2D Materials - Exciting Flatlands

WS 2021/2022, Ursula Wurstbauer (https://www.uni-muenster.de/Physik.PI/Wurstbauer/teaching/teaching.html)

Dear All,

given on the current pandemic situation we plan the master course *2D materials* in the winter term 2021/22 as onsite event (rules apply as given by the university that are currently the "3G rules"). In addition, we will open a Zoom session in order that you can actively follow the lecture online in case you cannot participate onsite. For onsite participation the current Corona regulations of university, department and government apply – this means currently the "3G rules". You will find detailed information on content and organizational issues below.

Looking forward to see many of you either onsite and or online to discuss the exciting physics of 2D materials.

Best regards,
Ursula Wurstbauer

Basic facts:

- Thursdays: 14:00-15:30, first lecture on 14. October
- Lecture Hall HS3
- 2 SWS
- Language: English
- Active participation via quiz, weekly groups works during the lecture and discussions;
- Lab visit and additional paper discussion on a volunteering basis is planned;
- Slides will be provided prior to lecture; lecture notes after the lecture via learnweb
- On-site lecture with option to participate via Zoom in parallel – priority will be given onsite participants (access information in learnweb)
- Materials: lecture slides will be provided before the lecture on learnweb pages of the course; lecture notes to each lecture after the lecture;
- Learnweb course: 2M-EF-2021_2 (please request key for enrollment at lecturer via email or during lecture)
- Literature: Research related literature will be provided in the lecture; in addition, I recommend the following lecture books as reminder and to strengthen your knolwege in solid state physics:
    - Rudolf Gross und Achim Marx, Festkörperphysik De Gruyter Oldenbourg, 2014 doi:10.1524/9783110358704 (sorry, only in German language)
    - Peter YU, Manuel Cardona, Fundamentals of Semiconductors, Springer Berlin, 2016, ISBN 978-3-642-00710-1 (excellent book, but I recommend to us it together with a standard solid-state textbook)
        - *Both books are available as e-book at the WWU library*

Content:

This module provides a detailed overview on a fascinating new class of solid-state materials and a fast-growing research area: two-dimensional (2D) materials that are truly two-dimensional solids with a thickness of about 1 nm. Within a layer there is strong covalent bonding between atoms and weak van-der Waals coupling between adjacent layers. Nevertheless, the properties of 2D solids strongly depends on the number of layers and interaction with environment/substrate. Depending on the chemical compositions, those materials exhibit fascinating properties making them very promising for electronic, opto-electronic, spin- and valleytronics applications, but also for solar and (photo-)electrochemical energy conversion and for the realization of quantum technologies. In this lecture, the following aspects will be covered:

- Overview and introduction to the field and different classes of 2D (quantum) materials
- Selected 2D materials (e.g. graphene, 2D semiconductors, 2D magnets, half-van der Waals materials) and their potential for applications in the areas of:
    - Electronics and optoelectronics
    - Sensing, biomedical and catalysis

    - Quantum applications
- Nanofabrication and preparation methods of 2D Materials
- Nanoanalytical methods to study 2D Materials
- Focus on light matter interaction in 2D materials including
    - visibility contrast and microscopy methods,
    - dielectric functions by spectroscopic ellipsometry
    - excitonic properties
    - Raman spectroscopy: the phonon fingerprint
- Focus topics to introduce peculiar properties of selected materials in more detail:
    - Relativistic charge carriers and the Quantum Hall effect in graphene and its role for the new systems of units;
    - Hetero-stacks, moiré effects, Mott-Hubbard simulator and 'magic' angles;
    - Single photon emitters

Learning Outcome:

After a successful participation of the module, the student is able to:

- Understand different classes of 2D solid state (quantum) materials and to apply the classification scheme of further 2D solid state materials.
- Understand the preparation and nanofabrication methods for 2D materials and to evaluate suitable methodologies for novel materials.
- Understand and evaluate optical and structural characterization methods for 2D materials, to analyze related results in recent literature and to apply suitable methodologies for given problems related to 2D material.
- Evaluate the Raman spectra from selected 2D materials.
- Evaluate absorption, excitonic and spin properties of transition metal dichalcogenides and other 2D semiconductors;
- Understand and discuss applications of 2D materials and their heterostructures for electronic, optoelectronic, spintronics devices and in solar energy conversion as well as quantum technology;
- Remember magnetotransport phenomena such as the quantum Hall effect in graphene and transport in topological protected surface states, special role of moiré superlattices and the meaning of "magic angle" in the context of moiré superlattices;