

OPERA COST Action Training School 2025

Applications and Characterization of Epitaxial Materials



4th OPERA COST Action Training School (hybrid event)
Applications and Characterization of Epitaxial Materials

For on-site participants at
Faculty of Science (Kotlářská Campus)
Masaryk University
Brno, Czech Republic

with technical session at
CEITEC, Brno University of Technology

Deadline for registration: 30th April 2025

No attendance fee

3rd to 6th June 2025

Chair: Lenka Zajíčková
E-mail: lenkaz@physics.muni.cz
<https://cost-opera.eu/>



Funded by
the European Union



MUNI
FACULTY
OF SCIENCE



CEITEC



BRNO
UNIVERSITY
OF TECHNOLOGY

General Information

About Training School

Aimed primarily at young researchers, specifically PhD students and early postdoctoral researchers, the courses will focus on the fundamentals of deposition and characterization methods and will also demonstrate the advanced applications of epitaxial materials. The Training School is organized within the COST Action OPERA, see <https://cost-opera.eu/>

Local Organizers

Chair

Lenka Zajíčková

Secretary

Kateřina Polášková

Local Organizing Committee

Martina Janůšová

Nima Bolouki

Laura Búšová

Venue

Lectures for on-site participants

- Faculty of Science (SCI), Masaryk University (MUNI), Kotlářská 2 (Kotlářská Campus), Brno; GPS coordinates 49.2047261N, 16.5968178E

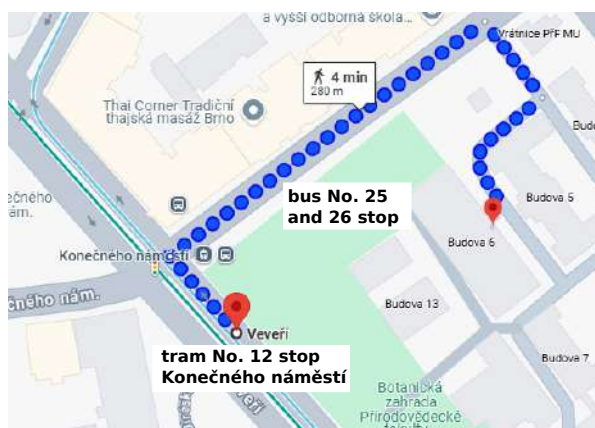
Technical sessions

- Department of Condensed Matter Physics, SCI MUNI, Kotlářská 2 (Kotlářská Campus), Brno; GPS coordinates 49.2047261N, 16.5968178E
- CEITEC, Brno University of Technology, Purkyňova 123, Brno; GPS coordinates 49.2331798N, 16.5747753E
- Czech Metrology Institute, Okružní 31, Brno; GPS coordinates 49.2342879N, 16.6228661E

For location details, see Daily Schedule.

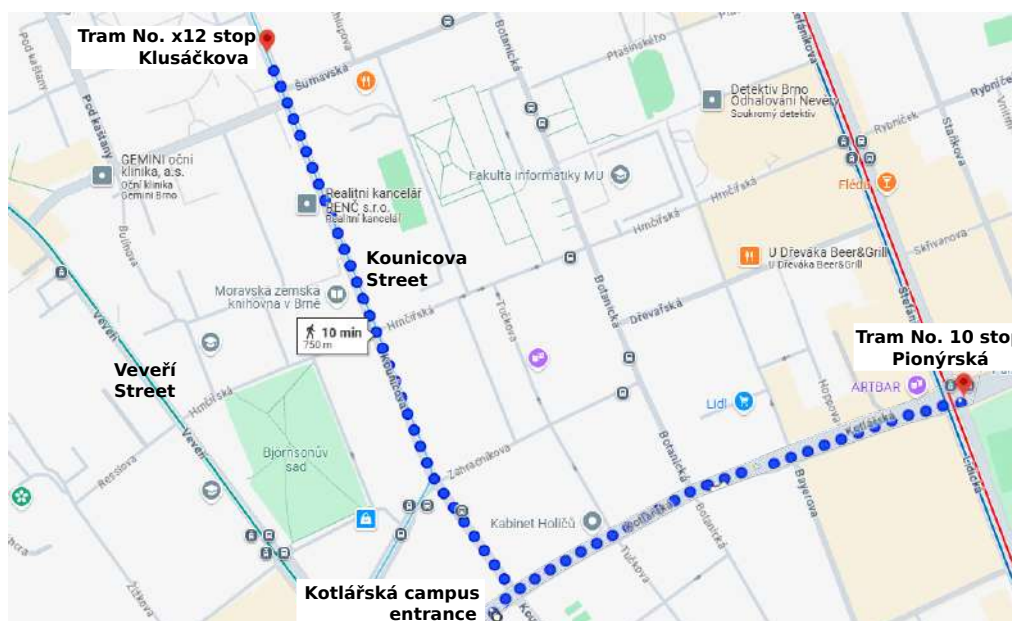
Transport in Brno

To reach the Kotlářská campus (Kotlářská 2) from the Brno central station (Hlavní nádraží, in the trams called out as Main train station) take tram No. 12, which has Rakovecká as its terminus. Get off at the stop Konečného náměstí, the nearest tram station:



Some technical sessions will be held at CEITEC, Brno University of Technology (Purkyňova 123), and Czech Metrology Institute, CMI (Okružní 31). A collective transfer from the Kotlářská campus using public transport will be organized. To go on your own, follow these instructions.

