 160
Lara-Avila, S. , 37
Lauret, J. , 60
Lazzeri, M. , 82
Leshtinska, L. , 164
Lee, D. S. , 99
Lee, J. , 49
Lee, K. , 139
Lee, T. , 49
Lee, Y. K. , 49
Lehmann, C. , 31
Leon, A. B. , 148
Leonelli, R. , 177
Levesque, P. , 177
Levi, R. , 99
Li, C. , 165
Li, F. , 151
Li, L. , 146
Li, Y. , 151
Libisch, F. , 48, 100
Lim, H. E. , 101
Lin, C. , 82
Lin, R. , 88
Lindenberg, A. , 54
Lindner, D. , 94
Liu, W. , 64
Livneh, T. , 101
Lizzit, S. , 143
Ljungberg, M. P. , 155
Loiseau, A. , 60, 177
Lorchat, É , 58
Lotsch, B. V. , 16
Luitz, D. J. , 19
Lungwitz, F. , 165
Müller, N. S. , 31, 59, 105
Müller, T. , 74
Márkus, B. G. , 102
Mackul’ak, T. , 163
<table>
<thead>
<tr>
<th>Name</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magyar, M.</td>
<td>67, 106, 156</td>
</tr>
<tr>
<td>Maier, S.</td>
<td>29</td>
</tr>
<tr>
<td>Makk, P.</td>
<td>65</td>
</tr>
<tr>
<td>Malic, E.</td>
<td>42, 49, 87</td>
</tr>
<tr>
<td>Mangler, C.</td>
<td>94, 95</td>
</tr>
<tr>
<td>Maniwa, Y.</td>
<td>94</td>
</tr>
<tr>
<td>Mannebach, E.</td>
<td>54</td>
</tr>
<tr>
<td>Mao, J.</td>
<td>117</td>
</tr>
<tr>
<td>Marcia, M.</td>
<td>105</td>
</tr>
<tr>
<td>Martel, R.</td>
<td>177</td>
</tr>
<tr>
<td>Marton, M.</td>
<td>163</td>
</tr>
<tr>
<td>Maruyama, S.</td>
<td>33, 38</td>
</tr>
<tr>
<td>Mateo-Alonso, Á.</td>
<td>55</td>
</tr>
<tr>
<td>Matsui, R.</td>
<td>83</td>
</tr>
<tr>
<td>Maultzsch, J.</td>
<td>43, 60, 64, 82, 89, 91, 109, 111</td>
</tr>
<tr>
<td>Mauri, F.</td>
<td>82, 172</td>
</tr>
<tr>
<td>Mauser, N.</td>
<td>88</td>
</tr>
<tr>
<td>May, P.</td>
<td>82</td>
</tr>
<tr>
<td>Malolepszy, A.</td>
<td>85</td>
</tr>
<tr>
<td>McDonald, A. R.</td>
<td>42</td>
</tr>
<tr>
<td>McEvoy, N.</td>
<td>139</td>
</tr>
<tr>
<td>Meden, V.</td>
<td>19</td>
</tr>
<tr>
<td>Medjanik, K.</td>
<td>47</td>
</tr>
<tr>
<td>Melkhanova, S.</td>
<td>95</td>
</tr>
<tr>
<td>Mercier, G.</td>
<td>93</td>
</tr>
<tr>
<td>Mertig, M.</td>
<td>149</td>
</tr>
<tr>
<td>Merz, M.</td>
<td>47</td>
</tr>
<tr>
<td>Meyer, J. C.</td>
<td>94, 95, 153, 155</td>
</tr>
<tr>
<td>Michel, K. H.</td>
<td>102</td>
</tr>
<tr>
<td>Michniak, P.</td>
<td>164</td>
</tr>
<tr>
<td>Mickelson, W.</td>
<td>55</td>
</tr>
<tr>
<td>Miller, B.</td>
<td>103, 143</td>
</tr>
<tr>
<td>Milošević, I.</td>
<td>103, 145</td>
</tr>
<tr>
<td>Misawa, T.</td>
<td>38</td>
</tr>
<tr>
<td>Mishchenko, A.</td>
<td>52, 75</td>
</tr>
<tr>
<td>Miyakawa, N.</td>
<td>178</td>
</tr>
<tr>
<td>Miyata, Y.</td>
<td>94, 101, 137</td>
</tr>
<tr>
<td>Miyazaki, A.</td>
<td>66</td>
</tr>
<tr>
<td>Mohn, M.</td>
<td>104</td>
</tr>
<tr>
<td>Moldovan, C. F.</td>
<td>104</td>
</tr>
<tr>
<td>Molinari, E.</td>
<td>52</td>
</tr>
<tr>
<td>Mogenstern, M.</td>
