5th FR-CZ Barrande workshop on Nanotechnologies, Photonics and Electronics

5. – 7. June 2024, Charles University, Faculty of Mathematics and Physics, Prague

CHARLES UNIVERSITY
Faculty of mathematics
and physics

INSTITUT FRANÇAIS
Prague

Abstract book

Venue

The workshop is held in a historical building of the Faculty of Mathematics and Physics, Charles University, located at Malostranské Square.

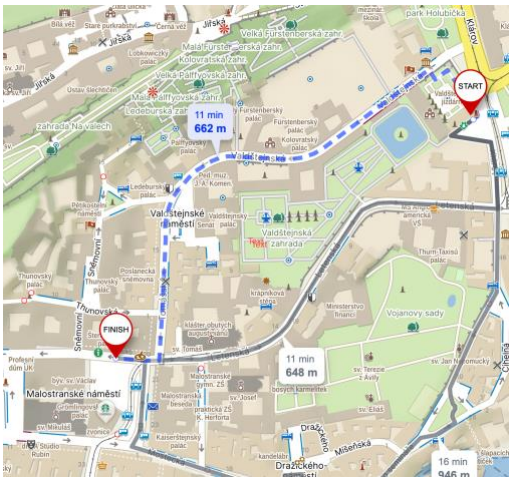
Address: Malostranské náměstí 25, 11800 Prague. There are two entrances to the building, please use the entrance on the **right side** of the square.

Directions by public transport:

Fares and Tickets: Prague public transport tickets are time-restricted and are valid for all types of transport (metro, trams, and buses). The tickets must be time-stamped at the first boarding. A single fare for 40 CZK is valid for 90 minutes and for unlimited transfers within the time period. We recommend buying the 72 hours ticket for 330 CZK, as it can cover the whole duration of the workshop. Tickets can be purchased in vending machines at metro stations and other points of sale or via the mobile app "PID lítačka" or "Citymove".

Tram: There is a tram stop named **Malostranské náměstí** located just in front of the building. You can take trams no. 12, 15, 20, 22, 23 from various places in Prague.

Metro: Metro station **Malostranská (line A - green)** is located approx. 5 minutes by walk from the building.



The workshop hall is located on the first floor. Please take the stairs on the right side after walking through the entrance and go to the **first floor, left side**. Elevators are located just next to the staircase. There will be signs with directions to the Barrande workshop. **Please note that there is another conference in the building** parallel to the Barrande workshop, situated on the right side of the first floor.

Programme at glance

Wednesday 5th June 2024

14:30	15:00	Arrival of attendants
15:00	15:30	Opening remarks
15:30	16:00	Mathias Vanwolleghem *Institute of Electronics Microelectronics and Nanotechnology* **THz photoacoustic detection of food spoilage indicators**
16:00	16:30	Christelle Kadlec *Institute of Physics of the Czech Academy of Sciences* **THz spectroscopy at FZU**
16:30	17:00	Christophe Consejo *Laboratoire Charles Coulomb (L2C), CNRS-Université de Montpellier* **Landau emission from 2D Dirac fermions in HgTe QWs**
17:00	20:00	Poster session and Welcome reception

Thursday 6th June 2024

9:00	9:30	Aurélien Manchon *Aix-Marseille Univ, CNRS, CINaM* **Theory of orbital generation, diffusion, and detection**
9:30	10:00	Vincent Repain *Matériaux et Phénomènes Quantiques, Université Paris Cité* **Vectorial magnetometry with magneto-optical spectroscopy**
10:00	10:30	Karel Výborný *Institute of Physics of the Czech Academy of Sciences* **Anomalous spectroscopical and DC transport effects in magnetically ordered systems**
10:30	10:45	Coffee break
10:45	11:15	Vojtěch Uhlíř *CEITEC BUT, Brno University of Technology* **Ultrafast Control and Dynamics of Metamagnetic Transitions in FeRh Nanostructures**
11:15	11:45	Jan Zemen *Czech Technical University in Prague, Faculty of Electrical Engineering* **Non-collinear magnetism in Mn-based antiperovskite nitrides**
11:45	12:15	Jakub Železný *Institute of Physics of the Czech Academy of Sciences* **Non-Relativistic Spin Currents and Torques in Antiferromagnets**

12:15	14:00	Lunch
14:00	14:30	Sergei Kruglik *Sorbonne University, Université Paris Cité* **Recent advances in Raman Tweezers Microspectroscopy for single nano-bioparticles research**
14:30	15:00	Nguyet-Thanh Ha-Duong *Université Paris Cité, ITODYS* **Plasmonic and magnetic nanostructures based on plant virus**
15:00	15:30	Haziq Naseer Khan *Université Paris Cité, ITODYS* **Grafting of Au NPs or Au@Ag-Au NPs over Tobacco mosaic virus for in-Solution Sensing Applications**
15:30	15:45	Coffee break
15:45	16:15	Jan Mistrík *CEMNAT, Faculty of Chemical Technology, University of Pardubice* **Optical properties of selected chalcogenides and their applications in nanophotonics and photothermal therapy**
16:15	16:45	Libor Veis *J. Heyrovsky Institute of Physical Chemistry* **Electronic structure calculations of polyradical nanographenes with peculiar magnetic properties**
16:45	17:15	Clément Faugeras *LNCMI Grenoble, CNRS* **Magneto-optics of magnetic ground states in van der Waals magnets**
19:30	23:00	Workshop dinner

Friday 7th June 2024

9:00	9:30	Florian Le Mardelé *LNCMI Grenoble, CNRS* **Magneto-optical response of magnon excitations in van der Waals layered antiferromagnets**
9:30	10:00	Michal Urbánek *CEITEC BUT, Brno University of Technology* **Mie-resonance-enhanced Brillouin light scattering microscopy for nanoscale spin wave research**
10:00	10:30	Nabil Challab *Université Paris Cité, ITODYS* **Magnetic nanostructures for straintronic applications: "Magneto-elastic control of spin waves"**