To get to CEITEC, take tram No. x12 from the stop Klusáčkova or tram No. 10 from Pionýrská and get off at their terminus, Technologický Park. Both stops are about the same walking distance from Kotlářská. However, to get to the stop Klusáčkova, you might need to take Veveří Street as Kounicova Street might be close to all pedestrians:



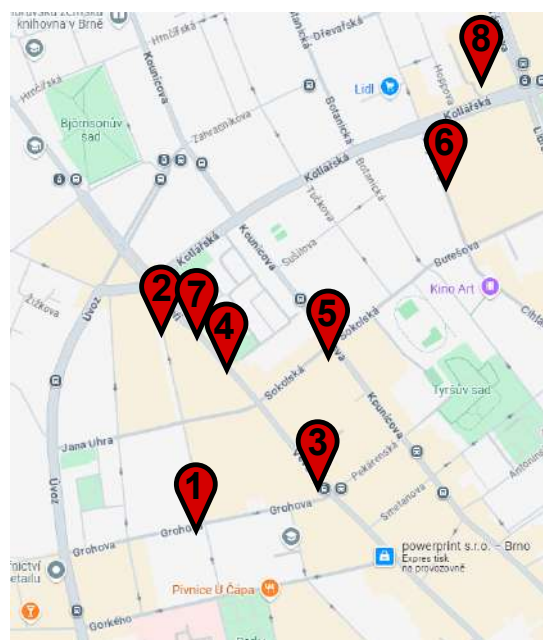
To get to CMI, take the trolleybus No. 25 (Terminus Jírova) from the bus stop Konečného náměstí, which is on the same street as the entrance to Kotlářská campus, to the Stop Lesnická. Switch to the bus No. 46 and get off at its terminus, Haškova. Alternatively, take the trolleybus No. 26 to Štefánikova čtvrť, which is its terminus stop. There, switch to bus No. 57 or No. 46 and get off at their terminus, Haškova. There are other ways to solve the transfer from the trolleybuses No. 25 and 26 to the buses No. 46 and 57. You can find them, and all other Brno public transport connections, on the <https://idos.cz/en/idsjmk/spojeni/> webpage.

Lunch break

In Czechia, most restaurants offer a lunch menu (in Czech, 'polední menu' or 'denní menu') between circa 11 am to 2 pm on working days. It is composed of a few mass-cooked meals taken from the larger restaurant menu and changes daily. The prices are quite affordable, and it is a highly recommended option for the participants.

Many restaurants preparing Czech and international cuisine are situated in Veverčí and adjacent streets. For inspiration, see the organizer suggestions:

- 1) Hospůdka u Bosé Nohy (Czech cuisine)
- 2) Restaurace u Ričího (Mix of Czech and international)
- 3) Restaurace Stavba (Mix of Czech and international)
- 4) The Immigrant Pub (Burgers)
- 5) La Strada restaurant & pizzeria (Italian)
- 6) Vietnamská restaurace HOA MAI (Vietnamese)
- 7) Everest Restaurant (Nepalese)
- 8) Padagali (Indian)



Alternatively, the participants can have lunch in a university canteen in building 4 of the Kotlářská campus; see map in Daily schedule. However, because the visiting persons are not available for a discount, the prices are close to those of a restaurant lunch menu.

Daily Schedule

Tuesday, June 3

Time	Activity	Location
11:00–12:30	Registration	SCI/06
12:30–13:00	Opening of Training School (Yamina Andre / Lenka Zajíčková)	SCI/06/F1
13:00–14:30	Principles of Epitaxial Growth and Epitaxy from Molecular Beams (MBE) (Eduard Hulicius)	SCI/06/F1
14:30–15:15	Coffee break	SCI/09
15:15–16:30	Scaling Up: SiC Epitaxy for Industrial Production (Tomáš Novák)	SCI/06/F1
16:30–17:45	Pulsed Laser Deposition: Principles and Applications (Adam Dubroka)	SCI/06/F1

Wednesday, June 4

Time	Activity	Location
08:30–10:00	Metalorganic Vapour Phase Epitaxy of Nitrides and III-V Nanoheterostructures (Alice Hospodková)	SCI/06/F1
10:00–11:30	X-ray Structural Characterization of Epitaxial Materials (Ondřej Čaha)	SCI/06/F1
11:30–13:30	Lunch break + individual transport to CEITEC	–
13:30–14:30	Excursion to CEITEC Nanotechnology Labs	CEITEC/C
14:30–17:00	Hands-on: Deposition and Characterization Methods (Viktor Danchuk, Adam Dubroka, Marek Eliáš, Daniel Franta)	CEITEC/C
17:00–19:30	Coffee break + poster session	CEITEC/S

Thursday, June 5

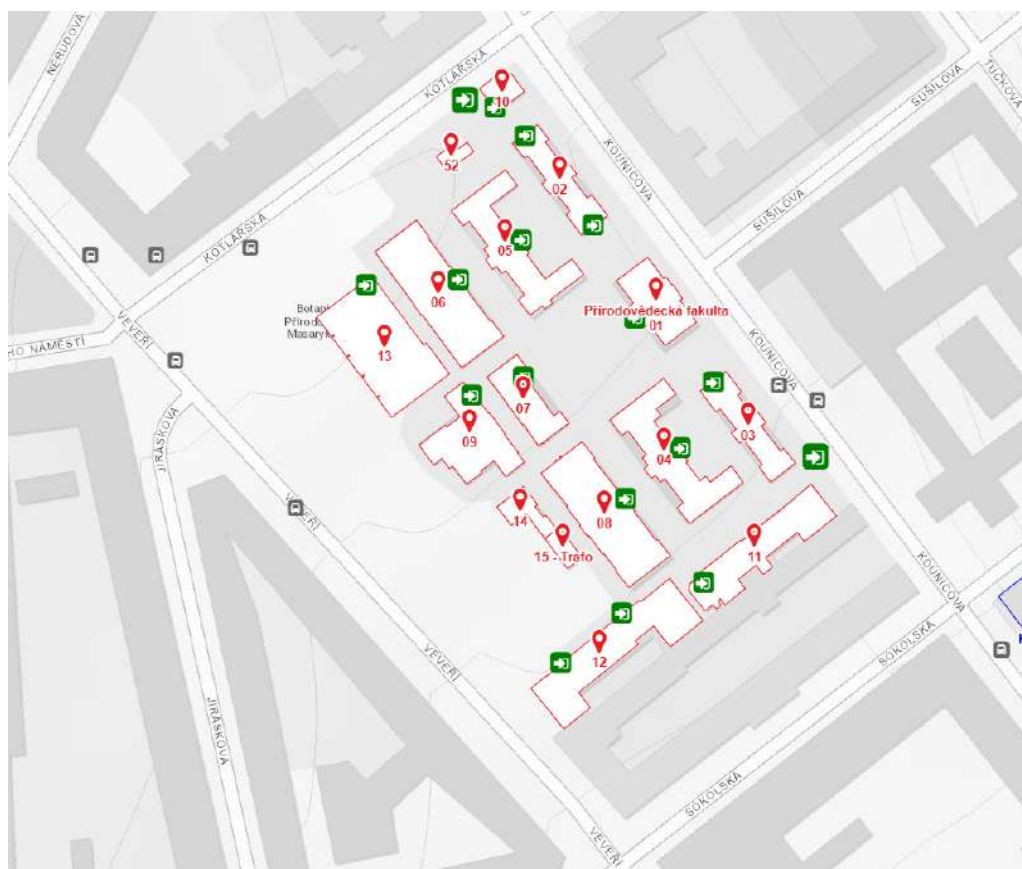
Time	Activity	Location
09:00–10:00	Fabrication and Characterization of Magnetic Nanowires and Nanotubes (Michal Staňo)	SCI/06/F1
10:00–12:30	Hands-on: Atomic Force Microscopy Data Analyses (David Nečas)/ Hands-on: Semiconductor Device Technology (Petr Mikulík)	SCI/06/F1 SCI/09
12:30–14:00	Lunch break	–
14:00–16:30	Hands-on: Atomic Force Microscopy Data Analyses (David Nečas)/ Hands-on: Semiconductor Device Technology (Petr Mikulík)	SCI/06/F1 SCI/09
16:30–17:00	Coffee break	SCI/09
17:00–18:00	CVD of Diamond and Its Quantum Computing Applications (Miloš Nesládek)	SCI/06/F1

