Insitute of Spintronics and Quantum Information
Faculty of Physics
Adam Mickiewicz University, Poznań

Symposium on Spintronics and Quantum Information & Opening Ceremony

Book of Abstracts

Institute of Spintronics and Quantum Information

Poznań, Poland, October 20–23, 2021

Symposium Venue

The Symposium will be held in a hybrid form.

The event will take place at the Faculty of Physics Adam Mickiewicz University, ul. Uniwersytetu Poznańskiego 2, Poznań, Poland. The lectures will be held in Auditorium Maximum named after prof. Franciszek Kaczmarek.

There will be also a possibility to active participation in sessions online via Zoom platform.

Links for Zoom meeting:

- Opening ceremony – Oct. 20th:
  https://zoom.us/j/92443017695?pwd=NjJXNW5TNXJHeEdhWUpNM1FIN2pFdz09
- Symposium Day 1 – Oct. 21st:
  https://zoom.us/j/96668781987?pwd=bkwxc1daQmQrc2wwTkVuUXdyMm1qUT09
- Symposium Day 2 – Oct. 22nd:
  https://zoom.us/j/92545352676?pwd=R3llaXJGZ1BldGhXbmMyVnp0dVRMdz09
- Symposium Day 3 – Oct. 23rd:
  https://zoom.us/j/98275589010?pwd=RkZFRisrRS9mQVBkZHkzdjVRdi9aZz09

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Head: prof. dr hab. Tomasz Kostyrko

About the Institute

Establishment of the Institute

The Institute of Spintronics and Quantum Information (ISQI) has been appointed on January 1, 2021 by Prof. Bogumiła Kaniewska, the Rector of Adam Mickiewicz University in Poznań. The Institute has been established on the initiative of three departments of the Faculty of Physics: the Department of Mesoscopic Physics, the Department of Nanostructures Physics and the Department of Nonlinear Optics. In September 2021 the Department of Theory of Condensed Matter joined the Institute.

Main focus of ISQI

The main scientific interests of the Institute encompass the most fundamental aspects of condensed matter physics including spintronics, magnonics, phononics, photonics, quantum matter physics, as well as quantum optics, quantum information and cavity- and circuit-electrodynamics. The conducted research is important for designing the nanodevices processing, transmitting and storing classical and quantum information. Our scientific investigations are focused on theory and numerical simulations, however, experimental studies on magnonic and phononic nanostructures are also carried out.

Webpage: http://isik.amu.edu.pl

Schedule

Wednesday, October 20 < *Join the Zoom meeting* >		
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	PRESENTATION AND OVERVIEW OF INSTITUTE'S ACTIVITIES Ireneusz Weymann, Director of the Institute of Spintronics and Quantum Information	
	OPENING LECTURE *Introduction to quantum information processing and superconducting qubits* Franco Nori, Center for Emergent Matter Science, RIKEN, Wako-shi, Saitama 351-0198, Japan	12
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Abstracts

INTRODUCTION TO QUANTUM INFORMATION PROCESSING AND SUPERCONDUCTING QUBITS

Franco Nori

Center for Emergent Matter Science, RIKEN, Wako-shi, Saitama 351-0198, Japan

The first part of the talk will provide a very non-technical overview of quantum information processing. The second part will show a very pedagogical introduction to quantum information processing using superconducting qubits. These type of quantum bits (or qubits) are attracting most of the investment from private companies, like IBM, Google, D-Wave, Rigetti, Amazon, Alibaba, NTT, and many other companies.

CHIRAL SPIN TEXTURES AND CHIRAL SPIN-ORBIT TORQUES FOR SPINTRONIC MEMORIES

Stuart Parkin

Max Planck Institute of Microstructure Physics, Halle (Saale), Germany
Corresponding author: stuart.parkin@mpi-halle.mpg.de

Atomically engineered magnetic heterostructures and their manipulation by current are key to several spintronic memory-storage technologies [1]. One of these is Racetrack Memory in which chiral domain walls can be moved very efficiently with current via spin-orbit torques in synthetic antiferromagnetic (SAF) racetracks [2]. The domain walls act as memory bits and are moved to read and write elements integrated into or adjacent to the racetracks. Using atomically thin "dusting" layers we have recently shown that the critical current density needed to move the domain walls can be reduced several-fold, while increasing the domain wall velocity by more than a factor of five for otherwise the same current density [3]. Racetrack Memory is non-volatile and has the potential, on the one hand, to replace the density memories today, namely hard-disk and solid-state drives and, on the other hand, the fastest, namely SRAM. The latter would be composed of a single domain wall racetrack that can be very fast (100 ps).

Recently a zoology of complex spin textures stabilized by volume or interface Dzyaloshinskii-Moriya interactions have been discovered including, in our work, anti-skyrmions [4], elliptical Bloch skyrmions [5], two-dimensional Néel skyrmions [6] and fractional antiskyrmions [7]. We discuss our recent observation of Néel skyrmions and conventional magnetic bubbles in two distinct but closely related 2D van der Waal's ferromagnetic compounds. SAF structures are highly promising for spintronics especially since this allows for magnetic structures that have zero net magnetization and, consequently, very small fringing magnetic fields, while, at the same time, these structures have magnetic surfaces that aid the detection of their magnetic state. Antiferromagnetic structures can have nearly zero net magnetization but are much more difficult to detect than SAFs. Highly interesting antiferromagnetic materials are those that are chiral and topological such as the family of Mn_3X (X=Ge, Sn, Sb) that have a Kagome structure. We discuss our recent work on the current induced manipulation of the antiferromagnetic order in thin epitaxial films of Mn_3Sn. In particular, we introduce the concept of seeded spin orbit torque (SSOT) that allows for the manipulation of the antiferromagnetic order, even in layers that are more than 100 nm thick. The triangular antiferromagnetic structure of Mn_3X [8] leads to highly interesting properties including an anomalous Hall effect derived from an intrinsic Berry curvature even though the magnetization is zero. Zero-moment chiral spin textures ranging from domain walls to anti-skyrmions have great promise for highly interesting spintronic technologies for Racetrack Memories and beyond.

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[4] A. K. Nayak et al., "Magnetic antiskyrmions above room temperature in tetragonal Heusler materials," *Nature* **548**, 561 (2017)
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[6] A. K. Srivastava et al., "Observation of Robust Néel Skyrmions in Metallic PtMnGa," *Adv. Mater.* **32**, p. 1904327, (2020)
[7] J. Jena et al., "Observation of fractional spin textures and bulk-boundary correspondence," submitted, (2021)
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THE COMING DECADES OF QUANTUM SIMULATORS

Maciej Lewenstein

Institute of Photonic Sciences, Barcelona, Spain

The universal quantum computers with large number of qubits, and fault tolerant error correction do not exist. The Noisy Intermediate Scale Quantum devices exhibit disputable quantum advantage in some academic problems. In this situation, analogue and digital quantum simulators offer the most immediate access to study open problems in physics and chemistry. I will review recent efforts of Mankind, in general, and the ICFO Quantum Theory Group in particular to design, analyze and numerically simulate quantum simulators of interesting models that exhibit topological order and mimic important phenomena of condensed matter and high energy physics.