10:30	10:45	Coffee break

10:45	11:15	Guillaume Agnus *C2N,Université Paris-Saclay* **Oxide thin films processing: some examples on how to take advantage of perovskite properties into devices**
11:15	11:45	Stanislav Kamba *Institute of Physics of the Czech Academy of Sciences* **Terahertz field-induced magnetic moment and polar distortion in the quantum paraelectric diamagnets**
11:45	12:15	Tomáš Maleček *Charles University, Faculty of Mathematics and Physics* **Magneto-optical spectroscopy as a probe to magnetism and electronic structure**
12:15	12:45	Kamil Postava *Technical University of Ostrava* **Terahertz time-domain spectroscopic ellipsometry**
12:45	13:00	Closing Remarks

13:00		Lunch

Wednesday
5th June 2024

THz photoacoustic detection of food spoilage indicators

Mathias Vanwolleghem
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THz spectroscopy at FZU

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I will briefly describe the principles of time-domain terahertz spectroscopy. Then I will introduce the different experimental setups available at the Institute of Physics of the Czech Academy of Sciences. Finally, I will present selected results we obtained in Prague thanks to our THz spectrometers.

Landau emission from 2D Dirac fermions in HgTe QWs

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Abstract – We report on the emission of Terahertz radiation from Landau quantized Dirac electrons in HgTe/CdHgTe based quantum wells. We show that this cyclotron emission is continuously tunable with magnetic field from 500 GHz up to 2.5 THz. Moreover, given the relativistic nature of charge carriers, the cyclotron mass and therefore the emitted frequency are also tunable with the electron density.

This work is embedded in a long search of achieving a Landau laser tunable over the terahertz frequency range [1]. Indeed, excited electron under high external magnetic can recombine radiatively and emit light of energy of tens of meV. Graphene was a promising candidate to achieve this goal, as its Landau levels (LLs) fan chart features a square-root-like behavior in magnetic field, due to its inherently linear energy dispersion. This would imply a drastic diminution of Auger scattering processes as the different LLs are not equidistant. Unfortunately, it has been shown [2] that such non radiative effects are still present in graphene as it is still possible to find different transitions between LLs that fulfill the energy conservation. In this work we were interested in different QWs based on HgTe/CdHgTe and hosting a Dirac fermion phase [3]. Indeed, in addition to its topological properties, its energy dispersion at zero magnetic field features both linear and quadratic terms so that the Auger scattering processes could be even more suppressed. We performed electrically driven cyclotron emission experiments, considering 2D massive and massless Dirac fermions in HgTe/CdHgTe QWs, of different carrier concentrations. This allowed us to measure a sizable cyclotron emission, tunable over the 0.5 to 3 THz range. Very recent additional experiments carried out on gated QWs are also presented. These latest results open a promising way to achieve a tunable laser covering the terahertz gap [4].

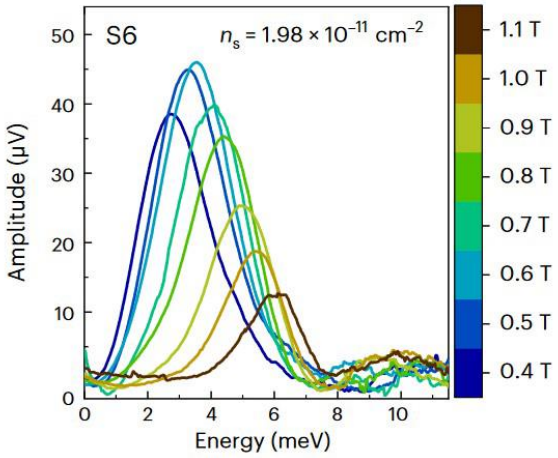

Fig. 1. Typical set of emission spectra, obtained at different magnetic fields applied on the sample. The electron density of the sample was determined by mean of magnetotransport measurements.

The Landau emission spectroscopy measurements were performed at 4 K using an n-InSb detector subjected to a high magnetic field, allowing a fine spectroscopy of the cyclotron emission from Dirac electrons. Figure 1 shows a typical set of emission spectra, obtained at different magnetic fields applied on the sample. One can see that the emission peak is evolving with the magnetic field. This evolution is driven by the cyclotron mass of the sample, determined by its electron carrier density, through the quasiclassical formula $E = (\hbar e/mc)B$ [5]. We measured

samples with different electron densities and extracted the cyclotron mass [6]. The behavior of the latter with the electron density is in perfect agreement with a low energy model that we developed.

Acknowledgments

This work was supported by the Terahertz Occitanie Platform, by the CNRS through IRP “TeraMIR”, by the French Agence Nationale pour la Recherche for Colector (ANR-19-CE30-0032), Stem2D (ANR-19-CE24-0015), and Equipex+ Hybat projects (ANR-21 -ESRE-0026), by the European Union through the Flag-Era JTC 2019 - DeMeGras project (ANR-19-GRF1-0006) and the Marie-Curie grant agreement No 765426, from Horizon 2020 research and innovation program, and by the Center of Exellence «Center of Photonics» funded by The Ministry of Science and Higher Education of the Russian Federation, contract № 075-15-2022-316.

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[6] S.Gebert, C.Consejo, S.S.Krishtopenko et al. “Terahertz cyclotron emission from two-dimensional Dirac fermions”, Nature photonics, vol 17, pp 244-249, 2023.

Thursday 6th June 2024

Theory of orbital generation, diffusion, and detection

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Recent progress in the physics of spin-charge interconversion mediated by spin-orbit coupling has shed new light on the orbital angular momentum degree of freedom. Indeed, while the orbital ordering driven by the crystal-field potential governs the interplay between crystal structure and electronic properties of strongly correlated materials such as Mott insulators, the possibility of transporting the orbital information in these materials has remained an open question so far. In the context of metallic spintronics though, it has been progressively realized that the orbital angular momentum can be generated out of equilibrium, transported, and detected, rather similarly to the spin angular momentum.