<td>59</td>
</tr>
<tr>
<td>Morinov, R.</td>
<td>47</td>
</tr>
<tr>
<td>Mori, S.</td>
<td>94</td>
</tr>
<tr>
<td>Moseenkov, S.</td>
<td>98</td>
</tr>
<tr>
<td>Mowbray, D.</td>
<td>155</td>
</tr>
<tr>
<td>Mundloch, U.</td>
<td>105</td>
</tr>
<tr>
<td>Musevic, I.</td>
<td>66</td>
</tr>
<tr>
<td>Mustonen, K.</td>
<td>106</td>
</tr>
<tr>
<td>Myers-Ward, R. L.</td>
<td>37</td>
</tr>
<tr>
<td>Németh, K.</td>
<td>67</td>
</tr>
<tr>
<td>Nagel, P.</td>
<td>47</td>
</tr>
<tr>
<td>Nagy, L.</td>
<td>67, 106, 156</td>
</tr>
<tr>
<td>Nakanishi, Y.</td>
<td>107</td>
</tr>
<tr>
<td>Negyedi, M.</td>
<td>154</td>
</tr>
<tr>
<td>Nemes-Incze, P.</td>
<td>59</td>
</tr>
<tr>
<td>Neugebauer, H.</td>
<td>108</td>
</tr>
<tr>
<td>Neumaier, D.</td>
<td>53</td>
</tr>
<tr>
<td>Neumann, C.</td>
<td>137</td>
</tr>
<tr>
<td>Nicholas, R. J.</td>
<td>37</td>
</tr>
<tr>
<td>Niimi, Y.</td>
<td>153</td>
</tr>
<tr>
<td>Nikolaus, C.</td>
<td>138</td>
</tr>
<tr>
<td>Nikolic, B.</td>
<td>145</td>
</tr>
<tr>
<td>Noda, K.</td>
<td>69</td>
</tr>
<tr>
<td>Noury, A.</td>
<td>63</td>
</tr>
<tr>
<td>Novikov, S.</td>
<td>51</td>
</tr>
<tr>
<td>Novoselov, K. S.</td>
<td>36, 52, 151</td>
</tr>
<tr>
<td>Nugraha, A. R. T.</td>
<td>120, 138</td>
</tr>
<tr>
<td>Nyerki, E.</td>
<td>156</td>
</tr>
<tr>
<td>Nygard, J.</td>
<td>50</td>
</tr>
<tr>
<td>O’Brien, M.</td>
<td>139</td>
</tr>
<tr>
<td>Obraztsova, E. A.</td>
<td>139</td>
</tr>
<tr>
<td>Obraztsova, E. D.</td>
<td>48, 139</td>
</tr>
<tr>
<td>Oddone, V.</td>
<td>59</td>
</tr>
<tr>
<td>Oellers, M.</td>
<td>140</td>
</tr>
<tr>
<td>Ogata, T.</td>
<td>67</td>
</tr>
<tr>
<td>Ohno, Y.</td>
<td>83, 141</td>
</tr>
<tr>
<td>Oikonomou, A.</td>
<td>31, 141, 162</td>
</tr>
<tr>
<td>Ojeda-Aristizabal, C.</td>
<td>40</td>
</tr>
<tr>
<td>Okada, M.</td>
<td>167</td>
</tr>
<tr>
<td>Okada, S.</td>
<td>101</td>
</tr>
<tr>
<td>Okotrub, A.</td>
<td>45, 85, 142, 152</td>
</tr>
<tr>
<td>Omachi, H.</td>
<td>101, 107, 157</td>
</tr>
<tr>
<td>Oshima, Y.</td>
<td>166</td>
</tr>
<tr>
<td>Osipov, V.A.</td>
<td>90</td>
</tr>
</tbody>
</table>
Index

Pahlke, A., 178
Paillet, M., 122
Pap, Z., 158
Papaj, M., 142
Parzinger, E., 103, 143
Pavlenko, E., 40
Pecker, S., 93
Peeters, F. M., 102
Penumatcha, A. V., 82
Pernice, W. H., 97
Peterlik, H., 153
Pham, T., 55
Phaneuf, A., 177
Phillips, M. R., 91
Pichler, T., 46, 55, 92, 98, 102, 143, 146, 148, 153, 154, 160
Pierret, A., 109
Pilarczyk, A., 144
Pilarczyk, W., 144
Pinakov, D., 142
Poliani, E., 64, 109
Polini, M., 96
Ponomarenko, L., 96
Popov, S. V., 84
Popović, Z. P., 103, 145
Potapova, I. N., 41
Potemski, M., 41, 125
Potie, A., 64
Potocký, Š., 87, 145
Pozo-Zamudio, O. D., 52, 151
Prato, M., 129