Friday, June 6

Time	Activity	Location
08:30–09:45	Non-destructive Characterization of Crystalline Defects using Diffraction Techniques in Scanning Electron Microscopes (Martin Čalkovský)	SCI/06/F1
09:45–11:15	Advanced Scanning Probe Microscopy (Petr Klapetek)	SCI/06/F1
11:15–13:30	Lunch break + transport to Czech Metrology Institute	–
13:30–14:30	Excursion to Czech Metrology Institute Labs (CMI)	CMI
14:30–16:30	Hands-on: Atomic Force Microscopy (Petr Klapetek)	CMI

Locations

- **SCI/06:** SCI MUNI, Kotlářská 2, pavilion 6, 1st floor, in front of room F1
- **SCI/06/F1:** SCI MUNI, Kotlářská 2, pavilion 6, 1st floor, lecture room F1
- **SCI/09:** SCI MUNI, Kotlářská 2, pavilion 9
- **CEITEC/C:** CEITEC BUT, Purkyňova 123, building C, 2nd floor, CF Nano labs
- **CEITEC/S:** CEITEC BUT, Purkyňova 123, building S, 1st floor
- **CMI:** Czech Metrology Institute, Okružní 31

Map of Kotlářská campus (SCI MUNI)

Abstracts of Lectures and Hands-on Sessions

Tuesday, June 3

13:00–14:30 Principles of Epitaxial Growth and Epitaxy from Molecular Beams (MBE)

Eduard Hulicius – *Institute of Physics of the Czech Academy of Sciences, Prague, Czechia*
hulicius@fzu.cz

In this lecture I will introduce the principle of epitaxial crystal growth, its advantages and disadvantages and the reasons for its introduction in semiconductor research and industry. I will briefly describe the different types of epitaxial growth (SSE, LPE, VPE). I will compare the properties and parameters of epitaxial layers compared to single crystals prepared by melt growth.

I will describe in more detail the principle and parameters of epitaxy from molecular beams – MBE. I will focus on the specific vacuum in-situ measurement method RHEED (Reflection high-energy electron diffraction).

15:15–16:30 Scaling Up: SiC Epitaxy for Industrial Production

Tomáš Novák – *Onsemi, Rožnov pod Radhoštěm, Czechia*
Tomas.Novak@onsemi.com

This lecture focuses on the epitaxy process of silicon carbide (SiC), a key material for manufacturing efficient semiconductor devices used in demanding power switching applications. We will introduce the basic principles and challenges of SiC epitaxy in the industrial environment, along with the existing hot-wall chemical vapor deposition (CVD) epitaxial reactors. An important aspect in the mass-scale production is the characterization and control of critical parameters of SiC epitaxial layers: thickness, doping, and defectivity. Established characterization methods will be presented, and recent technological advances will be highlighted. Finally, we will summarize the challenges for the near future.

16:30–17:45 Pulsed Laser Deposition: Principles and Applications

Adam Dubroka – *Department of Condensed Matter Physics, Masaryk University, Brno, Czechia*
dubroka@physics.muni.cz

In the talk, the principle of pulsed laser deposition will be first introduced, and some aspects of deposition conditions will be discussed. Examples from epitaxial growth of several transition metal oxide thin films will be given, like $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$, LaCoO_3 , and $\text{La}_{0.3}\text{Sr}_{0.7}\text{CoO}_3$. Reflection of low energy electron diffraction (RHEED) will be introduced. The application of RHEED on the growth of $\text{LaFeO}_3/\text{SrTiO}_3$ superlattices will be demonstrated.

Wednesday, June 4**08:30–10:00 Metalorganic Vapour Phase Epitaxy of Nitrides and III-V Nano-heterostructures****Alice Hospodková** – *Institute of Physics ASCR, Prague, Czechia**hospodko@fzu.cz*

MOVPE is the most widely used industrial epitaxy technique for nitride semiconductors. The lecture will briefly cover the basics of MOVPE (MOVPE principle and equipment design, types of reactors, their advantages and disadvantages, different types of precursors and when to use them). In-situ growth monitoring will be explained, touching on the main techniques currently in use such as reflectance, wafer curvature, true temperature measurement, reflectance anisotropy. A short history of GaN technology will be mentioned with challenges that have been solved and appreciated by Nobel Prize. The way to grow nanoheterostructures (quantum wells, quantum dots, nanowires, core-shell structures) will be explained.

10:00–11:30 X-ray Structural Characterization of Epitaxial Materials**Ondřej Caha** – *Department of Condensed Matter Physics, Masaryk University, Brno, Czechia**caha@physics.muni.cz*

This lecture will present structural characterization of epitaxial films using x-ray scattering methods. We will present several scattering techniques: x-ray reflectivity, x-ray diffraction, especially reciprocal space mapping.