The interconversion between charge and orbital currents, via orbital Hall and orbital Rashba effects for instance, might be much more efficient than its spin counterpart because it arises from the orbital texture imposed by the crystal-field potential rather than from spin-orbit coupling. Therefore, corresponding phenomena such as orbital torque and orbital magnetoresistance have been proposed and experimentally reported. Recent phenomenological models of orbital diffusion have been recently proposed but lack quantitative predictability by overlooking microscopic details. Understanding the way orbital currents and densities propagate in metals and accumulate at interfaces requires determining transport coefficients such as orbital conductivity or diffusivity, as well as the ability to interconvert spin currents into orbital currents via spin-orbit coupling.

In this presentation, I intend to provide a discussion of the theoretical aspects of orbital generation, transport, and detection. After introducing general ideas about orbital ordering and orbital angular momentum, I will first discuss the orbital-charge interconversion mechanisms, orbital Hall, and orbital Edelstein effects. I will insist on the distinction between intra-atomic and inter-atomic orbital contributions in these two effects [1]. Then, I will present a quantum theory of orbital diffusion and uncover several mechanisms governing orbital torque and magnetoresistance phenomena, including orbital diffusivity, spin-orbit polarization, orbital swapping, and orbital mixing conductance [2,3]. These new concepts are crucial to the understanding of experimental results and can be computed from first principles. Finally, I will discuss the possibility of detecting orbital densities optically using the orbital Kerr effect. I will particularly emphasize the central role played by the second-order Hall effect, which is a companion phenomenon to the orbital Edelstein effect.

[1] Pezo et al., *Orbital Hall effect in crystals: inter-atomic versus intra-atomic contributions*, Physical Review B 106, 104414 (2021); *Orbital Hall physics in two-dimensional Dirac materials*, Physical Review B 108, 075427 (2023).

[2] Aurélien Manchon, A. Pezo, Kyoung-Whan Kim, Kyung-Jin Lee, *Orbital diffusion, polarization and swapping in centrosymmetric metals*, arXiv:2310.04763

[3] Ning et al., *unpublished*

[4] Diego Garcia Ovalle, Armando Pezo, Aurélien Manchon, *Orbital Kerr effect and terahertz detection via the nonlinear Hall effect*, arXiv:2311.11889

Vectorial magnetometry with magneto-optical spectroscopy

A. Wu-Vignolo, A. Bellec, **V. Repain**

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J. Harmle, M. Veis

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The control of magnetization direction is a key feature of modern magnetism with the rise of ultrathin films and interface magnetic anisotropy. While out-of-plane magnetization has been widely studied and transferred to devices (hard disk drives, magnetic memory…), it appeared recently that breaking symmetries could lead to more efficient spin-orbit torque magnetization switching.

I will show that using low-symmetry surfaces, it is possible to obtain canted magnetization with strong magnetic anisotropy in cobalt ultrathin films. Among the different magnetometry techniques used to determine the complex magnetization reversal in such samples, I will particularly focus on magneto-optical Kerr effect. Indeed, we have measured quite unusual properties, such as a strong change of the hysteresis cycle shape with different wavelengths. I will show that this is a direct consequence of the canted magnetization and that a singular value decomposition method on the full magneto-optical spectroscopy dataset allows to extract independently both the in-plane and out-of-plane components of the magnetization during a reversal cycle, allowing a better understanding of magnetization reversal in low-symmetry magnetic ultrathin films.

Anomalous spectroscopical and DC transport effects in magnetically ordered systems

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Permittivity tensor of magnetically ordered systems contains information about a large number of effects, many of which had earlier been associated with ferromagnets. While it is arguable which of those effects deserve the qualifier "anomalous", we will begin with one which has *traditionally* been called the anomalous Hall effect (AHE) which can be understood as the DC limit of a wider class of effects occuring at finite frequencies. In a broader context, we will then discuss anomalies related to the occurence of these (and related) effects in materials beyond ferromagnets.

More specifically, taking several antiferromagnetic materials as an example, anisotropic magnetoresistance (AMR) will be covered [1] and then magneto-optical Kerr effect and x-ray magnetic circular dichroism [2]. These are related to diagonal and off-diagonal elements [3] of permittivity tensor at various frequencies. It will be explained how AMR combined with AHE can be used to determine the direction of Néel vector in a MnTe sample (collinear antiferromagnet) and the prospects of exploiting their "cousins" in x-ray range to achieve sub-micron spatial resolution.

Finally, optical studies in materials with non-collinear order will be briefly mentioned and put in context with previously discussed materials.

[1] Philipp Ritzinger and Karel Výborný, *Anisotropic magnetoresistance: materials, models and applications*, R Soc Open Sci 10, 230564 (2023).

[2] A. Hariki et al., *X-Ray Magnetic Circular Dichroism in Altermagnetic MnTe*, Physical Review Letters 132, 176701 (2024).

[3] N. Tesařová et al., *Systematic study of magnetic linear dichoism and birefringence in (Ga,Mn)As*, Physical Review B 89, 085203 (2014).

Ultrafast Control and Dynamics of Metamagnetic Transitions in FeRh Nanostructures

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Metamagnetic materials are outstanding candidates for finding and exploiting new functionalities and emergent phenomena on the meso- and nanoscale. For instance, the transition from antiferromagnetic to ferromagnetic order in sub-micron-wide FeRh wires becomes greatly asymmetric when comparing the heating and cooling cycles [1,2]. This recovery of the abrupt transition in nanostructures enables fast, low-energy control of magnetic properties, leading to potential applications in sensing, spintronics, and magnetic resonance imaging. I will discuss our recent results featuring local control of phase coexistence in FeRh micro- and nanostructures, realized by strain, magnetic field, and femtosecond laser pulses. The systems will range from continuous films [3] through patterned structures to self-assembled nanoislands [4], which sustain the metamagnetic transition.