ULTRAFAST SPIN-TO-CHARGE CONVERSION IN TOPOLOGICAL INSULATORS SURFACE STATES PROBED BY THz EMISSION SPECTROSCOPY

Henri Jaffrès[1], E. Rongione[1,2], L. Baringthon[1,3], S. Fragkos[4], P. Tsipas[4], J. Hawecker[2], T.-H. Dang[1], E. Xenogiannopoulou[4], P. Lefèvre[3], N. Reyren[1], G. Patriarche[5], A. Lemaître[5], A. Dimoulas[4], R. Lebrun[1], J.-M. George[1], S. Dhillon[2]

[1] *Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, F-91767 Palaiseau, France*

[2] *Laboratoire de Physique de l'Ecole Normale Supérieure, ENS, Université PSL, CNRS, Sorbonne Université, Université de Paris, F-75005 Paris, France*

[3] *Synchrotron SOLEIL, Cassiopée beamline, F-91190 Saint-Aubin, France*

[4] *Institute of Nanoscience and Nanotechnology, National Center for Scientific Research "Demokritos", G-15310 Athens, Greece*

[5] *Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, F-91120 Palaiseau, France*

Corresponding author: henri.jaffres@cnrs-thales.fr

Spin-charge conversion (SCC) by inverse spin Hall and/or inverse Rashba-Edelstein effects at the interface of heavy metals or topological insulators (TIs) and involving high spin-orbit interactions are of a prime importance for today's spintronics and its applications e. g. using spin-orbit torque functionalities. In that prospect, THz emission spectroscopy can offer a very reliable probe to investigate ultrafast spin and charge currents to probe the spin-injection efficiency in devices [1]. Systems either consist in nanometer-thin multilayers composed by a ferromagnetic (FM) layer and a heavy metal (HM) from the 3d-5d family giving rise to SHE with engineered interfaces [2, 3]. Alternative path for spin-orbit torque technologies now turns to bilayers of FM and topological insulator (TI). TIs present conductive topological surface states (TSS) which allow interfacial SCC via the inverse Rashba-Edelstein effect (IREE). In these systems, enhanced SCC is expected owing to i) the large Fermi velocity of related TSS together with ii) the insulating behavior of the TI bulk.

In this study, we demonstrate large ultrafast spin-charge interconversion and THz emission using the TSS of $Bi_{1-x}Sb_x$ and Bi_2SnTe_4 TI quantum interfaces. As an example, we have reported on Fig. 1a THz emission features from dynamical spin-injection in $Bi_{0.79}Sb_{0.21}$ (15 nm) and Bi_2SnTe_4 (5SL) compared to Co/Pt ISHE STE. Stoichiometry of Bi_2SnTe_4 has been chosen to minimize the presence of bulk bands at the Fermi crossing [4] contrary to other Bi-based TIs such as Bi_2Se_3 [5]. Emission performances of $Bi_{0.79}Sb_{0.21}$ and Bi_2SnTe_4 are about the same order of magnitude as Co/Pt ISHE SCC state-of-the-art STE. Moreover, thickness-independent renormalized emission shown in Fig. 1b on Bi_2SnTe_4 is in favor of an interfacial SCC carried by IREE. Besides, Fig. 1c presents azimuthal crystalline dependence of the THz magnetic contribution which reveals an isotropic emission, expected from an IREE model for SCC. In conclusion, TIs here illustrated by $Bi_{1-x}Sb_x$ and Bi_2SnTe_4 would be suitable candidates for strong STE output power and THz emission spectroscopy allows to explore TSS mediated SCC mechanism.

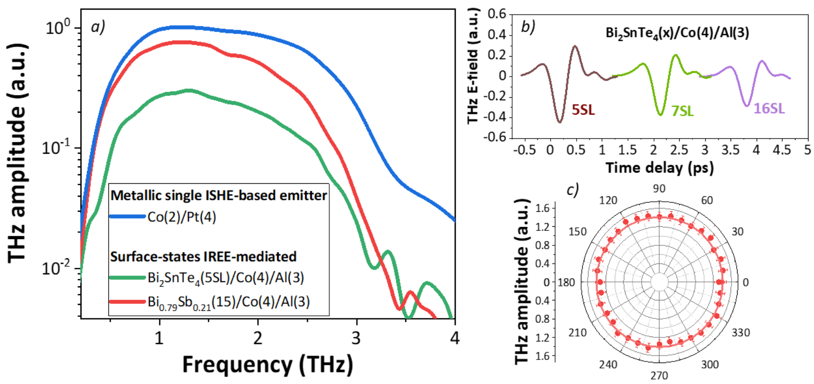

Fig. 1: (a) $Bi_{0.79}Sb_{0.21}$/Co and Bi_2SnTe_4/Co THz emission compared to Co/Pt ISHE STE. (b) Absorption renormalized THz emission as a function of Bi_2SnTe_4 thickness. (c) $Bi_{0.79}Sb_{0.21}$/Co isotropic THz emission mapped as a function of the azimuthal crystalline orientation.

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[2] Dang T. H. et al., "Ultrafast spin-currents and charge conversion at 3d-5d interfaces probed by time-domain terahertz spectroscopy", *Appl. Phys. Rev.* **7**, (2020)

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SUPERCONDUCTING SPINTRONICS WITH SPIN-ORBIT COUPLING AND SYMMETRY FILTERING

Farkhad G. Aliev*

Dpto. Física Materia Condensada, Universidad Autónoma de Madrid, Spain

Realizing exotic states and emerging low-dissipation applications in superconducting spintronics focuses on overcoming the competition between ferromagnetism and superconductivity through long-range triplet (LRT) proximity effects. Unfortunately, common approaches are not compatible with commercial spintronic applications based on ferromagnets, such as a Fe or Co, which with MgO tunnel barriers ensure record values of room-temperature magnetoresistance (MR). To overcome these limitations, we propose a new platform for superconducting spintronics based on interfacial spin-orbit coupling (SOC) and symmetry-filtering in all-epitaxial V/MgO/Fe junctions. Remarkably, as supported by detailed theoretical calculations, we experimentally demonstrate that the resulting transport phenomena, consistent with LRT, are strongly influenced by SOC, even when its role in the normal state is negligible [1]. The unique features in our epitaxial junctions arise from the spin reorientation non-volatile transition below 80 K [2] which allows for the creation and control of different remanent magnetization states even at zero applied magnetic field.

We also report the experimental observation of superconductivity-induced modification of both the in-plane and perpendicular magnetization anisotropies (PMA) in ferromagnet/superconductor junctions with engineered spin-orbit coupling [3,4]. We present evidence for in-plane magnetization reorientation in a ferromagnetic layer by driving the system through a superconducting phase transition. We observe the effect in V/MgO/Fe(001) systems where the cubic anisotropy of (soft) Fe(001) is modulated by the superconductivity of V through spin-orbit coupling at the MgO/Fe interface, triggering a rotation of the magnetization direction of Fe(001) [3]. Finally, we demonstrate that the modification of the PMA is controlled by the competition between the in-plane and out of plane anisotropies [4] and consider both the microscopic origin (magnetization-dependent spin triplet Cooper pair formation) and the influence of macroscopic effects (interaction between superconducting vortices and magnetic textures).

* In collboration with César González-Ruano, Diego Caso, Lina G. Johnsen, Petra Högl, Isidoro Martínez, Coriolan Tiusan, Michel Hehn, Niladri Banerjee, Jaroslav Fabian, Igor Žutić, Jacob Linder.

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SKYRMION LATTICE MELTING IN GaV_4S_8

Pavel Baláž*, Marek Paściak, Jiří Hlinka

Department of Dielectrics, FZU-Institute of Physics of the Czech Academy of Sciences Na Slovance 1999/2, 182 21 Prague 8, Czech Republic

Corresponding author: balaz@fzu.cz

GaV_4S_8 belongs to the group of lacunar spinels - materials falling into the group of narrow-gap Mott insulators showing a number of interesting physical phenomena like relativistic spin-orbit effects, pressure-induced superconductivity or two-dimensional topological insulator state [1]. Below approximately 50 K lacunar spinels undergo the Jahn–Teller distortion to a rhombohedral R3m state with C_{3v} symmetry. In the rhombohedral state GaV_4S_8 is a ferromagnet with Curie temperature about 15 K. Its magnetic moments are formed by the V_4 clusters organized in hexagonal layers having spin ½ each. These magnetic moments interact via the exchange interactions as well as Dzyaloshinskii-Moriya interaction (DMI). Importantly, as a consequence of the polar axial symmetry, GaV_4S_8 has been shown to host Néel-type Skyrmions, which form skyrmion lattice in a certain range of applied magnetic fields and temperatures [2].