The x-ray reflectivity serves mostly as a tool for film thickness and roughness metrology. For x-ray diffraction we will focus on the procedures to determine lattice parameters and strain in the epitaxial layers. We will also present effects of misfit and threading dislocations in the relaxed epitaxial layers.

Finally, we will briefly present x-ray absorption spectroscopy as a tool for determination of dopant atom position.

14:30–17:00 Hands-on: Deposition and Characterization Methods**Viktor Danchuk¹, Adam Dubroka², Marek Eliáš¹, Daniel Franta³** –¹*Central European Institute of Technology, Brno, Czechia*²*Department of Condensed Matter Physics, Masaryk University, Brno, Czechia*³*Optics for Thin films and Solid Surfaces, Masaryk University, Brno, Czechia*¹*danchuk@vut.cz*, ²*dubroka@physics.muni.cz*, ¹*marek.elias@ceitec.vutbr.cz*, ³*franta@physics.muni.cz*

Location: CEITEC Nano C 1.38

Dr. Viktor Danchuk

NanoSAM Demonstration Experiment

Sample: Prototype of the SEM cathode (Tungsten Tip covered with epoxy) on the Stainless-steel sample holder.

Progress of the demonstration experiment:

1. Transfer the sample from the Preparation Chamber to the Main Chamber. (5 min)
2. Mount the sample on the sample Stage. (5 min)
3. HQ (High Quality) SEM image construction. (15 min)
4. Analytical SEM image construction and sample tilting. (15 min.)

5. AES spectra:
 - (a) Full spectra Epoxy spot (15 min)
 - (b) Full spectra W spot (15 min)
6. SAM image at Low resolution to demonstrate the principle of the SAM image construction (15 min)
7. Presentation of the SEM cathode SAM images previously captured at high resolution. (10 min)

The estimated duration of the NanoSAM Demonstration Experiment is 95 min.

The number of participants is no more than four people.

Thursday, June 5**09:00–10:00 Fabrication and Characterization of Magnetic Nanowires and Nanotubes****Michal Staňo** – *Central European Institute of Technology (CEITEC), Brno, Czechia**Michal.Stano@ceitec.vutbr.cz*

In this talk, we will discuss methods for the preparation and investigation of magnetic (mostly metallic) nanowires (NWs) [1, 2] and nanotubes (NTs) [3].

Epitaxial magnetic NWs can be prepared by molecular beam epitaxy and other vapour deposition techniques yielding high crystal quality [1]. However, these methods offer limited control over nanostructure geometry (primarily diameter), restrict the range of available materials, and some semiconductor-based NWs are (ferro)magnetic only at low temperatures. Another approach is to begin with epitaxial magnetic thin films (produced, for example, by magnetron sputtering or pulsed laser deposition) and then pattern them using lithography (typically ion etching). This approach becomes increasingly challenging for smaller wire diameters and is not well-suited for vertical, high-aspect-ratio structures.

Here, we will focus mainly on template-based synthesis combined with chemical methods, which offer better control over geometry (diameter); nanostructure spacing/density in ordered arrays). In particular, electroplating allows epitaxial deposition of thin films from liquid solution near room temperature [4, 5]. While epitaxy is uncommon for NWs and NTs, electroplating can yield single-crystalline NWs and NTs even when starting from a polycrystalline substrate. Magnetic nanotubes are often fabricated via electroless plating or atomic layer deposition, which do not require an electrically conductive substrate, provide more conformal coatings, enable control over nanotube shell thickness, and are suitable for multilayered or core–shell structures [3].

We will also briefly present examples of magnetic characterization of NWs and NTs, focusing on individual objects. This includes electrical transport measurements (magnetoresistance) and magnetic imaging using X-ray, electron, and scanning probe microscopies.

[1] Vázquez (Ed.), *Magnetic nano- and microwires: design, synthesis, properties and applications* (1st edition), Woodhead Publishing (2015).

[2] Vázquez (Ed.), *Magnetic nano- and microwires: design, synthesis, properties and applications* (2nd edition), Woodhead Publishing (2020).

[3] Staňo & Fruchart, *Magnetic nanowires and nanotubes*, in *Handbook of magnetic materials* (Vol. 27, pp. 155-267), Elsevier (2018).

[4] Guo et al., *Electrochemical epitaxy of nanostructures*, *Nano Trends* 4, 100024 (2023).

[5] Switzer & Banik, *Epitaxial Electrodeposition of Ordered Inorganic Materials*, *Accounts of Chemical Research* 56(13), 1710-1719 (2023).

10:00–12:30 & 14:00–16:30 Hands-on: Atomic Force Microscopy Data Analyses / Hands-on: Semiconductor Device Technology**David Nečas**¹ / **Petr Mikulík**² – ¹*Central European Institute of Technology, Brno, Czechia*²*Department of Condensed Matter Physics, Masaryk University, Brno, Czechia*¹*david.necas@ceitec.vutbr.cz*, ²*mikulik@physics.muni.cz*

Atomic Force Microscopy Data Analyses: Scanning Probe Microscopy is not just a technique for obtaining pretty pictures of nanostructures. However, quantitative results require understanding what we measure and what to do with the acquired data. This hands on will consist of two parts. The first will be a brief talk with interactive elements, which will highlight the importance of measuring the right thing using several real-world cases. The main part will be hands-on data preprocessing and evaluation

in Gwyddion using provided data files. It will include basics tasks as well as some more challenging examples. Both parts will primarily focus on topographical data as the most common measurement type.

Semiconductor Device Technology: The workshop will run in the clean room facility for semiconductor technology (class ISO5) at the Department of Condensed Matter Physics, which we run in collaboration with the onsemi company. The participants will experience chip production techniques on 4" silicon wafers, such as optical lithography and etching on wafers coated with dielectric and metallic layers.

17:00–18:00 CVD of diamond and its quantum computing applications

Miloš Nesládek – *Institute for Materials Research, Hasselt University, imec division, imec vzw, Wetenschapspark 1, B 3591 Hasselt, Belgium*
milos.nesladek@uhasselt.be

Diamond, as a material for quantum bits, has seen rising interest from scientific and applied communities over the past two decades. It is being explored as a promising quantum material due to its potential as a resource to quantum coherence and entanglement in real-life devices.