Furthermore, I will present the dynamic response of the electronic and magnetic order to ultrafast laser excitation, followed by time-resolved photoemission electron spectroscopy [5]. This technique, unlike those probing the total magnetization in the sample, provides a direct comparison to the dynamic response of the structural order. The transient photoemission spectra of FeRh thin films show that the ferromagnetic phase, characterized by a minority band near the Fermi energy, is established in less than 500 fs after laser excitation [5]. Finally, I will employ ultrafast x-ray diffraction to study the laser-induced magnetostructural phase transition in FeRh nanoislands [6], revealing an intrinsic 8 ps timescale for the nucleation of ferromagnetic domains [7]. This comparison with continuous FeRh films highlights the unique behavior of nanoislands, where more homogeneous optical excitation results in a faster nucleation-dominated phase transition.

References

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[4] L. Motyčková et al., ACS Appl. Mater. Interfaces 15, 8653–8665 (2023).

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[6] M. Mattern et al., Adv. Funct. Mater. (2024). doi: 10.1002/adfm.202313014

[7] M. Mattern et al., accepted to APL Mat., arXiv preprint arXiv:2305.02094 (2023).

Non-collinear magnetism in Mn-based antiperovskite nitrides

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Metallic antiperovskites are a broad family of materials hosting a range of spintronic and caloric effects. Mn-based antiperovskite nitrides with non-collinear antiferromagnetic structure have received significant interest due to their potential for memory and logic applications in recent years. The frustrated exchange interactions underpin strong sensitivity of the magnetic structure to stimuli such as lattice strain or electric field. An overview of effects traditionally expected in ferromagnetic materials including the Anomalous Hall effect (AHE), Magneto-optical Kerr effect (MOKE), and Anomalous Nernst effect (ANE) will be presented in the context of the canted antiferromagnetic structure of thin films comprising Mn3NiN and other members of the antiperovskite family. Recent observation of local strains in antiperovskite films and their impact on spintronic functionality will be discussed.

Non-Relativistic Spin Currents and Torques in Antiferromagnets

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Contrary to the early understanding of antiferromagnets as limited compared to ferromagnets, a rich landscape of phenomena in antiferromagnets has been demonstrated that could be utilized for various spintronics functionalities. Here, we discuss recent advances in understanding of how electrical current can induce spin currents or spin torques in antiferromagnetic systems, focusing primarily on non-collinear antiferromagnets and on phenomena that originate from the non-collinear order without requiring the relativistic spin-orbit coupling. We show that antiferromagnets can host spin-polarized currents and that these can be utilized for magnetic junctions, that antiferromagnets can be used for spin-charge conversion, potentially even without any spin loss, and that a non-relativistic current-induced torque analogous to the spin-orbit torque can exist in antiferromagnets.

Recent advances in Raman Tweezers Microspectroscopy for single nano-bioparticles research

Sergei G. Kruglik, Ph. D.

Sorbonne University, Laboratory Jean Perrin University Paris City, Laboratory MSC-Med

The variety of bioparticles in the nanoscale domain attract nowadays an increasing attention of researches looking for both new fundamental knowledge and modern biomedical applications, including diseases diagnostics and therapies. These bioparticles include extracellular vesicles (EVs), protein aggregates, lipoproteins, bacteriophages and viruses, to name a few.

One of the major interests in my research lies in studying EVs, small specialized membranous bioparticles secreted from living cells and carrying specific biomolecular cargo. Recent general acceptance of the fact that EVs are intrinsically heterogenous not only by size, but also by biomolecular content, calls for new methods of investigation targeting single EVs, in addition to well established methods of bulk EVs characterization.

Raman Tweezers Microspectroscopy (RTM) is one of such investigation tools, combining Raman spectroscopy with particles' optical trapping. In my talk, first I'll provide a general description of the RTM technique which allows direct characterization of general biomolecular composition of single nanoscale bioparticle without using any external label.

Then, I'll focus on our recent results when quantitative data derived from the RTM analysis of single EVs provide new information on biological processes with their participation. Special attention will be devoted to Raman spectra decomposition using Biomolecular Component Analysis for quantitative concentration measurements of major general classes of biomolecules: proteins, lipids, and nucleic acids.

Here is the list of recent relevant publications with my participation:

- - Nature Protocols, 2021, DOI: 10.1038/s41596-021-00551-z
- - Journal of Thrombosis and Haemostasis, 2024, DOI: 10.1016/j.jtha.2024.01.004
- - Journal of Extracellular Biology, 2024, DOI: 10.1002/jex2.140
- - Scientific Reports, 2024, DOI: 10.1038/s41598-024-56788-7

Plasmonic and magnetic nanostructures based on plant virus

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The ability to construct three dimensional architectures via nanoscale engineering is important for emerging applications of nanotechnology in sensors, catalysis, controlled drug delivery, microelectronics, and medical diagnostics. Because of their well-defined and highly organized symmetric structures, high robustness over wide ranges of temperature, pH, buffer, and in the presence of organic solvents, viral capsid proteins then provide a 3D scaffold for the precise placement of plasmon or magnetic materials yielding hierarchical hybrid materials. In this study, we use several plant viruses with different shapes and morphologies: Turnip yellow mosaic virus (TYMV), Rice yellow mottle virus (RYMV), Tobacco mosaic virus (TMV). To obtain assemblies of nanoparticles onto capsids at room temperature, we used two different synthesis: grafting pre-formed nanoparticles or biomineralization.

In the first part of this work, I will present the synthesis and characterization of new nano-bio-hybrid materials, which are soluble and stable in solution. Gold nanoparticles (AuNP) of different sizes (5, 10 and 20 nm) were grafted on icosahedral capsid, according to two strategies. After purification, the resulting nano-biohybrids were characterized by different technics (DLS, TEM, XPS...). Similarly, we grafted onto the virus capsid iron oxide nanoparticles (IONP) synthetized by the polyol process, and then characterized the objects, specifically their magnetic properties.