Pratzer, M., 59
Prezzi, D., 92
Pu, J., 146
Puebla-Hellmann, G., 65
Puech, P., 40
Pyatkov, F., 97
Rümmeli, M. H., 137
Réti, B., 67
Radičová, M., 164
Ranjan, V., 65
Reich, S., 31, 43, 46, 59, 61, 105, 152, 160
Reichardt, S., 137
Robert, D., 158
Robertson, J., 51, 54, 108, 166
Rocquefelte, X., 155
Rohringer, P. A., 146, 153, 154
Rooney, A. P., 36, 52, 64, 75
Rotas, G., 155
Rotkin, S. V., 137
Rubio, A., 153
Rudolf, P., 132
Ruffieux, P., 24
Ruini, A., 52
Süss, T., 88
Saito, R., 120, 138
Saito, T., 92, 148
Sakai, T., 38, 67, 68
Sakanoue, T., 146
Sandler, N., 59
Sasaki, S., 94
Sasaki, Y., 147
Sauer, M., 148
Sawazaki, T., 167
Scardamaglia, M., 156
Schäfer, S., 148
Schönenberger, C., 62, 65
Schöppler, F., 150
Scharfenberg, L., 149
Scherubl, Z., 50
Scheuschner, N., 89, 110
Schilling, D., 150
Schirowski, M., 150
Schlögl, R., 15, 84
Schneider, B., 134
Schoenhense, G., 47
Schreiner, P. R., 107
Schulte, K., 148
Schumann, E., 165
Schuppler, S., 47
Schuster, J., 58
Schwarz, S., 151
Schweiger, M., 111
Seifert, G., 99
Seifert, M., 44
Index

Seifert, P., 151
Senkovskiy, B., 152
Setaro, A., 61 152
Shaffer, M., 130
Shakouri, A., 64
Shammass, I., 93
Sharma, A., 153
Shi, L., 55, 98, 146, 153
Shinohara, H., 101, 107, 147, 157, 167
Shiozawa, H., 92, 143, 148
Sich, M., 151
Siffalovic, P., 45
Silva, C. H. B., 154
Simon, F., 46, 102, 154
Singh, V., 134
Siregar, S., 120
Skákalová, V., 86, 155
Skolnick, M. S., 151
Smatko, V., 45
Smet, J., 155
Smirnova, T. E., 98
Smith, J. M., 151
Soldatov, A. V., 41
Soszyński, M., 85
Späth, F., 150
Spanier, J. E., 101
Staňová, O. V., 163, 164
Staiger, M., 110
Stampfer, C., 53, 89, 100, 137, 140
Starczewska, O., 144
Steele, G., 134
Stegmaier, A., 109
Stobiński, L., 85
Suena, K., 35, 153
Summerfield, A., 51
Susi, T., 155
Susiaev, V., 98
Suzuki, T., 68
Szabó, T., 156
Szegetes, Z., 67
Szekeres, G. P., 67
Tóth, T., 156
Tagmatachis, N., 151
Takenobu, T., 155
Taki, Y., 69
Talyzin, A., 93, 157
Tanaka, H., 66
Tanaka, T., 17
Taniguchi, T., 52, 53, 94, 137, 140
Tanoue, K., 69
Tartakovskii, A. I., 52, 151
Taylor, H. K., 64
Taylor, J. R., 84
Teich, D., 99
Temperini, M. L. A., 154
Tenne, R., 61, 99
Terrés, B., 89, 100
Terrones, M., 46
Thendie, B., 157
Thissen, N., 153
Tishkova, V., 40
Tokumoto, M., 66
Ton-That, C., 91
Tornatzky, H., 110
Torre, I., 96
Torrisi, F., 84
Trichet, A. A. P., 151
Tsioutios, I., 63
Tsuzuki, M., 47
Tune, D., 158
Turchanin, A., 94
Turchinovich, D., 64
Tyborski, C., 111
Tzalenchuk, A., 37
Vajda, K., 158
Valeš, V., 159, 161
Vanko, G., 87
Varey, S., 162
Varga, E., 67
Varga, M., 145, 160
Vecera, P., 102, 160
Vega-Diaz, S., 46
Vejpravová, J., 159, 161
Verhagen, T., 159, 161
Vernickel, A., 103

188