In this talk, we review the current status of chemical vapor deposition (CVD) diamond technologies and the bottlenecks associated with using this material in quantum applications. In particular, we will discuss the fabrication of single nitrogen-vacancy (NV) qubits, as well as NV ensembles, which are in high demand for quantum sensing.

The main workhorse for quantum spin state readout is Optical Detection of Magnetic Resonance (ODMR). In parallel, we have initiated a semiconductor-type readout approach called Photoelectric Detection of Magnetic Resonance (PDMR), which is being explored for applications and scale-up in both quantum sensing and quantum computing. In this talk, we will review this principle and discuss the fidelity of qubit quantum states, a key parameter for harnessing scalable dipole-dipole coupled quantum devices as quantum registers.

In the final part of the talk, we will discuss other applications in space technologies as well as sensing in biological environments.

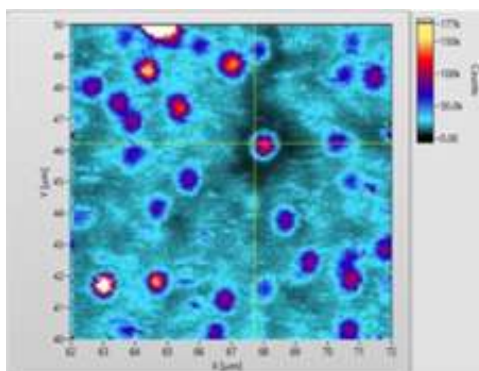


Figure: Photoluminescence from single NV centres, after implantation to a depth of 30 nm to quantum grade CVD diamond. The NV centres are generated by recombining the nitrogen atoms with vacancies.

References:

1. Bourgeois E., et al, 6, 8577, Nature Comm. (2015)
2. Siyushev P., Nesládek M., et al Science, 363,728-731, (2019) DOI: 10.1126/science.aav2789,
3. M. Gulka, D. Wirtitsch, et al, Nature Comm., 12, 4421 (2021), doi.org/10.6084/m9.figshare.14748138.v1.

Friday, June 6**08:30–09:45 Non-destructive Characterization of Crystalline Defects using Diffraction Techniques in Scanning Electron Microscopes**

Martin Čalkovský – *Thermofisher, Brno, Czechia*
martin.calkovsky@thermofisher.com

The requirements for crystalline defect analysis have increased with the introduction of compound semiconductors in electronic applications. To maintain device yield at profitable levels, it is essential to characterize crystalline defects during epitaxial growth optimization and to control defectivity in the fabrication process. Specifically, threading dislocations (TDs) in GaN negatively impact the performance of optoelectronic devices by acting as centers of non-radiative recombination, which leads to current leakage and reduced device performance and lifetime. Given the importance of these issues, the semiconductor industry needs a quick and comprehensive method to investigate the presence and types of TDs over large areas ($>100 \mu\text{m}^2$). To address this need, we propose a unique, semi-automated, non-destructive, high-throughput, and quantitative crystalline defect metrology system for GaN.

Our approach utilizes electron channeling contrast imaging (ECCI), a Scanning Electron Microscopy technique that visualizes, classifies, and quantifies TDs based on electron diffraction. TDs are visualized by orienting the specimen under specific channeling conditions and detecting backscattered electrons using appropriate imaging parameters. Different diffraction conditions allow for the determination of dislocation types (a-, c-, a+c type). AI-assisted identification and quantification of TDs enhance efficiency, while denoising techniques on ECCI datasets enable faster data acquisition compared to current defect metrology techniques in the semiconductor industry.

09:45–11:15 Advanced Scanning Probe Microscopy

Petr Klapetek – *Czech Metrology Institute, Brno, Czechia*
pklapetek@cmi.cz

Scanning Probe Microscopy is a widely used tool for characterisation of properties of solids, offering almost no sample preparation and wide range of physical properties that can be addressed. This talk will introduce different SPM methods that can be used for measurements of local dimensional, mechanical, electrical and thermal properties, focusing on quantitative aspects of these methods, i.e. in measuring not only images, but obtaining numbers with known measurement uncertainty. Key methodology aspects and reference samples needed for quantitative measurements will be introduced and demonstrated on real world examples.

14:30–16:30 Hands-on: Atomic Force Microscopy

Petr Klapetek – *Czech Metrology Institute, Brno, Czechia*
pklapetek@cmi.cz

Poster session

Wednesday, June 4

17:00-19:30

In-Situ SEM Observation of the Graphene Layers Etching by O₂, H₂, and CO

Hossein MIRDAMADI¹, Michal DYMÁČEK², Tomáš ŠIKOLA^{1,2}, Petr BÁBOR^{1,2}, Miroslav KOLÍBAL^{1,2}

¹CEITEC BUT, Brno University of Technology, Purkyňova 123, 612 00 Brno, Czech Republic

²Institute of Physical Engineering, Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic

sayed.hossein.mirdamadi.khouzani@ceitec.vutbr.cz

The electronic properties of graphene are significantly influenced by the shape and size of its layers. Additionally, it is possible to control the electronic states in graphene-based applications by interacting with adsorbed species and by intercalating atoms and molecules between graphene and the substrate, known as the van der Waals gap. Understanding the processes leading to intercalation or adsorption is crucial, though it is a complex issue. A practical approach for studying these processes is in-situ microscopy, which allows for monitoring and evaluating the dynamics during various species' etching of graphene stacks [1]. This contribution presents a systematic study assessing the interaction of oxygen, hydrogen, and carbon monoxide molecules (isothermal etching) with the underlying graphene layer(s). This experiment provides insights into the interaction strength of both graphene-graphene and graphene-substrate interfaces. Initially, a graphene layer was synthesized on a Pt wire at elevated temperature using ethylene (C₂H₄) gas as a precursor within the ultrahigh vacuum (UHV) scanning electron microscope (SEM) chamber. To achieve multilayer graphene in an inverted-wedding-cake configuration, the sample was cooled to different temperatures (900 °C, 950 °C, and 1000 °C) after the first layer grew, resulting in carbon segregation from the Pt substrate and the formation of multilayer graphene islands. Subsequently, the samples were exposed to O₂ or H₂ (similar to [2]) or CO to monitor the etching behaviour of the first layer and that underneath. The process of growing and etching the graphene layers will be presented in a series of movies, thanks to SEM observation during the experiment. The acquired data reveal surprising details of the intercalation process and enable the quantification of essential parameters such as diffusion length and activation energy of the relevant processes.