In the second part, gold biomineralization experiments on TMV will be described. The size, morphology, monodispersity of AuNP and gold assembly on virus were studied according to the experimental conditions (concentrations of reactant, number of cycle, nature of reductant…) and in situ TEM observations directly in liquid media were also performed to unravel the nucleation and growth mechanisms.

Finally, I will show some applications of these new nano-biohybrid materials in the field of sensors and therapy.

Grafting of Au NPs or Au@Ag-Au NPs over Tobacco mosaic virus for in-Solution Sensing Applications.

Haziq Naseer Khan †, Cora Moreira Da Silva †, Nathaly Ortiz-Pena ‡, Stéphanie Lau-Truong† , Tomas Moravec¶, Damien Alloyeau ‡ and Nguyet Thanh Ha Duong † *

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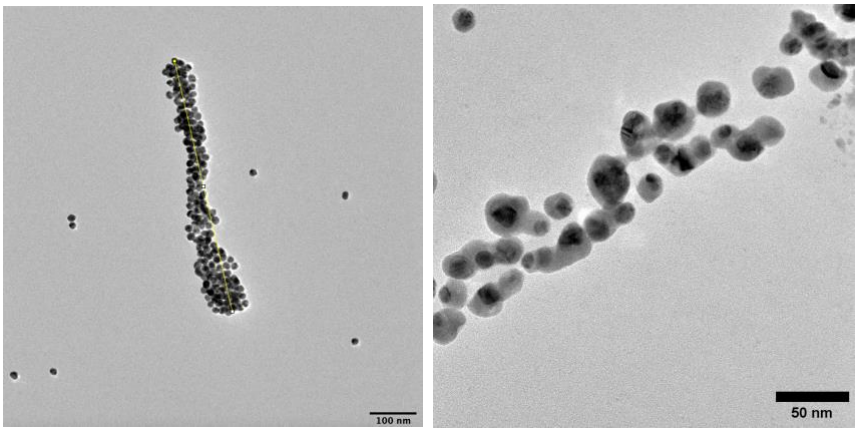
Abstract:
The use of biomolecular templates has been instrumental in generating complex hybrid materials. The nanotechnology field has shown a keen interest in plant viruses due to their symmetrical attributes, multivalency, uniformity in size, and self-assembly capabilities. An important advancement is employing plant virus capsids as frameworks to organize three-dimensional nanostructures, which has led to the emergence of novel functional nanomaterials. The demand for these hybrid nanostructures is on the rise because of their prospective applications in medical imaging, drug delivery, chemical detection, and catalysis. The Tobacco mosaic virus (TMV) is particularly recognized for its robustness against heat and chemical degradation. It is also considered safe for human handling and can be modified with a variety of functional materials[1-3].

This study examines the use of TMV modified with surface-attached Cysteine (TMV-Cys) as a base for assembling gold nanoparticles (AuNPs) and "Gold core@gold-silver alloy nanoparticles (Au@Au-Ag NP) in varying proportions to create nanohybrids with exact control over their size and shape. The proximity arrangement and combination of the nanoparticles substantially alter their plasmonic characteristics. We have utilized biomineralization and direct attachment methods to adhere NPs onto TMV-Cys. The attachment of AuNPs on TMV-Cys was monitored through In-situ transmission electron microscopy and confirmed through fluorescence quenching tests. Additionally, we probed the surface modification of TMV-Cys combined with AuNPs and TMV-Cys with Au@Ag-Au NP hybrids employing Raman reporter molecules (BPE & Rhodamine). Our research suggests that the TMV-Cys@NP composite is highly promising as a versatile tool for in-solution Surface-Enhanced Raman Spectroscopy (SERS), especially for detecting biomolecules. Moreover, these hybrids can also exhibit potential as photothermic agents.



(a) (b)

Fig 1: (a) TEM image of the AuNPS grafted onto TMV-C (b) Au@Ag-Au NPs grafted over TMV-Cys

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Optical properties of selected chalcogenides and their applications in nanophotonics and photothermal therapy

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ABSTRACT
Chalcogenide-based materials containing group XVI elements, such as S, Se, and Te, have been successfully used commercially, for example, in data storage [1]. They are continuously intensively studied due to their anticipated potential in other fields, such as photonics, optoelectronics, photovoltaics, etc. In the present lecture, we focus on our recent optical studies of selected chalcogenides motivated by their applications in photothermal therapy (MoS_2) [2] and in reconfigurable photonic elements based on phase change materials (GST, GSST, Sb_2S_3, and Sb_2Se_3) [3,4].

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Electronic structure calculations of polyradical nanographenes with peculiar magnetic properties

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J. Heyrovsky institute of Physical Chemistry

In this talk, I will present our recent advancements in developing computational methods for electronic structure calculations of strongly correlated molecules. I will introduce the massively parallel Density Matrix Renormalization Group (DMRG) method, along with its extensions for capturing dynamical electron correlations using the adiabatic connection approach. In the second part of the presentation, I will showcase applications of these methods on selected nanographenes, highlighting their unique magnetic properties.

Magneto-optics of magnetic ground states in van der Waals magnets

Clement Faugeras
LNCMI-CNRS, Grenoble

Magnetic van der Waals materials are attracting a lot of interest from both the fundamental and application viewpoints. They can host a broad variety of magnetic ground states depending on the magnetic exchange interactions and of anisotropies. In this talk, using few selected exemples, I will show how optical techniques such as Raman scattering and photoluminescence, combined with extreme experimental conditions of low temperature, high magnetic field and high pressure can provide a tool to understand and manipulate the magnetic orders in these materials.