Recently, it has been shown by atomistic simulations of 2D Heisenberg model with DMI [3] that thermal fluctuations can disturb the order of the solid-like hexagonal skyrmion lattice and induce its melting towards skyrmion liquid. Since skyrmion lattice is essentially a two dimensional system, it is natural to expect that, in analogy with system of 2D discs, it will undergo topological phase transition described by the Kosterlitz-Thouless-Halperin-Nelson-Young theory (KTHNY). An important result of this theory is the prediction that the transition from the solid-like phase into the liquid one will happen via a so-called hexatic phase, which has been recently also observed experimentally in a skyrmion lattice in Cu_2OSeO_3 [4].

In this talk we present our theoretical results analysing the skyrmion lattice melting in GaV_4S_8. By means of an atomistic spin model based on ab initio calculations [2] we performed large scale simulations and analysed the positional and orientational correlations of skyrmions in GaV_4S_8 in order to demonstrate the existence of hexatic phase in the skyrmion lattice [5].

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TOPOLOGICAL ANTIFERROMAGNETIC SKYRMIONS

Alireza Qaiumzadeh

Centre of Quantum Spintronics (QuSpin), Department of Physics, Norwegian University of Science and Technology, Norway

In this talk, I present our recent results on fast generation of isolated AFM skyrmions, nonlinear topological solitons in relativistic magnetic systems, inside a confined geometry. These topological skyrmions can be used as non-volatile magnetic bits in future spintronic-based data storage and processing information. I will also present the fast dynamics of single skyrmions in antiferromagnetic insulators under an applied temperature gradient.

SPIN-ORBITAL SEPARATION IN HUND METALS

Jan von Delft

Arnold Sommerfeld Center for Theoretical Physics, Center for NanoScience, and Munich Center for Quantum Science and Technology, Ludwig-Maximilians-University Munich, Germany

Hund metals are multiorbital materials with broad bands which are correlated via the ferromagnetic Hund coupling J, rather than the Hubbard interaction U. They are characterized by spin-orbital separation (SOS), a two-stage Kondo-type screening process in which spin screening occurs at much lower energy scales than spin screening. By contrast, Mott-correlated metals, dominated by U rather than J, lie close to the phase boundary of a metal-insulator transition, where the SOS window becomes negligibly small. We study the interplay between Hund and Mott physics for a minimal model for Hund metals, the orbital-symmetric three-band Hubbard-Hund model (3HHM) for a lattice filling of 1/3. Using Dynamical Mean-Field Theory and the Numerical Renormalization Group as real-frequency impurity solver, we identify numerous fingerprints distinguishing Hundness from Mottness in the temperature dependence of various physical quantities.

INTERPLAY OF SUPERCONDUCTIVITY AND MAGNETISM IN NANOSTRUCTURES

Tadeusz Domański

Institute of Physics, M. Curie-Skłodowska University, 20-031 Lublin, Poland

Magnetism is usually in conflict with superconductivity in bulk materials. Their relationship in nanostructures, however, is much more subtle. Under specific conditions it becomes pretty constructive, leading to emergence of qualitatively new states of matter. I shall provide a few examples of this synergy. For instance, semiconducting nanowires with the strong spin-orbit coupling proximized to isotropic superconductors and in presence of external magnetic develop the inter-site triplet pairing, which at critical magnetic field undergoes transition to the topologically nontrivial phase. Natural tendency towards topological phase is observable in nanoscopic chains of magnetic impurities deposited on superconducting substrates, which arrange themselves into such helical texture that energetically prefers the nontrivial superconducting state (topofilia). Other possible realizations of topological superconducting phases are feasible in magnetic ladders and/or nanoscopic magnetic islands on conventional superconductors. I will discuss the properties of exotic quasiparticles emerging on boundaries of these topological superconductors and present means to manipulate them with a spatial and temporal precision.

TRANSITIONS IN MATTER INDUCED BY INTENSE X-RAY RADIATION AND THEIR DIAGNOSTICS

Beata Ziaja-Motyka

CFEL, DESY, Notkestrasse 85, 22607 Hamburg, Germany

INP, PAS, Radzikowskiego 152, 31-342, Krakow, Poland

Corresponding author: ziaja@mail.desy.de

X-ray induced structural transitions in solids are in focus of this talk. Depending on the dose absorbed, an irradiation with a femtosecond X-ray pulse can trigger an ultrafast electronic or structural transition in solid materials. In magnetic materials, an X-ray triggered ultrafast demagnetization can also occur. In this talk, selected study cases [1-9] for these transitions are presented. Dedicated theoretical modeling reveals complex multistage evolution of the irradiated systems, confirmed by experimental measurements performed at FERMI and at other XFEL facilities. Challenges remaining for the modeling and quest for further improvements of the necessary diagnostics tools are discussed.

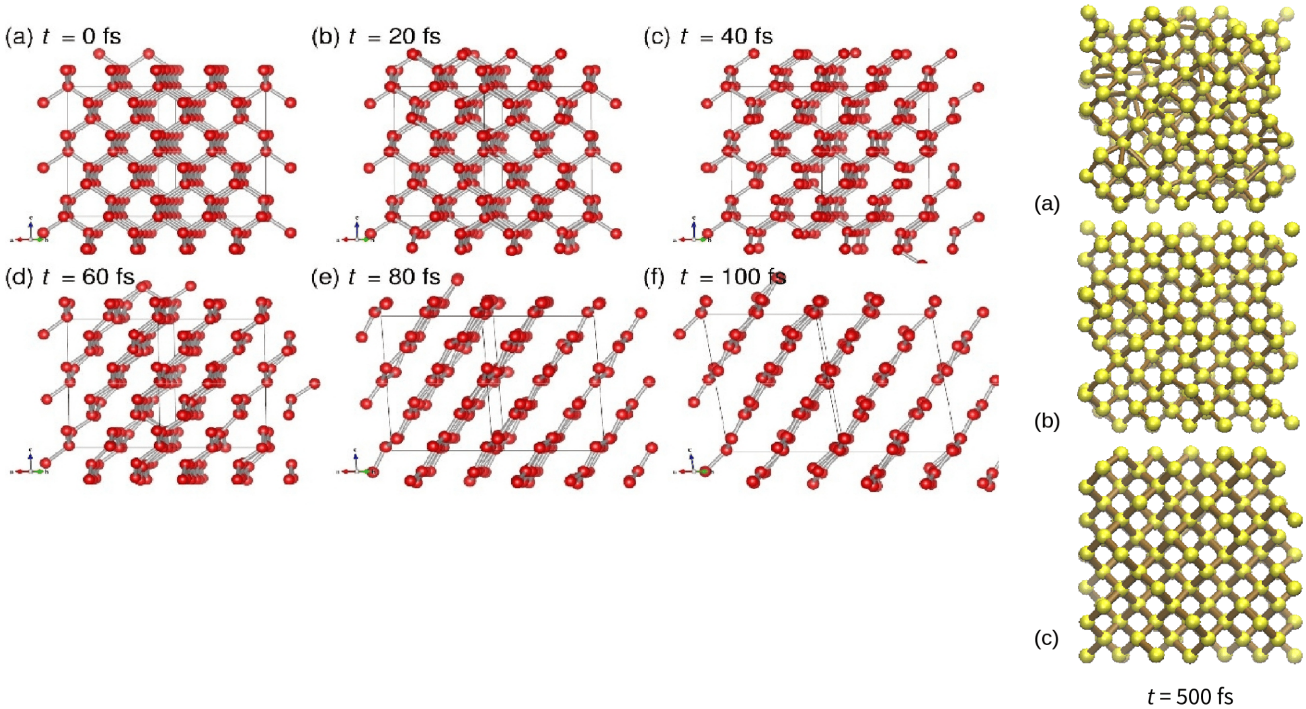

Fig. 2: Ultrafast graphitization of diamond triggered by soft X-ray pulse of 10 fs duration (left) & dose-dependent structural changes in silicon crystal triggered by hard X-ray pulse of 25 fs duration (right)

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KONDO CLOUD IN A SUPERCONDUCTOR

Gergely Zarand

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

Magnetic impurities embedded in a metal are screened by the Kondo effect, signaled by the formation of an extended correlation cloud, the so-called Kondo or screening cloud. In a superconductor, the Kondo state turns into sub-gap Yu-Shiba-Rusinov (Shiba) states, and a quantum phase transition occurs between screened and unscreened phases once the superconducting energy gap Δ becomes sufficiently large compared to the Kondo temperature, TK.