References

[1] Wang, Zhu-Jun, Nature Communications, 1 (2016) 13256.

[2] Wei, Wei, Science China Chemistry, 5 (2017) 656-662.

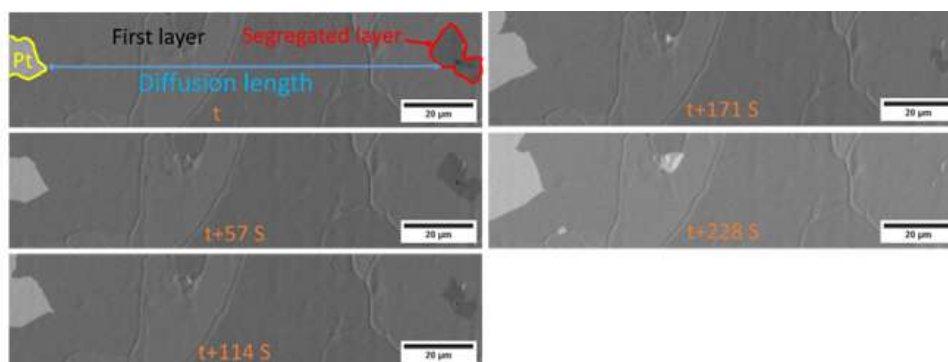


Figure: Snapshot of in-situ SEM H₂ etching of the first layer and the second layer (carbon segregation from the substrate)

Interaction graphene with atomic oxygen

V. Mikerásek^{1,2}, J. Piastek^{1,2}, O. Špaček^{1,2}, M. Bartošík^{1,2}, J. Mach^{1,2}, and T. Šíkola^{1,2}

¹Central European Institute of Technology (CEITEC), Brno University of Technology (BUT), Purkyňova 656/123, 612 00 Brno, Czech Republic

²Institute of Physical Engineering, Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic
208900@vutbr.cz

This study focuses on the modification of graphene with atomic oxygen and the control of the reaction to provide a suitable substrate for the covalent and non-covalent binding of antibodies to high-quality graphene, which is necessary for the selective sensitivity of biosensors.

The experiments used monocrystal graphene grown by CVD and transferred by a wet method with a PMMA support layer. The structural and chemical compositions were primarily analysed by Raman spectroscopy (Fig. 1) and XPS. The UHV-SEM was also used to observe the entire process in real time. Atomic oxygen was produced by high-thermal dissociation (1800 °C) on an iridium filament from molecular oxygen filled into the UHV chamber ($P_{O_2} \approx 1 \times 10^{-4} Pa$). Another approach was to apply a development device containing a high-temperature heated iridium capillary, which provides higher efficient oxygen dissociation.

Graphene was observed to react with atomic oxygen, mainly by defect growth. Prolonged exposure led to complete removal of the monolayer graphene. The increase in the number of defects was mainly at the location of the disrupted hexagonal structure in the centre and at the edges of the single crystals formed during growth.

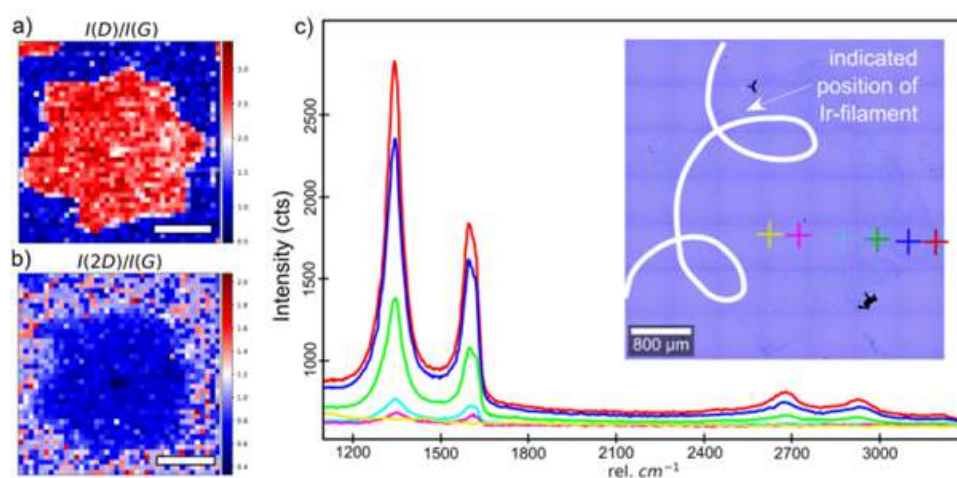


Figure 1: a-b) Spatial distribution of defects in graphene monocrystal shown by Raman spectroscopy mapping after exposure to atomic oxygen on a SiO₂/Si substrate (scale bar: 10 μm). c) Raman spectrum of graphene at varying distances from an iridium filament, serving as the atomic oxygen source.

Acknowledgement

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Molecular adsorption on support-decoupled 2D Metal-Organic Frameworks: an STM study

Dominik Hruža¹, Zdeněk Jakub¹, Jakub Planer¹, Azin Shahsavari¹, Jiří Pavelec², Jan Čechal^{1,3}

¹CEITEC – Central European Institute of Technology, Brno University of Technology, Purkyňova 123, 61200 Brno, Czech Republic

²Institute of Applied Physics, TU Wien, Wiedner Hauptst. 8-10/E134, Wien 1040, Austria

³Institute of Physical Engineering, Faculty of Mechanical Engineering, Brno University of Technology,

*Technická 2896/2, Brno, Czech Republic.
208642@vutbr.cz*

Detailed atomic-scale understanding is a crucial prerequisite for rational design of next-generation single-atom catalysts (SACs). However, the sub-angstrom precision needed for systematic studies is difficult to achieve on common SACs. We present a 2D metal-organic system with Fe-N₄ single-atom sites, where the height of individual Fe atoms is precisely modulated by the 0.4 Å corrugation of the underlying graphene/Ir(111) support. Our results indicate that sub-angstrom structural deformations have a profound effect on the adsorption properties and reactivity of SACs.

