

Atomically Thin 2D Materials: Advances and Challenges (2025)

Goal

The goal of the Course is to give the students an **overview of the 2D material research**, in particular covering the expertise here at Chalmers. The course will have a broad spectrum, including the five focus areas of the Graphene Center (fundamentals, electronics, composites, energy, and bio-applications). The course will be given on the Chalmers campus (MC2 seminar room) or via Zoom for some lecturers.

Structure

The course will take place in the **third study period (22 January – 19 March 2025)** and will consist of **16 lectures** from teachers covering different areas of fundamentals and applications of 2D materials. At the end of the course, students will present one seminal paper on 2D materials.

A. 2D MATERIAL MOTIVATION

1. Introduction (Saroj Dash) [22 January 10-12, Room MC2-A820 Fasrummet]: learning outcomes, organization, introduction in 2D materials and related van der Waals heterostructures

B. 2D MATERIAL CHARACTERIZATION

2. Optics and non-equilibrium dynamics (Ermin Malic/Joshua Thompson: online Zoom lecture) [24 January 10-12, Room MC2-A820 Fasrummet]: Brief introduction to theoretical concepts, optical spectra (absorption, photoluminescence, pump-probe), electron-electron, electron-phonon, electron-photon interaction, excitons.

3. Optical spectroscopy (Timur Shegai) [29 January 10-12, Room MC2-A820 Fasrummet]: Optical spectra of transition metal dichalcogenides (TMDs) and heterostructures, photoluminescence, trions, valley polarization.

4. Transport properties theory (Mikael Fogelström: online Zoom lecture) [31 January 10-12, Room MC2-A820 Fasrummet]: Green's function formalism for conductivity, quantum Hall effect.

5. Transport properties experiment (Samuel Lara Avila) [05 February 10-12, Room MC2-A820 Fasrummet]: Quantum transport in epitaxial graphene mono- and bilayers.

6. Charge, Spin and Quantum transport (Saroj Dash) [07 February 10-12, Room MC2-A820 Fasrummet]: Electronic charge, spin and quantum transport in 2D quantum materials and twisted van der Waals heterostructures.

7. Electron microscopy (Andrew Yankovich) [12 February 10-12, Room MC2-A820 Fasrummet]: Advanced electron microscopy for characterizing 2D material.

C. 2D MATERIAL GROWTH

8. Growth of 2D materials (Avgust Yurgens) [14 February 10-12, Room MC2-A820 Fasrummet]: CVD methods for growing graphene and other 2D materials, qualitative strategies for obtaining large area single crystalline 2D materials

9. Chemistry of 2D materials (Xiaoyan Zhang) [19 February 10-12, Room MC2-A820 Fasrummet]: Chemical functionalization of 2D materials, potential applications of chemically functionalized/modified 2D materials.

D. 2D MATERIAL APPLICATIONS

10. Electronics (Andrei Vorobiev) [21 February 10-12, Room MC2-A820 Fasrummet]: High-frequency electronics, field effect transistors, fabrication techniques, novel device concepts based on 2D materials

11. Thermal management (Johan Liu) [26 February 10-12, Room MC2-A820 Fasrummet]: basic theory for thermal transport, 2D materials development for thermal management, functionalization of graphene to increase heat spreading performances, thermal characterization, current and future applications

12. Biomedical applications (Ivan Mijakovic) [28 February 10-12, Room MC2-A820 Fasrummet]: medical diagnostics, fighting bacterial infections and applications in bio-economy (sustainable bio-production), physical interactions of graphene with living cells.

13. 2D composites for multi-functional applications (Zhenyuan Xia) [05 March 10-12, Room MC2-A820 Fasrummet]: How 2D sheets shall be used to create new “sandwich” composite materials and 3-dimensional foams for aerospace, automotive, energy storage and environmental applications

14. 2D Quantum Materials based devices (Saroj Dash) - [07 March 10-12, Room MC2-A820 Fasrummet]: 2D quantum materials and twisted van der Waals heterostructure based devices for electronic, spintronic and quantum technologies.

15. SIO Graphene lecture (Johan Ek Weis) [12 March 10-12, Room MC2-A820 Fasrummet]: The Swedish 2D material ecosystem. The current status from an industrial perspective.

16. Guest Lecture/Seminar on 2D materials from Academia/Industry [14 March, 10-12, Room MC2-A820 Fasrummet]

E. 2D MATERIAL BREAKTHROUGH PAPER PRESENTATION

17. Student presentations [19 March, 10-12, Room MC2-A820 Fasrummet]
Teachers provide suggestions for seminal papers, and each student must pick one with the condition that there is no large overlap with their own PhD thesis.