We show that, although the Kondo state does not form in the unscreened phase, the Kondo cloud does exist in both quantum phases. However, while screening is complete in the screened phase, it is only partial in the unscreened phase [1]. Compensation, a quantity introduced to characterize the integrity of the cloud, is universal, and shown to be related to the magnetic impurities' g-factor, monitored experimentally by bias spectroscopy. We also discuss the implication of these results in the context of tunneling experiments, detecting a surprisingly extended Shiba state [2].

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MAGNETIC PATTERNING OF Co/Tb BY He^{+} ION BOMBARDMENT

Ł. Frąckowiak[1], F. Stobiecki[1], G. D. Chaves-O'Flynn[1], M. Urbaniak[1], M. Matczak[2], P. P. Michałowski[3], A. Maziewski[2], M. Reginka[4], A. Ehresmann[4], P. Kuświk[1]

[1]*Institute of Molecular Physics, Polish Academy of Sciences, Smoluchowskiego 17, Poznań, Poland*

[2]*Faculty of Physics, University of Białystok, Ciołkowskiego 1L, Białystok, Poland*

[3]*Łukasiewicz Research Network - Institute of Microelectronics and Photonics, Aleja Lotników 32/46, Warsaw, Poland*

[4]*Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, Kassel, Germany*

Recently, interest in ferrimagnetic/sperimagnetic rare earth transition metal films has experienced a renaissance due to their multitude of applications (e.g. all-optical switching, current-induced magnetization switching with spin-orbit torque effect, creation and fast propagation of skyrmions). For such applications, the spin configuration and its influence on the magnetization reversal play a crucial role, because they determine applicability in novel devices.

This work presents a new magnetic patterning approach to change the contribution of Tb sublattices to effective magnetic properties of perpendicularly magnetized Tb/Co multilayer by 10-keV He^{+} ion bombardment. In this system, ion bombardment shifts the compensation point of the two magnetic subsystems towards a higher concentration of Tb. This type of modification enables local change of the domination from Tb+(RE+) to Co+(TM+) in systems that are Tb+ prior to the bombardment. This effect was used for local magnetic patterning and to fabricate a 2D-lattice of artificial magnetic domains displaying a particularly stable magnetic configuration, in which adjacent magnetic domains with oppositely oriented effective magnetization exist without domain walls in between (Fig. b) [1]. These domains are particularly stable because they show a deep minimum in their free energy due to flux closure of the stray fields and corresponding energy reduction without exchange and anisotropy energy increases associated with domain walls. In contrast, in magnetic saturation the corresponding monodomain state of the effective magnetization shows domain walls in the two magnetic subsystems (Fig. a). The presence of this type of magnetic spin texture strongly affects the magnetization reversal which will be analyzed with magnetooptical magnetometry and microscopy [2].

Acknowledgement: The work was financed by the National Science Centre Poland under SONATA BIS funding (2015/18/E/ST3/00557). Ł. F and F. S. acknowledge support from the National Science Centre Poland through the PRELUDIUM Project (2018/31/N/ST5/01810).

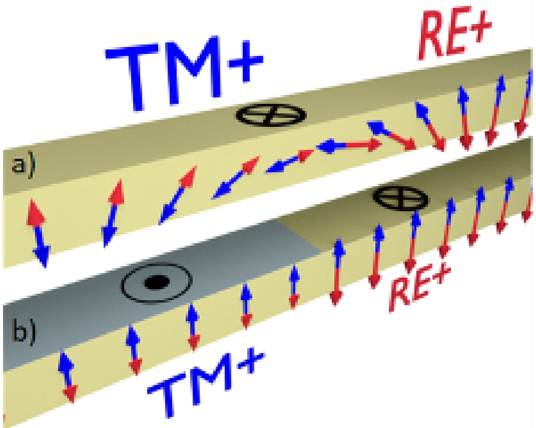

Fig. 3: a) Domain wall (DW) between TM+ and RE+ areas with effective magnetizations directed downwards, b) magnetic domains without DW after switching of the TM+ area

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QUANTUM COMPUTING – VISION AND FUTURE BY IBM QUANTUM

Piotr Biskupski

IBM Polska Sp. z o.o., Warszawa, Poland

Quantum computing takes advantage of the laws of quantum mechanics found in nature to create a powerful new paradigm of information processing. Quantum information science has immense potential to realize transformative technologies revolutionizing areas of science, engineering, and industry involving computation, communication, highly precise measurement, and others. This has driven an ever-increasing number of researchers to work enthusiastically and intensely to realize this potential.

IBM's history with quantum information science can be traced back to the late 1960s, when IBM researchers Ralph Landauer and Charles Bennett started their revolutionary work exploring the relationship between quantum mechanics and information — i.e., the classical Turing computing machine – that ultimately gave rise to the field. Later on in the early 1980s another pioneer, Paul Benioff, suggested quantum mechanics – which governs physical laws at the fundamental level – as a model for computation and Richard Feynman demonstrated that a classical computer cannot efficiently simulate quantum phenomena such as entanglement. Since then, the underlying technology has advanced rapidly. IBM's commitment to bring quantum computers to the world led us to launch the IBM Q Experience in May 2016 as a resource for people to learn about and use quantum computers for business and science. This was a groundbreaking moment offering access to the world's first publicly available quantum cloud computer. Today, anyone can write their own quantum programs by accessing a fleet of IBM quantum systems over the secure IBM cloud through the Qiskit (https://qiskit.org/) open source software framework via the secure IBM Q Experience quantum cloud services platform (https://www.ibm.com/quantum-computing/technology/experience/), and learn quantum computing using Qiskit with IBM Q open source textbook (https://community.qiskit.org/textbook/preface.html), constantly updated with community help to include the latest developments. Importantly, IBM believes that offering the full quantum technology stack in house – the most advanced hardware, integrated systems, cloud services, quantum application development research. IBM Q systems have been widely used by the quantum information science community, resulting in the publication of scientific papers by users of the IBM Q Experience, in addition to significant research published in peer reviewed scientific articles by our quantum researchers, including theoretical proof of quantum advantage and applications of quantum for artificial intelligence, chemistry, and finance.

IBM Quantum roadmap that we think will take us from the noisy, small-scale devices of today to the million-plus qubit devices of the future. Our team is developing a suite of scalable, increasingly larger and better processors, with a 1,000-plus qubit device, called IBM Quantum Condor, targeted for the end of 2023. In order to house even more massive devices beyond Condor, we're developing a dilution refrigerator larger than any currently available commercially. This roadmap puts us on a course toward the future's million-plus qubit processors thanks to industry-leading knowledge, multidisciplinary teams, and agile methodology improving every element of these systems. All the while, our hardware roadmap sits at the heart of a larger mission: to design a full-stack quantum computer deployed via the cloud that anyone around the world can program.