Structural and Optical Characterization of 2,3,6,7,10,11-Hexamethoxytriphenylene Thin Films on Single-Layer Graphene and Bare 6H-SiC(0001)

Devanshu Varshney^a, Mikhailo Shestopalov^b, Tomáš Krajňák^c, Jan Čechal^{c,d}, Jan Kunc^b, Jiří Novák^{a,d,*}

^a*Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic*

^b*Charles University, Faculty of Mathematics and Physics, Institute of Physics, Ke Karlovu 5, CZ-121 16, Prague 2, Czech Republic*

^c*Institute of Physical Engineering, Brno University of Technology, Brno, Technická 2896/2, 61669, Czech Republic*

^d*CEITEC – Central European Institute of Technology, Brno University of Technology, Brno, Purkyňova 123, 61200, Czech Republic
devanshu@sci.muni.cz*

In this study, we investigate the structural behavior of the triphenylene-based donor molecule 2,3,6,7,10,11-hexamethoxytriphenylene (HMTP) on graphene-organic semiconductor hybrid structures (GOSHS). The integration of graphene onto silicon carbide (SiC) substrates has emerged as an effective strategy to enhance the functionality and performance of organic semiconductor devices. Graphene, known for its exceptional electronic, mechanical, and thermal properties, provides a versatile platform for improving device efficiency. In particular, epitaxial graphene grown on SiC offers notable advantages, including high thermal stability, elevated carrier mobility, and compatibility with wafer-scale fabrication. In this work, epitaxial single-layer graphene was grown on the Si-face of 6H-SiC(0001) via thermal decomposition.

X-ray diffraction techniques, including pole figure measurements and symmetrical scans, were employed to investigate the crystallographic orientation of HMTP thin films with respect to the underlying substrates. Pole figure analysis reveals that HMTP exhibits preferential in-plane orientation on single-layer graphene, whereas a random orientation is observed on the native oxide of the 6H-SiC(0001) substrate. However, the 0002 reflection of HMTP is observed in the specular XRD scans for both substrates, showing that films share the same out-of-plane crystallographic orientation. Raman spectroscopy confirms the presence of single-layer graphene on the SiC(0001) substrates through the detection of characteristic G and 2D bands. Additionally, the surface morphology of the HMTP films on both substrates was characterized using atomic force microscopy.

Surface and Interface Engineering of Radiation- Modified NBR Composites with Nano Graphene Oxide: A Multi-Technique Characterization Approach

Rana Khankishiyeva

Laboratory of Radiation Chemistry and Technology of Polymers, Institute of Radiation Problems, Azerbaijan National Academy of Science, Baku, Azerbaijan

r.khankishiyeva@irp.science.az

This study explores the surface and interface behavior of nitrile butadiene rubber (NBR) composites reinforced with nano graphene oxide (nGO) and modified using gamma irradiation in the dose range of 0–250 kGy. A multi-technique characterization approach—comprising Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and X-ray Diffraction (XRD)—is applied to investigate structural transformations, interfacial interactions, and phase morphology. The results reveal that increasing radiation dose enhances crosslinking, nGO dispersion, and interfacial bonding, leading to improved structural organization and potential performance gains. This work contributes to the design of advanced elastomeric materials through controlled microstructural engineering.

Direct growth and application of 2D single crystals of MXenes

Pranjali Jadhao¹, Stanislav Voborný^{1,2}, Josef Polčák^{1,2}, Tomáš Šíkola^{1,2}

¹*CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno 612 00, Czech Republic*

²*Institute of Physical Engineering, Brno University of Technology, Technická 2, Brno 616 00, Czech Republic*

pranjali@vutbr.cz

Keywords: Chemical vapor deposition, Molecular beam epitaxy, Mo₂C, SEM-EDS, Nano-SAM (scanning Auger Microscopy).

This work represents a comprehensive exploration of Mo₂C MXene synthesis. We employed an advanced setup, specifically Ultra-High Vacuum Chemical Vapor Deposition (UHV-CVD) and Ultra-High Vacuum Scanning Electron Microscopy (UHV-SEM), for the direct growth of two-dimensional (2D) single crystal MXenes. Our primary objective was to gain insight into the surface properties of Mo₂C.

We utilized analytical techniques such as Scanning Electron Microscopy (SEM), and Energy-Dispersive X-ray Spectroscopy (EDS), Nano-SAM (scanning Auger Microscopy). Our observations revealed that, at elevated temperatures, copper (Cu) droplets coexisted with needle-like molybdenum (Mo) structures. However, a detailed understanding of such dynamics is still missing. Therefore, the integration of Molecular Beam Epitaxy (MBE) apparatus with a Mo electron beam cell, direct epitaxial growth of Mo₂C MXenes can be studied. Incorporating the vertical UHV e-beam evaporator enhances the method performance and provides better control over MXenes synthesis offering new possibilities and insights for future applications

MoSe[2] and WSe[2] shell morphology control via temperature optimization during two-step growth of ZnSe-based core-shell nanowires

Luize Dipane¹, Liora Kotlara¹, Viktors Vibornijs¹, Katrina Laganovska¹, Aleksejs Zolotarjovs¹, Eriks Dipans¹, Jevgenijs Gabrusenoks¹, Boris Polyakov¹, Edgars Butanovs¹

¹*Institute of Solid State Physics, University of Latvia, Kengaraga street 8, Riga, Latvia, LV-1063*

luize.dipane@cfi.lu.lv

Achieving uniform and controlled transition metal dichalcogenide (TMD) shell growth on nanowires (NWs) remains a key challenge, limiting the development of high-quality core-shell heterostructures for optoelectronic and photocatalytic applications. In this work, the fabrication of ZnSe-MoSe[2] and ZnSe-WSe[2] core-shell NWs was successfully demonstrated. ZnSe NWs were grown via the vapor-liquid-solid growth mechanism, while TMD (MoSe[2] or WSe[2]) shells were formed through a two-step process of sacrificial oxide layer deposition via magnetron sputtering followed by selenization process in a chemical vapor transport reactor. As-grown nanostructures were characterized using X-ray diffraction, transmission electron microscopy, X-ray photoelectron spectroscopy, Raman spectroscopy and photoluminescence spectroscopy. It was observed that the TMD shell morphology can be controlled through the selenization process temperature optimization, which arises due to different growth mechanisms discussed here. The studied trends could be further extended to other semiconductor NW and TMD

core-shell heterostructure growth, offering promising avenues for advanced nanoscale applications.

