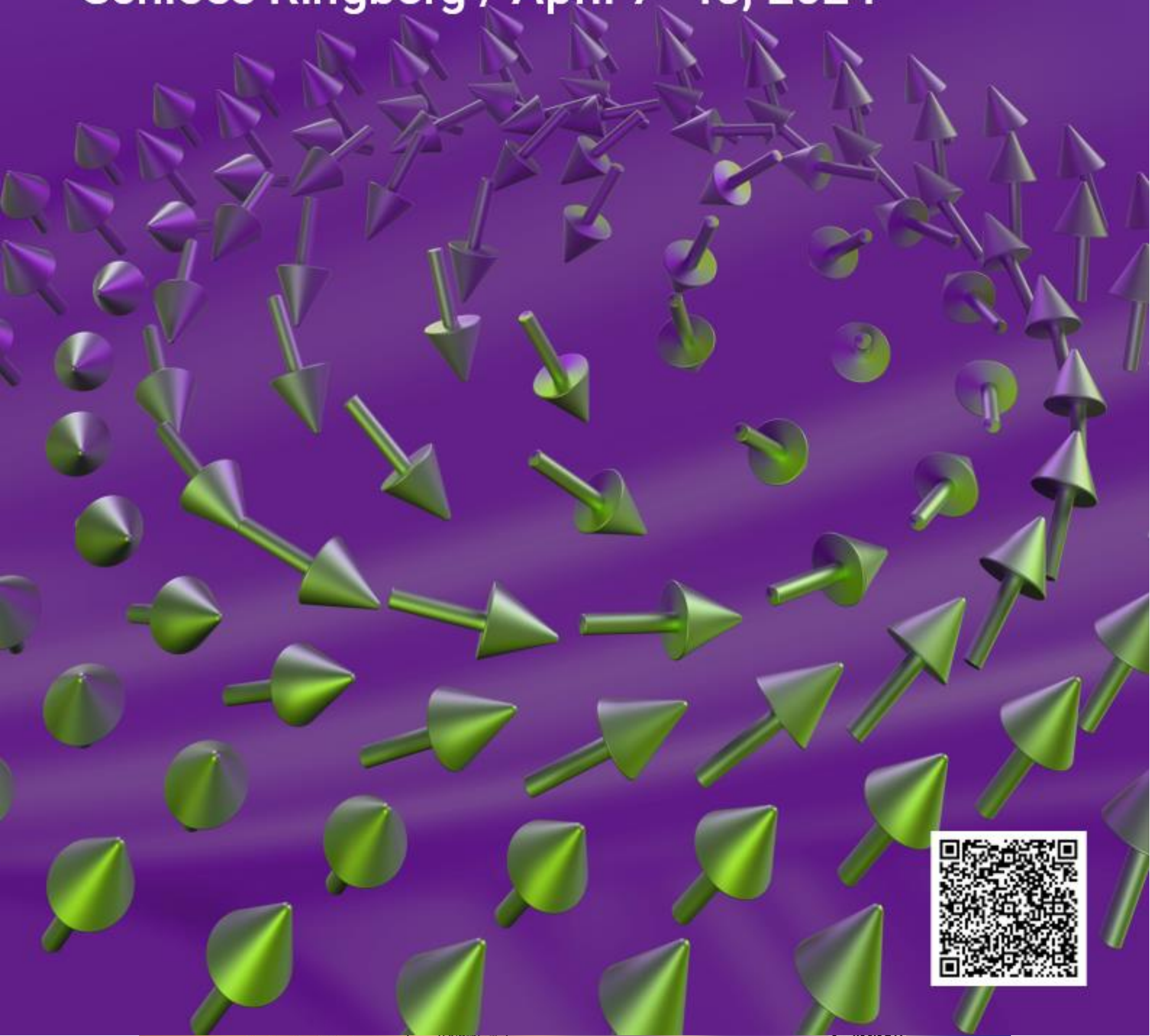
MAX PLANCK INSTITUTE
OF MICROSTRUCTURE PHYSICS

QUANTUM FRONTIERS:
SPINTRONICS AND EMERGENT MATTER

Schloss Ringberg / April 7–10, 2024



Aim of the Workshop

This workshop concerns recent developments in quantum materials and devices especially related to spin-based phenomena including spin currents, spintronics and superconducting spintronics, as well as chiral spin textures and how to create novel memory and computing devices using novel physical effects. In this regard neuromorphic computing paradigms are of special interest. The workshop is limited to ~40 participants to encourage interaction among the participants and stimulating discussions.

Start | End Time

We invite you to arrive on Sunday, April 7th at Ringberg from 4 p.m. onwards. At that time rooms will be available for check-in.

On Tuesday afternoon you are invited to join an excursion/hike.

The workshop will end on Wednesday, April 10th around 12.30 p.m. (lunchboxes will be provided before departure). Check-out is foreseen after breakfast.

Address | Info on Accommodation

Schloss Ringberg - Schlossstraße 20 - 83708 Kreuth | Phone: +49 (0)8022 27 90 | https://www.schloss-ringberg.de/convention-site/contact

The access code for internet access is available in the reception hall.

Breakfast is served from 8:00 a.m. to 9 a.m.

Munich Airport / Central Station ←→ Tegernsee

For your arrival / departure by public transportation, please check the website of "Deutsche Bahn" at https://www.bahn.com/en. Please change at either Munich Central Station or Munich Donnersbergerbrücke. Make sure to you board the part of the train going to Tegernsee. The train will be split!

You can buy your ticket online. Your destination is "Tegernsee".

Please take a taxi from the train station "Tegernsee" to the castle.