Knowing the way forward doesn't remove the obstacles; we face some of the biggest challenges in the history of technological progress. But, with our clear vision, a fault-tolerant quantum computer now feels like an achievable goal within the coming decade.

UNIDIRECTIONAL EDGE STATES IN TRIANGULAR Py ELEMENTS

J. Feilhauer[1], M. Zelent[2], Z. Zhang[3], J. Christensen[4] and M. Mruczkiewicz[1,5*]

[1] *Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska Cesta 9, SK-841-04 Bratislava, Slovakia*

[2] *Faculty of Physics, Adam Mickiewicz University in Poznan, ul. Uniwersytetu Poznańskiego 2, Poznań, 61-614 Poland*

[3] *Department of Physics, Nanjing 210093, China*

[4] *Universidad Carlos III de Madrid, Department of Physics, Avenida de la Universidad 3028911 Leganes, Madrid, Spain*

[5] *Centre For Advanced Materials Application CEMEA, Slovak Academy of Sciences, Dubravska cesta 9, 845 11 Bratislava, Slovakia*

Corresponding author: michal.mruczkiewicz@savba.sk

Topological edge states, insensitive to defects, were demonstrated in many wave hosting systems. Topological magnonics is an emerging topic in modern magnetism. Until now, it mainly exploits the analogies of topological waves considered in other wave hosting systems. However, the field of magnonics provides a platform for studying new kinds of phenomena that are specific to spin wave, due to intrinsic nonreciprocal or nonlinear properties of SWs.

In spite of several theoretical demonstration of topological magnonics, the experimental confirmation is still missing. The main obstacles preventing experimental observations are: difficulty of nano-fabrication of complex geometry, low coupling between elements, difficulty to control the ground state, low sensitivity of in-plane dynamical field component, high density of modes when scaling up of structures, or high damping in case of DMI-based concepts. One of the designs that is closest to realization is based on perpendicularly magnetized YIG [1], but still requires a complex nano-patterning, high external field and measurements of in-plane field components.

Here, we present a numerical demonstration of structure that potentially solves many of the experimental obstacles. Therefore, it is one of the most suitable candidate for realization of unidirectional edge waves in magnonic crystal. Our design is composed of Py squares with side length of 150 nm, cut along diagonals and formed in rectangular lattice (Fig. left). The formation of the topological edge state can be realized when each square is in the closed domain state with the same chirality and finite perpendicular component of magnetization (Fig. right) [2]. We demonstrate that required magnetic state can be controlled by external magnetic field or MFM tip. Our design shows a potential for scaling up the size of the structure.

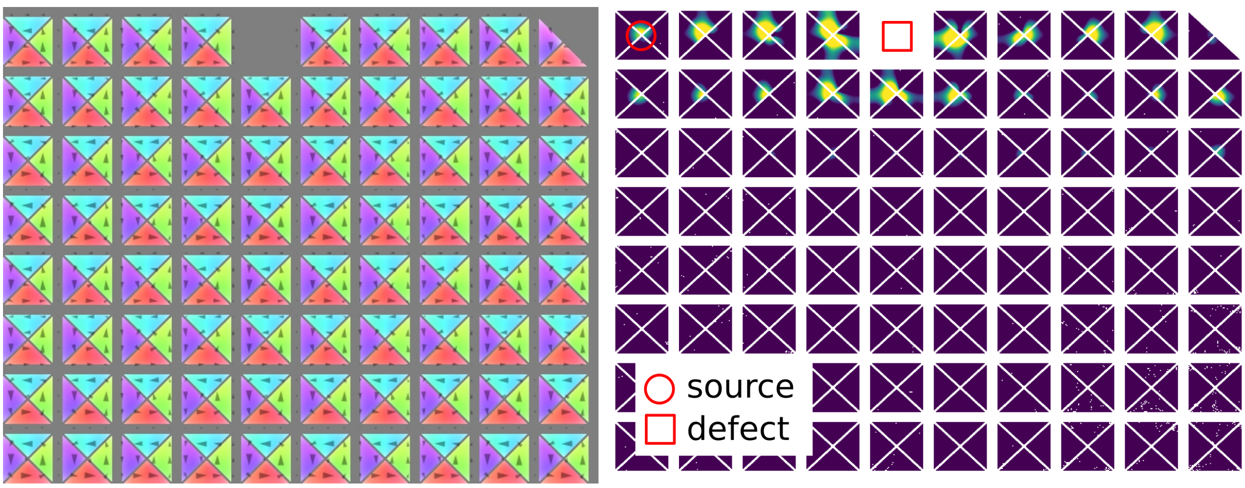

Fig. 4: Left: A finite magnonic crystal state stabilized by external magnetic field. Right: Snapshot of a propagating spin wave in finite magnonic crystal

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NANOMAGNONICS WITH FERROMAGNETIC GRATINGS – FROM LOGIC OPERATION TO MEMORY

Dirk Gründler

Laboratory of Nanoscale Magnetic Materials and Magnonics (LMGN), Institute of Materials
Institute of Electrical and Micro Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland
Corresponding author: dirk.grundler@epfl.ch

Collective spin excitations (spin waves) in thin-film materials and nanostructures have generated a large interest in fundamental research and the applied sciences during the recent years. The findings substantiate that short- wave magnons offer novel perspectives for information processing in integrated circuits operating in the GHz frequency regime [1]. However, many magnonic devices are still limited due to anisotropic characteristics of spin waves and the lack of an on-chip storage process of propagating spin wave signals. The latter would enable an architecture for data processing which avoids the von Neumann bottleneck, i.e., the physical separation between processor unit and data storage device.

In our presentation we discuss our recent research in nanomagnonics by which we explore the interference between short-wave magnons propagating in arbitrary directions of a thin-film device and the switching of magnetic bits (ferromagnetic nanomagnets) by propagating spin waves. In both cases we make use of nanoengineered ferromagnet/ferrimagnet hybrid structures consisting of nanostructured permalloy on top of an yttrium iron garnet thin film [2]. Depending on the targeted functionality, the nanostructures are arranged as ferromagnetic gratings either aperiodically (in a quasicrystalline manner [3,4]) or periodically [2]. Our experiments are based on microwave spectroscopy using coplanar waveguides [5], scanning inelastic light scattering [3,4] and magnetic force microscopy. Our recent results [6,7] lay the grounds for wave-based logic operations at the nanoscale and in-memory computation. The findings promise beyond von Neumann device architectures in magnonics.

Acknowledgement: The work was possible due to excellent cooperation with Korbinian Baumgaertl, Vinayak S. Bhat, Ping Che, Elif Dayi, Carsten Dubs, Mohammad Hamdi, Anna Kukolova, Andrea Mucchietto, Shixuan Shan, and Sho Watanabe. Our work is supported by SNSF via projects 163016, 177550, 197360 and the sinergia project 171003 Nanosykrmionics.