Friday
7th June 2024

Magneto-optical response of magnon excitations in van der Waals layered antiferomagnets

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Magnetic van der Waals (vdW) materials represent an appealing playground for studying magnetism that arises from the interaction of magnetic moments organized in a two-dimensional layer. The ongoing research in this fast expanding field targets not only fundamental issues, mostly related to novel topological and quantum phases of matter, but also test possible ways to use them in various applications, thus giving rise to the fast-expanding area of magnonics. Antiferromagnetically ordered materials often exhibit optically active magnon excitations in the sub-THz and THz spectral range, relevant for future high-speed communication technologies.

On the system $FePSe_3$ the observed magnetic response contains several types of magnon excitations. Two of them are conventional transverse magnons described by a classical theory of antiferromagnetic resonance. Two other modes are identified as multimagnon hexadecapole excitations with an anomalous g factor approximately equal to four times the g factor of a single Fe^{2+} ion. These quasiparticles correspond to full reversals of iron spins that coherently propagate in the up-down antiferromagnetic structure. They constitute a novel type of collective excitations in anisotropic magnetic solids, called longitudinal magnons.

On the mixed material $Fe_{1-x}Ni_xPS_3$, we experimentally demonstrate the wide and on-demand tuning of magnon energy by altering the composition of an antiferromagnetic van-der-Waals alloy. Through antiferromagnetic resonance measurements on $Fe_{1-x}Ni_xPS_3$ samples with varying x, we observe that magnon energy can be controlled by the mixing ratio x, indicating an effective single-ion magnetic anisotropy. Remarkably, even at high nickel concentrations (up to $x = 0.9$), the alloys retain a perpendicular anisotropy typical of $FePS_3$.

Mie-resonance-enhanced Brillouin light scattering microscopy for nanoscale spin wave research

Michal Urbánek
CEITEC BUT, Brno University of Technology

Magnonics is seen nowadays as a candidate technology for energy-efficient data processing in classical and quantum systems. Wavelike nature with pronounced nonlinearity and anisotropy of dispersion relations of spin waves and their quantum mechanical counterparts magnons require advanced measurement instrumentation and methodology. Brillouin light scattering (BLS) spectroscopy and microscopy was a technique of choice for many pioneering magnonic experiments. However, for device miniaturization, a shift towards nanoscale spin waves is necessary. Until now, the BLS technique fell short here due to its fundamental limit in minimum detectable spin wave wavelength (approx. 600 nm).

Previous attempts to measure nanoscale spin waves relied on nanosized apertures or other plasmonic structures made of metals to locally enhance the electromagnetic field and increase the range of the accessible k-vectors. Unfortunately, the efficiency of the plasmonic approach is severely limited by high optical losses in metallic structures, which makes it unsuitable for convenient magnon measurements.

Our approach uses the advantage of reduced dissipative losses of dielectric nanoresonators. We have recently demonstrated that a simple silicon disk which supports Mie resonances, can increase the magnon signal by a factor of 5 and enhance the range of accessible k-vectors beyond the fundamental limit of a conventional BLS microscopy setup. Here, I will present how Mie-resonance-enhanced BLS microscopy can be used to characterize spin waves with nanoscale wavelengths excited by parametric pumping and by nanoscale stripline antennas.

Magnetic nanostructures for straintronic applications: “Magneto-elastic control of spin waves”

Nabil Challab[1,*] Damien Faurie[2], Mohamed Haboussi[2] , A. O. Adeyeye[3,4] and Fatih Zighem[2]

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Since its discovery by Joule in 1847, magnetoelasticity has been the subject of ongoing research, driven by both its fundamental principles and practical applications. These applications include flexible magnetic systems, typically consisting of thin or multilayer films, which can be nanostructured and applied to a polymer substrate. These systems have applications ranging from everyday devices to aerospace equipment. Throughout their operational lifetime, these devices undergo significant and often complex deformations that dynamically affect their magnetic properties[1].
To investigate the effect of strain on magnetic behaviour, research has been conducted in two main areas: i) a computational approach, involving the development of a numerical model using COMSOL Multiphysics® to study magnetoelastic couplings in flexible magnetic systems[2]; and ii) an experimental approach, focusing on the investigation of magnetoelastic properties within nanostructured magnetic systems on flexible substrates. Together, these two perspectives shed light on the interplay between deformation distribution and both static and dynamic magnetic properties.
Based on numerical predictions, we have embarked on experimental studies of the dynamic magnetic response of networks composed of magnetic nanostructures while subjected to controlled deformations induced by a ferroelectric actuator. These networks manifest a multifaceted magnetic response alongside a remarkable heterogeneity in the mechanical current distribution. Figure 3 shows an example of such a network studied during ferromagnetic resonance under mechanical testing. To facilitate these investigations, we have developed a methodology to locate and measure magnetoelastic effects within nanostructured surfaces.

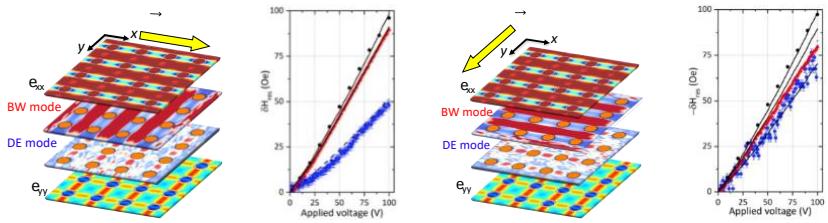

Figure 1: Differential control of magnetic modes by localized elastic deformation. a) and c) represent the maps of the deformation field (xx and yy components) and of the "Backward" and "Daemon-Eshbach" magnetic modes. b) and c) represent the evolution of spectral shifts as a function of the voltage applied to the ferroelectric substrate [3].

First, we performed a spatial and temporal identification of magnetic oscillation modes, coupled with a precise localisation of mechanical deformations within the nanostructures. We then estimated the local concentration ratio of strain tensor components to measure induced spectral shifts. Our results demonstrate the feasibility of manipulating spectral shifts within such nanostructures by changing the orientation of the applied magnetic field relative to the direction of deformation. In particular, the evolution of the spectral shifts reveals the ability to induce a shift in one mode without significantly altering the behaviour of another mode by adjusting the magnetic field orientation.