Solution-Based Epitaxial Growth of LSMO/BSTO Bilayers with Magnetoelectric Properties

Danica Piper¹, Jelena Vukmirović¹, Marija Milanović¹, Ivan Stijepović¹, Xuyun Guo², Damir Pajić³, Vladimir V. Srdić^{1,4}

¹University of Novi Sad, Faculty of Technology Novi Sad, Novi Sad, Serbia

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

³Department of Physics, Faculty of Sciences, University of Zagreb, Horvatovac 102a, 10000 Zagreb, Croatia

³Serbian Academy of Sciences and Arts, Belgrade, Serbia

danica.piper@uns.ac.rs

The development of multifunctional thin films with controlled electronic and magnetic properties is vital for future device applications. In this work, we investigate bilayer epitaxial thin films composed of $\text{La}_x\text{Sr}_{1-x}\text{MnO}_3$ (LSMO) and $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ (BSTO), combining ferromagnetic and ferroelectric functionalities to enable magnetoelectric coupling. The films were grown on single-crystal SrTiO_3 substrates using a solution-based spin-coating technique. LSMO was synthesized via polymer-assisted deposition with PEI and EDTA, while BSTO was prepared using a classical sol-gel route. A multi-step annealing process up to 900 °C was applied to achieve high crystallinity and structural control.

X-ray diffraction and HR-TEM confirmed epitaxial growth and good interface quality. Magnetic measurements (VSM, SQUID) verified the formation of the desired LSMO phase and successful Sr incorporation. Preliminary electrical characterization showed a clear photoresponse under laser illumination, suggesting the potential for light-tunable magnetoelectric devices.

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AlGaIn buffer layers grown on sapphire substrates

J. Batysta^{1,2*}, A. Hospodková¹, T. Hubáček¹, J. Pangrác¹, F. Hájek¹, K. Kuldová¹, F. Dominec¹, M. Slavická-Zíková¹, M. Palič^{1,2}

¹FZU - Institute of Physics, Czech Academy of Sciences, Cukrovarnická 10, 16200, Prague 6, Czech Republic

²Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 11519 Prague 1, Czech Republic

*email: batystaj@fzu.cz

Keywords: MOVPE, AlGaIn, UV LED

Growing AlGaIn directly on sapphire has been identified as a niche area of research, since most applications involving AlGaIn material can rely on a growth of binary compounds (GaIn or AlIn) as a nucleation and buffer layers. GaIn has been identified as an optimal buffer layer for most of UVA emitters, however, with increasing Al content and layer thickness of AlGaIn grown on top of GaIn, the layers become susceptible to cracking due to a tensile strain. It is therefore technically relevant to manufacture light sources down to around 340 nm of emission wavelength. The employment of AlIn as a buffer layer is beneficial for UVC and UVB range, and the utilization of AlIn in UVB up to around 310 nm of emission wavelength was published [1]. This leads to a known gap with low external quantum efficiency (EQE) in the emission region 310-340 nm, as reported in [2].

In order to enhance EQE in the region of 340 to 310 nm, we propose the process of growing high quality

AlGa_N buffer directly on sapphire substrate. This process is generally considered as very difficult, due to the different Al and Ga adatom mobility causing phase separations and the emergence of defects [3]. This contribution will discuss a series of AlGa_N buffers grown on sapphire using thin Ga_N nucleation, with concentration of Al of around 30 %. Different growth process parameters will be discussed regarding the solid-state Al: Ga ratio, surface quality with regard to the “pancake defects” [4] and threading dislocation density. These are evaluated via Raman spectroscopy, photoluminescence, scanning electron microscopy, etch pit density, and X-ray diffraction.

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MOCVD Growth and Characterization of Ga₂O₃ Thin Films on (111) Si with AlN Buffer

M. Krettová^{1*}, K. Hušková¹, M. Wosko², E. Dobročka¹, Z. Zápražný¹, I. Kozak¹, H. Chouhan¹, F. Egyenes¹, O. Pohorelec¹, M. Ťapajna¹, R. Paszkiewicz² and F. Guemann¹

¹*Slovak Academy of Sciences, Slovakia*

²*Department of Microelectronic and Nanotechnology, Faculty of Electronics, Photonics and Microsystems, University of Science and Technology, ul. Janiszewskiego 11/17, 50-372 Wrocław, Poland*
miriam.krettova@savba.sk

Ultrawide bandgap gallium oxide (Ga₂O₃) has emerged as a promising material for next-generation high-power and high-voltage semiconductor devices due to its exceptional material properties. This study investigates the heteroepitaxial growth of unintentionally-doped Ga₂O₃ thin films on industrially compatible (111) silicon substrates, aimed at enabling scalable and cost-effective device fabrication. Using a 150 nm-thick AlN buffer layer, phase-pure monoclinic β -Ga₂O₃ and predominantly orthorhombic κ -Ga₂O₃ films with minor β -phase inclusions were grown via liquid-injection metal-organic chemical vapor deposition. The structural, surface, and optical properties of the films were characterized through X-ray diffraction, atomic force microscopy, and photoluminescence spectroscopy, confirming high crystalline quality and phase-specific characteristics.

Ge-on-Si dual-band detectors for solvent recognition

Afonso de Cerdeira Oliveira

Polytechnic University of Milan, Italy

afonso.oliveira@polimi.it

Light sensing beyond the visible spectrum has always played an important role in scientific advances. By connecting two photodiodes in a back-to-back architecture, creating a dual-band detector, it is possible to sense in two different spectral regions depending on the semiconductor band gap and applied voltage bias. Those features allow such devices to operate without any mechanical or dispersive elements, acquiring spectral information at the pixel level in two different bands, data which could be reliably combined to provide information that neither band can give by itself.

Here, we resort to a Ge-on-Si dual-band detector, capable of sensing from visible and near infrared (Si photodiode) to short-wave infrared (Ge photodiode) to discriminate between different solvents.