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CENTIMETER SCALE NANOSTRUCTURES: LITHOGRAPHY-FREE METAMATERIALS FOR PHOTOCONVERSION, PHOTODETECTION, LIGHT EMISSION, SENSING, AND FILTERING

Ekmel Özbay

NANOTAM-Nanotechnology Research Center, Bilkent University, 06800 Ankara, Turkey

Corresponding author: ozbay@bilkent.edu.tr

The efficient harvesting of electromagnetic (EM) waves by subwavelength nanostructures can result in perfect light absorption in the narrow or broad frequency range. These metamaterial-based perfect light absorbers are of particular interest in many applications. Although advances in nanofabrication have provided the opportunity to observe strong light–matter interaction in various optical nanostructures, the repeatability and upscaling of these nano units have remained a challenge for their use in large scale applications. Thus, in recent years, the concept of lithography-free planar light perfect absorbers has attracted much attention in different parts of the EM spectrum, owing to their ease of fabrication and high functionality. In this presentation, we will explore the material and architecture requirements for the realization of light perfect absorption using these multilayer metamaterial designs from ultraviolet (UV) to far-infrared (FIR) wavelength regimes. We show that, by the use of proper material and design configuration, it is possible to realize these lithography-free light perfect absorbers in every portion of the EM spectrum [1]. This, in turn, opens up the opportunity of the practical application of these perfect absorbers in large scale dimensions. In last couple of years, we adopted these lithography-free techniques in many applications including photoconversion, photodetection, light emission, sensing, filtering and thermal camouflage [2–9]. This presentation will summarize our recent accomplishments in this field.

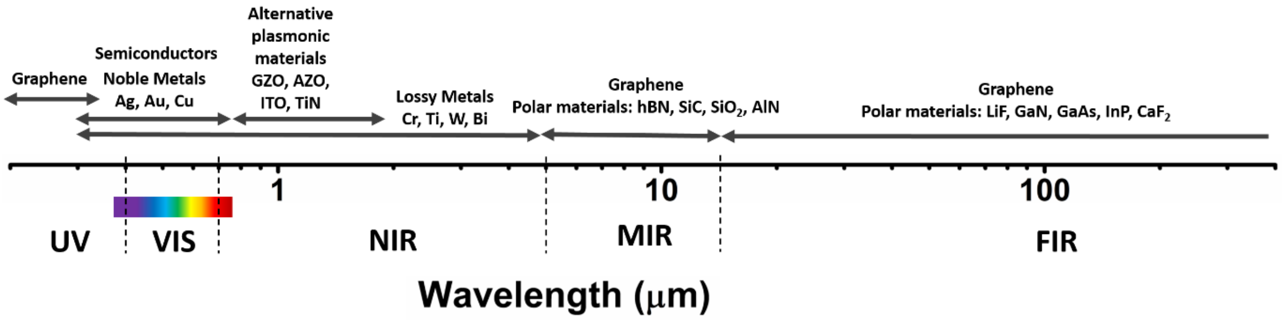

Fig. 5: A graph summarizing the proper choice of materials to realize light perfect absorption in different parts of EM spectrum

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ULTRAFAST SPIN DYNAMICS AND SPIN WAVES IN GRAPHENE/FERROMAGNETIC THIN FILM HETEROSTRUCTURES

Anjan Barman

S. N. Bose National Centre for Basic Sciences, Block JD, Sector 3, Salt Lake, Kolkata, 700106, India
Corresponding author: abarman@bose.res.in

Graphene/ferromagnet interface promises a plethora of new science and technology. They will form important building block for carbon-based spintronics due to the ability of graphene to transport spin current over very long distance and possible increase in spin-orbit coupling due to proximity and hybridization, which may provide new opportunities for the spin-based device fabrication [1]. For the ultra-high speed spintronics applications, it is essential to have a deep insight about the magnetization dynamics occuring over nanosecond to femtosecond timescale. The optimization of these devices demands understanding and possible control of ultrafast demagnetization, Gilbert damping as well as spin-wave propagation.

We will discuss the ultrafast spin dynamics occurring over femtosecond to nanosecond timescale measured by an all-optical time-resolved magneto-optical Kerr effect technique [2] in single layer graphene (SLG)/CoFeB thin film heterostructures with varying CoFeB thickness. We will compare the results with reference CoFeB thin films without SLG underlayer. The modulation of Gilbert damping with CoFeB layer thickness is extensively modelled to extract the spin-mixing conductance for SLG/CoFeB interface and isolate the contribution of two-magnon scattering from spin pumping. In SLG/CoFeB, we have established an inverse relationship between the ultrafast demagnetization time and the Gilbert damping parameter dominated by the interfacial spin accumulation and pure spin currents transport via spin pumping mechanism [3].

The interfacial Dzyaloshinskii Moriya interaction (iDMI) is crucial for stabilizing chiral spin textures, which are important for future spintronic devices. Here, we will present direct evidence of iDMI in graphene/Ni80Fe20/Ta heterostructure from asymmetry in spin-wave dispersion using Brillouin light scattering (BLS) technique. Linear scaling of iDMI with the inverse of Ni80Fe20 thicknesses confirms purely interfacial origin of iDMI. Both iDMI and spin-mixing conductance increase with the increase in defect density of graphene obtained by varying argon pressure during sputter deposition of Ni80Fe20. This suggests that the observed iDMI stems from defect-induced extrinsic spin-orbit coupling at the interface [4].

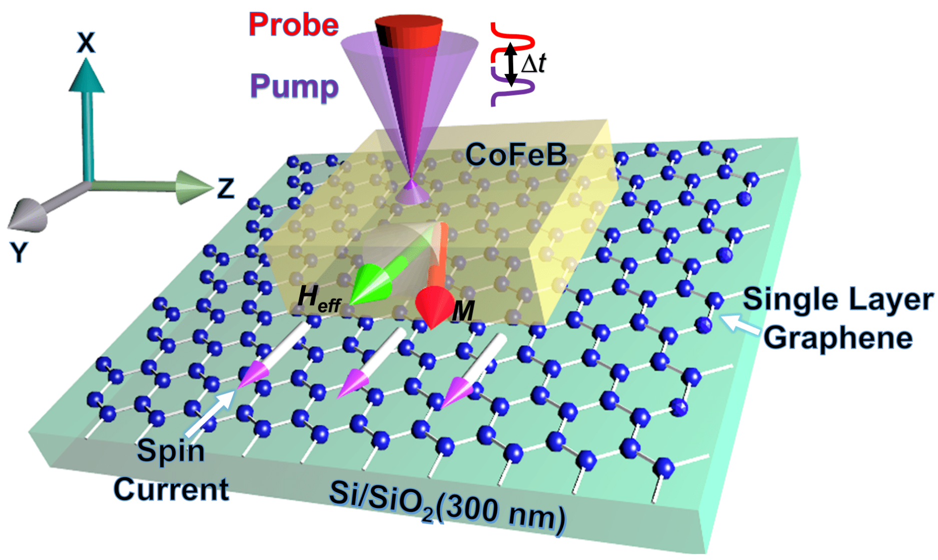

Fig. 6: Schematic of spin current driven ultrafast spin dynamics in graphene/CoFeB heterostructure

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MAGNETIZATION DYNAMICS FROM FEMTO- TO NANOSECOND TIME SCALE

Susmita Saha

Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden

The research on the light mater interaction is immensely increased, in last decades, as it leads to various novel effects such as all optical switching [1], heat assisted magnetic recording, optical intersite spin transfer effect [2], spin current [3], etc. When a ferromagnet is excited by a femtosecond laser pulse, the magnetization of a ferromagnet is quenched in sub pico second time scale. This is known as ultrafast demagnetization. In 1996, Beaurepaire et al. [4] first time reported the ultrafast demagnetization and the subsequent spin dynamics in a ferromagnetic Ni thin film induced by 60 fs optical pulses. At longer time scale the precession of magnetization is observed. The damping associated with magnetization precession as well as spin waves are observed from sub-ns to tens of ns time scale.

In this talk I will describe two different system showing two different magnetization dynamics at two different time scale. The first system is Ni-ferrite [5] which is an insulating ferrimagnet with an inverse spinel structure, already has gained a huge attention of scientific community due to its potential applications in spintronic devices. we use table-top high harmonic generation (HHG) in the extreme ultraviolet (XUV) regime to investigate the underlying mechanisms for the M-edge spectroscopy for Ni-Ferrite at femtosecond time scale. Recently, HHG has emerged as a powerful tool that can probe the M-edge resonances (3p core levels) in 3d transition metals compounds, which enables the investigation of the element specific response of a multi-sublattice systems.