Furthermore, in additional studies, although not detailed here, we have identified parameters and configurations capable of modifying and fine-tuning the magnetic properties of nanostructures. These findings provide additional mechanisms to control and regulate magnetic modes, offering promising avenues for future applications in spintronics, straintronics and flexible magnonics, all with reduced energy consumption.

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Oxide thin films processing: some examples on how to take advantage of perovskite properties into devices.

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Functional oxides represent a promising avenue for enhancing the performance of electronic devices, offering a rich spectrum of physical properties within the perovskite structure, depending on its cationic chemical composition. [1] Their integration is increasingly acknowledged as a viable strategy to elevate electronic device capabilities.

Presently, 2 major pathways are being explored to pioneer novel device paradigms that leads to research activities on different sample configurations.
On one hand, complete oxide structures and growth processes on top of oxides substrates capitalize on the minimal lattice mismatch between layers, yielding films of high crystalline quality. However, this route presents its own set of technological challenges, notably the necessity for selective etching to realize freestanding devices. Compatibility with silicon-based electronics seems not compatible at first sight but can however be reached thanks to transfer technologies, like the ones used to combine III-V and Si.
On the other hand, the direct epitaxial integration of oxides onto semiconductor platforms like silicon or gallium arsenide offers a pathway to augment silicon's functionalities for electronic or optical applications. [2-3] In this configuration, the challenges lie in the adaptation layers to reached high crystalline quality films and strain management to maintain the physical properties and devices integrity.

The next step to reach devices consist in processing the films into devices at the micro-nanoscale and remains a challenge, in particular for the etching steps due to the chemical stability of functional oxides. The primary technological hurdles revolve around identifying and implementing compatible technologies capable of designing and fabricating these innovative devices. During this presentation, I will present some examples on how to take advantage of perovskite properties into devices thanks to oxide thin films processing. A focus will be made on MEMS based sensors.

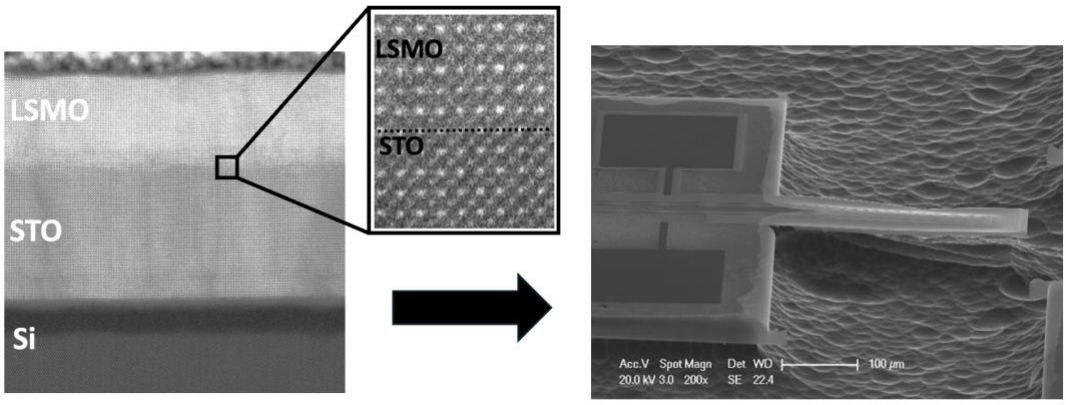

Figure 1: (Left) TEM images of perovskite oxides thin films on Si (Right) SEM image of oxide MEMS device.

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Terahertz field-induced magnetic moment and polar distortion in the quantum paraelectric diamagnets

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Juraschek *et al.*[1,2] theoretically predicted that circularly polarized phonons should carry orbital magnetic moment even in diamagnetic or paramagnetic materials. The macroscopic orbital magnetic moment should be induced by the excitation of two perpendicularly polarized degenerate polar phonons using circularly polarized THz radiation. Unfortunately, experimental evidence of this phenomenon has been absent until recently.[3]

We decided to pump the ferroelectric soft phonon in quantum paraelectric $KTaO_3$ single crystal using extremely intense pulses with frequency 0.7 THz. The pulses with a duration of about 10 ps were generated by accelerator-based source with undulator at the TELBE beamline in the Helmholz Zentrum in Dresden-Rossendorf. The transient magnetic moment on the picosecond time scale was measured via magneto-optic Faraday effect at a probe wavelength of 800 nm. A possible breaking of inversion symmetry was sensed by measuring the second harmonic generation at 400 nm. The experiments were performed between 10 and 300 K.

At low temperatures, the THz pump frequency was close to the soft-mode frequency, and a rather strong transient birefringence was observed. However, THz pump-induced transient birefringence was detected not only using a circularly polarized THz beam, but also upon pumping with a linearly polarized beam. We explain this by the THz-field-induced ionic electro-optic Kerr effect which was recently observed also in the quantum paraelectric $SrTiO_3$.[4] In $KTaO_3$, a transient polarization and the related broken inversion symmetry were proved also by measuring the transient second harmonic generation.

In summary, we demonstrated that a transient polarization and magnetization can be induced simultaneously, by a strong *resonant* excitation of polar phonons in a diamagnetic and quantum paraelectric crystal $KTaO_3$. Similar effects were recently observed in $SrTiO_3$.[3,4] It is theoretically predicted that there are other materials where one would expect an order of magnitude stronger magnetic moment induced by circularly polarized THz radiation.[5] We conclude this talk by introducing such materials.