The second system is artificial spin ice displaying anisotropic magnetostatic interactions and long-range ordering. The magnetization dynamics at nanosecond time scale will be explored for such spin ice system by using a time resolved magneto optical Kerr effect microscope. The evolution of individual spinwave modes, from building blocks up to larger arrays, highlighting the role of symmetry breaking in defining the mode profiles will be described [6].

Both the observations have a significant impact of the fundamental understanding of the ultrafast processes and application of spinwaves in future spintronic devices.

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SPIN WAVE CONTROL USING CHIRAL MAGNONIC RESONATORS

Volodymyr Kruglyak

University of Exeter, Physics Building, Stocker Road, Exeter, EX4 4QL, United Kingdom

Spin waves are actively explored as signal and data carriers within future devices of magnonics, spintronics and their spinouts across discipline boundaries. In my talk, I will discuss how spin waves can be injected, manipulated, and detected with help of nanoscale chiral magnonic resonators [1,2], with a focus on the recent discovery of their dark-mode version [3]. In the end, I will touch the emerging topic of magnon valleytronics, showing how chiral magnonic resonators can be used to set and to read-out magnonic pseudospin [4].

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TUNABLE MAGNONIC INTERCONNECTIONS: COUPLERS AND 3D STRUCTURES

Alexandr Sadovnikov

Saratov State University, Saratov, Russia

In recent years much research has been directed towards the use of spin waves for signal processing at microwave and subterahertz frequencies due to the possibility to carry the information signal without the transmission of a charge current. Recent theoretical and experimental studies suggest that strain can be used to engineer energy-efficient complicated 2D and 3D piezoelectric material and heterostructures.

The main topic of the proposed talk will be devoted to the the experimental observations of the spin-wave coupling phenomena in different magnonic structures based on the asymmetric adjacent magnonic crystals, adjacent magnetic yttrium iron garnet stripes and array of magnetic stripes, which demonstrates the collective spin-wave phenomena such as the discrete soliton formation. The voltage-controlled spin-wave transport along bilateral magnonic stripes was demonstrated. The model describing the spin-wave transmission response and predicting its value is proposed based on the self-consistent equations. It was shown that the strain-mediated spin-wave channels can be used to route the magnonic information signal and thus the composite magnon-straintronic structure could provide to fabricating magnonic platforms for energy-efficient signal processing. The obtained results open new perspectives for the future-generation.

QUANTUM COMPUTERS AND NEGATIVE BITS

Dagomir Kaszlikowski

Centre for Quantum Technologies, National University of Singapore, Singapore
Corresponding author: phykd@nus.edu.sg

We have already entered the era of commercial quantum computing and quantum information processing [1]. Our understanding of quantum Turing machines uses Hilbert space representation of quantum theory. However, one can look at quantum mechanics as quasi-probability processes in phase space [2]. One of the pragmatic reasons to do this is our rather poor understanding of quantum speedup origins, or more colloquially, what makes quantum computer tick. There are also fundamental reasons to explore this alternative picture, some of which I would like to discuss here.

I will show how you can represent quantum mechanics as a positive probability theory with positive stochastic processes, controlled by a negative probabilistic bit (nebit). Nebit produces 0 with probability 1+x and 1 with probability -x. Avoiding any philosophical interpretations of quasi-probabilities I will discuss basic information properties of nebit and argue that you can see it as a source of non-classical properties of quantum theory, including the origins of quantum speedup in some class of oracle based quantum algorithms [3].

In the last segment of the talk, I will use nebit to discuss a wider class of probabilistic theories not observed in Nature but consistent with some of its fundamental principles such as finite speed of information propagation and locality.

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IDENTIFICATION AND QUANTIFICATION OF NONCLASSICALITY OF EXPERIMENTAL OPTICAL FIELDS

Jan Perina Jr.

Joint Laboratory of Optics of Palacky University and Institute of Physics of the Czech Academy of Sciences, 17. listopadu 12, 772 07 Olomouc, Czech Republic

Nonlinear Optics Division, Faculty of Physics, Adam Mickiewicz University, ul. Uniwersytetu Poznańskiego 2, 61-614 Poznań, Poland

Nonclassical optical fields are useful in numerous applications at present. Identification and quantification of their nonclassicality thus represents an important task. In the talk, identification of nonclassicality of optical fields via the so-called nonclassicality witnesses will be discussed in general using the experimental intensity moments as well as the measured photocount histograms (photon-number distributions). Different methods for the derivation of nonclassicality witnesses will be discussed and compared considering a general N-mode optical field. Applicability of the nonclassicality witnesses based on intensity moments and elements of photocount histograms (photon-number distributions) will be discussed. Quantification of the nonclassicality in relation to the discussed nonclassicality witnesses and using the concept of the Lee nonclassicality depth will also be mentioned. Photocount and photon-number distributions belonging to several types of experimental single mode, two-mode as well as three-mode non-classical optical fields (sub-Poissonian fields, fields with (anti-)correlations in photocounts and photon numbers) will be used to demonstrate the general results.

NONLINEARITY, QUBITS AND CORRELATIONS

Wiesław Leoński

Quantum Optics and Engineering Division Institute of Physics, University of Zielona Góra, ul. prof. Z. Szafrana 4a, 65-516 Zielona Góra, Poland

Corresponding author: w.leonski@if.uz.zgora.pl

We consider a nonlinear model of the Bose-Hubbard type. It contains the Kerr-like nonlinearity that is excited by a train of ultra-short pulses. We show that such the system can exhibit various nonclassical phenomena, including photon/phonon blockade, the appearance of quantum chaos, and quantum correlations. In particular, we shall concentrate on the time-correlations related to the Leggett–Garg inequalities violation. Such inequalities are analogs of the well-known Bell ones. They can be applied in detecting violations of macrorealism, thus showing the nonclassical character of the system.

REAL SPECTRA AND EXCEPTIONAL POINTS IN NON-HERMITIAN HAMILTONIANS HAVING RT-SYMMETRY

Ewelina Lange

Faculty of Physics, Department of Nonlinear Optics, Adam Mickiewicz University, Poznań, Poland

I will give an introduction to non-Hermitian open bosonic systems. I will describe the foundations of PT symmetry and exceptional points (EPs) related to symmetry breaking. Then I am going to present results of investigations of the group I am part of, containing formalism of Rotation-time symmetry (RT symmetry). Finally, I am going to give a short overview of physicals phenomena related to symmetries and symmetry-breaking phase transition.

ULTRASTRONG AND DEEP-STRONG COUPLING BETWEEN LIGHT AND MATTER

Salvatore Savasta

Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Universita di Messina, Italy

Ultrastrong coupling between light and matter has, in the past decade, transitioned from a theoretical idea to an experimental reality. In this new regime of quantum light–matter interaction, beyond weak and strong coupling, the coupling strength is comparable to the transition frequencies in the system. Here we review the theory of quantum systems with ultrastrong coupling, discussing entangled ground states with virtual excitations, and new avenues for nonlinear optics. We also overview a subset of the multitude of experimental setups, including superconducting circuits, organic molecules, semiconductor polaritons, and optomechanical systems, that have now achieved ultrastrong coupling. I also discuss recent achievements of the so-called deep strong coupling regime, where the coupling strength becomes larger than the transition frequencies of the system. I conclude by discussing the potential applications enabled by these achievements.

BYPASSING THE INTERMEDIATE TIMES DILEMMA FOR OPEN QUANTUM SYSTEM

Michał Horodecki

International Centre for Theory of Quantum Technologies, University of Gdańsk, Poland

The famous Davies-GKLS Markovian master equation is tremendously successful in describing the evolution of open quantum systems in terms of just a few parameters. However, Davies equation fails to describe time scales short enough, i.e., comparable to the inverse of differences of frequencies present in the system of interest. A complementary approach that works well for short times but is not suitable after this short interval is known as the local master equation. Both the approaches do not allow to have any faithful dynamics in the intermediate time period between the very beginning of the evolution and when reaching the steady state. To cope with the lack of the dynamical equation in this "grey" time zone, we derive equations that work in the whole time range and are based on the same few parameters describing the environment as the Davies equation, thus free from cut-off problems. Our key insight is proper regularizations of the previously known equation based on a cumulant expansion. The evolution is still non-Markovian - as it must be if it is to work all time scales. We illustrate our approach by means of the spin-boson and qutrit-boson models and show how it interpolates between the local and global master equations in the intermediate time regime. We anticipate that our equation is a promising step towards analyzing open systems with quasi-continuous spectra that are at the moment entirely intractable.

TRANSFER OF QUANTUM CORRELATIONS TO POPULATED QUBITS

Zbigniew Ficek

Quantum Optics and Engineering Division, Institute of Physics, University of Zielona Góra, Poland

We discuss the process of transferring quantum correlations (entanglement) to uncorrelated qubits. Particular interest is paid to determine how the transfer process of quantum correlations depends on the initial population of the qubits. We show that depending on the initial population of the qubits, the transfer of the quantum correlations can be delayed even though the absorption of photons from the field is not sensitive to the initial population. In the absence of the initial population, the transfer of the quantum correlations begins immediately after the entangled field is turned on. In contrast, if the qubits are initially prepared in some of the excited states, the transfer is delayed by a finite time interval. A detailed discussion will be given on the dependence of the delay transfer time on the one and two photon populations, and damping rates of the qubits. The physical origin of the delayed transfer of quantum correlations is explained in terms of quantum jumps.

NEW TOOLS AND DEVICES FOR QUANTUM INFORMATION PROCESSING

Vojtech Trávníček

RCPTM, Joint Laboratory of Optics of Palacky University and Institute of Physics of the Czech Academy of Sciences, Czech Republic

The talk is based on three experiments from the field of quantum information processing realized on the platform of linear optics. These experiments were performed at the Joint Laboratory of Optics of Palacký University and Czech Academy of Sciences and focus on the detection of entanglement in hyper-entangled states, characterization of errors that could occur during an entanglement swapping and a distance measure between quantum states.

TENSOR NETWORKS AND QUANTUM MANY-BODY DYNAMICS

Mari Carmen Bañuls

Max Planck Institute of Quantum Optics, Garching, Germany

Tensor Network States (TNS) can efficiently represent certain states of quantum many-body systems. In one spatial dimension, the paradigmatic example is the family of Matrix Product States (MPS), extremely powerful to study ground states, low energy excitations, and thermal equilibrium states. In contrast, in out-of-equilibrium scenarios, and for high energy eigenstates of generic systems, the scaling of entanglement with time and system size severely limits a direct application of MPS. However, beyond the standard algorithms, MPS and more general TNS techniques can still be used to explore some of the most interesting dynamical properties. One example is the determination of the density of states, and other spectral properties, which can in turn be used to probe thermalization.

PROSPECTS OF ULTRACOLD ALKALINE-EARTH ATOMS IN OPTICAL LATTICES FOR QUANTUM SIMULATIONS

Andrii Sotnikov

National Science Center "Kharkiv Institute of Physics and Technology", Ukraine

Quantum gases of alkaline-earth(-like) atoms are playing a significant role in understanding of physically rich phenomena of multiflavor fermionic mixtures. The unique decoupling of nuclear spin degrees of freedom from the electronic ones, as well as accessibility of metastable orbital states with realization of state-dependent optical lattices make these systems versatile and powerful for quantum simulations. Our theoretical studies reveal that by realizing a multicomponent quantum lattice model with well-controlled parameters one can simulate various phenomena, such as conventional ferromagnetic and antiferromagnetic instabilities, orbital ordering, and orbital-selective metal-insulator transitions in spin-1/2 systems, as well as more exotic flavor-selective transitions and plaquette-ordered configurations appearing in systems with high spin symmetries.

THE DISCOVERY OF A LOW-TEMPERATURE ORTHOROMBIC PHASE OF $Cd_2Re_2O_7$ SUPERCONDUCTOR

Konrad Kapcia

Institute of Spintronics and Quantum Information, Adam Mickiewicz University, Poznań, Poland

Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, D-22607 Hamburg, Germany

Corresponding author: konrad.kapcia@amu.edu.pl

The absence of an inversion center induces the antisymmetric spin-orbit coupling, enabling a mixture of the spin-singlet and spin-triplet Cooper pairing. The 5d material $Cd_2Re_2O_7$ is the first discovered pyrochlore oxide superconductor [1,2]. The material undergoes several structural phase transitions [3]. We studied the structural and phonon properties of the high-temperature cubic and two low-temperature tetragonal phases [4]. The favorable combination of Raman spectroscopy of the lattice vibrations with ab initio phonon calculations enables us to pinpoint a low-temperature orthorhombic phase which hosts the cryptic 1 K superconducting phase. We revealed the soft mode in the Brillouin zone center, which breaks the tetragonal symmetry and induces the orthorhombic structure. This result explains the recent Raman measurements.

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3D TOPOLOGICAL CHARGE OF THE BLOCH POINT IN A SPHERICAL MAGNETIC NANOPARTICLE

Konstantin Guslienko

The University of the Basque Country and Ikerbasque, San Sebastian, Spain

A hedgehog or Bloch point is a point-like 3D magnetization configuration in a ferromagnet. We calculate the 3D topological charge (Hopf index) of the Bloch point in a spherical soft magnetic particle applying the concepts of the emergent magnetic field and Dirac string. Using an inhomogeneous helicity of the Bloch point magnetization we showed analytically and confirmed by simulations that the Hopf index has some finite, non-integer value determined by the magnetization configuration of the Bloch point. The Bloch points form a new class of hopfions – 3D topological magnetization configurations, whereas traditional toroidal hopfions considered before have an integer Hopf index.

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	20.10.2021 Wednesday	21.10.2021 Thursday	22.10.2021 Friday	23.10.2021 Saturday
10:00 – 10:30		Stuart Parkin	Piotr Biskupski	Salvatore Savasta
10:30 – 11:00			Michał Mruczkiewicz	Michał Horodecki
11:00 – 11:30		Maciej Lewenstein	Dirk Grundler	Zbigniew Ficek
11:30 – 12:00			Ekmel Özbay	Vojtech Trávníček
12:00 – 12:30		Lunch	Lunch	Lunch
12:30 – 13:00				
13:00 – 13:30		Henri Jaffres	Anjan Barman	Mari Carmen Bañuls
13:30 – 14:00		Farkhad Aliev	Susmita Saha	Andrii Sotnikov
14:00 – 14:30		Pavel Baláž	Volodymyr Kruglyak	Konrad Kapcia
14:30 – 15:00		Alireza Qaiumzadeh	Alexandr Sadovnikov	Konstantin Guslienko
15:00 – 15:30	Opening ceremony & opening lecture (Franco Nori) & reception	Coffee break	Coffee break	Symposium closing
15:30 – 16:00		Jan von Delft	Dagomir Kaszlikowski	
16:00 – 16:30		Tadeusz Domański	Jan Perina	
16:30 – 17:00		Beata Ziaja-Motyka	Wiesław Leoński	
17:00 – 17:30		Gergely Zarand	Ewelina Lange	
17:30 – 18:00		Piotr Kuświk		

legend:

plenary session	
scientific session	
lunch / coffee break	