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Magneto-optical spectroscopy as a probe to electronic structure and magnetism of materials and nanostructures

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Abstract:

Magneto-optical effects play an important role in both research and application fields. Magneto-optical experiments are widely used as non-destructive, depth sensitive and extremely precise tools to explore basic and novel physical phenomena and properties of magnetic materials. Magnetic field dependent magneto-optical measurements under different field orientations can provide a useful insight into the magnetic anisotropy of studied materials even for very small magnetizations. On the other hand, one can use spectrally dependent measurements in combination with ab-initio calculations to analyze electronic transitions across the band structure to map particular electronic states with large splitting. Moreover, a combination of the field and spectrally dependent magneto-optical measurements, which gives energy dependent hysteresis loops, can provide useful insight into the magnetism of various sublattices in multi-sublattice magnetic systems, interface phenomena or surface magnetism. The talk will provide an overview of the recent magneto-optical research and sketch new possibilities and opportunities.

Terahertz time-domain spectroscopic ellipsometry

Kamil Postava
Technical University Ostrava

Terahertz time-domain spectroscopic ellipsometry (THz-TDSE) provides several advantages and opens a wide range of applications. We demonstrate the measurement of complete ellipsometric spectral response in terms of the Jones or Mueller matrix based on polarization switching by using a spintronic THz emitter (STE). The ellipsometric application of STE was significantly contributed by French and Czech research. The general method is demonstrated on THz-TDSE of anisotropic crystal of Mercury Chloride (Calomel). Applications of THz-TDSE in the field of THz optical activity and contactless measurement of surface electric properties are proposed.

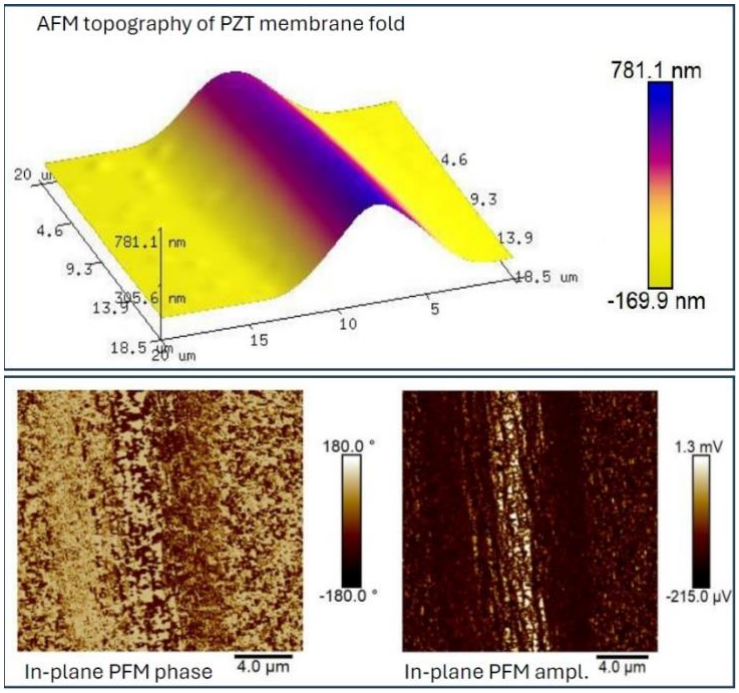
Posters

Strain-induced polarization rotation in a freestanding ferroelectric oxide membrane

Freestanding perovskite oxide membranes offer a new route for exploring the properties of oxide thin films [1]. Recent advances in the fabrication of oxide membranes have made it possible to achieve higher strain states than with state-of-the-art epitaxial strained films. Theoretical works on ferroelectrics materials such as $BaTiO_3$[2,3] have shown that a high bending state in a ferroelectric membrane can induce a polarization switching from out-of-plane to in-plane polarization.

In this study, we report on the experimental observation of polarization rotation in ferroelectric $Pb(Zr,Ti)O_3$ (PZT) membranes having a wrinkle-like morphology with locally high strain states. The membranes were fabricated through the use of an acid-dissolved $(La,Sr)MnO_3$ sacrificial layer. We show with piezo-response microscopy (PFM) analysis the direct effect of strong bending strain on the ferroelectric polarization in a PZT membrane fold: The out-of-plane ferroelectric polarization of the as-grown film has its amplitude greatly reduced as the tensile strain increases along the fold, while the in-plane polarization component rises.

Our work demonstrates experimentally the capability of topography engineering in crystalline oxide membranes to modify their functional properties. Going towards the next step, for an on-demand tuning of topography and strain in freestanding membranes, we will also show our first results obtained with an exciting new method of light-induced tunable patterning of ferroelectric oxide membranes.



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Magnetism at low symmetry interfaces

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Crystal symmetries are generally driving the physical properties. In magnetism, such symmetries are particularly important to define the axis of easy magnetization and the value of the magnetic coercive field. Controlling those parameters is crucial for the development of magnetic memories or spintronic devices. In this work, I explore the impact of very low symmetry interfaces on the magnetic properties of ferromagnetic ultrathin films. More particularly, I investigate substrates with no mirror planes, that can be therefore called 'chiral' surfaces.

I will present results on Co films deposited on a Au(643) surface which is composed of a nanometric array of step edges and atomic kinks with a point group symmetry 2. The 'chirality' of this surface has been characterized by Low Energy Electron Diffraction and X-Ray Diffraction.

A sandwich of Pt(1.5nm)/Co(0.7nm)/Pt(2nm) was deposited by sputtering, resulting in a canted magnetization of the substrate. A reference sample was prepared in the same batch, on a silicon oxyde substrate. The most striking result is the very high anisotropy of the sample. Indeed, more than 2 Tesla are needed to saturate the magnetization in the sample plane. Furthermore, the switching field is found to be very anisotropic in the plane of the sample. We have also observed the magnetic domains which are very elongated, showing again a strong magnetic anisotropy. Finally, we have probed magnon modes by Brillouin Light Spectroscopy, and an azimuthal angular dependence of the asymmetry between the Stokes and the anti-Stockes frequencies was observed, in contrary to what has been measured on the reference sample.

The results pave the way to the use of low-symmetry substrates to generate original magnetic and spintronics properties.

Acknowledgments

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Additional Posters to be announced during the workshop.