Taxi Jasinski – tel. +49 (0)8022 / 95 0 99

Taxi Pektas – tel. +49 (0)8022 / 507 14 38

We look forward to welcoming you at Ringberg. Have a save trip and see you soon!

Stuart Parkin

Director, NISE, Max Planck Institute of Microstructure Physics, Halle (Saale)

Sunday, April 7

Time	Speaker	Topic
16:00		*Arrival / Coffee*
17:00		*Welcome*
17:30	Prineha Narang	Quantum Sensing of Quantum Matter: Probing electromagnetic nonreciprocity with the quantum geometry of photonic states
18:30		*Dinner*

Monday, April 8

Time	Speaker	Topic
08:00		*Breakfast*
09:00	J. Joshua Yang	Analog computing with high precision and programmability enabled by memristors
10:00	Massimiliano Di Ventra	MemComputing, long-range order and efficient computation
11:00		*Coffee*
11:30	Arnaud Théry	Quantum sensing of axion dark matter with a phase resolved haloscope
12:30		*Lunch*
14:00	Abhay K. Srivastava	Skyrmionic spin textures in layered magnetic van der Waals compounds
14:45	Banabir Pal	Realization of a spin glass ground state in a layered 2D van der Waals material
15:30		*Coffee*
16:00		Poster Session
18:30		*Dinner*

Tuesday, April 9

Time	Speaker	Topic
08:00		*Breakfast*
09:00	Andreas Heinrich	Towards Quantum Computing with Spins on Surfaces
10:00	Kerem Çamsarı	Probabilistic Computing with p-bits: Optimization, Machine Learning and Quantum Simulation
11:00		*Coffee*
11:30	Cheng Song	Crystal Design of Altermagnets and 180° Electrical Switching of Néel Vector
12:30		*Lunch*
14:00		*Social activity / Hike* Let's go for a hike in the picturesque surroundings of Schloss Ringberg, e.g. down to Lake Tegernsee, or take the funicular to Mt. Wallberg (1,722 m). **In any case, please make sure to bring some sturdy shoes!** *In case of bed weather, the gym in the castle can be used, or you can simply discuss in a relaxed atmosphere.*
18:30		*Dinner*

Wednesday, April 10

Time	Speaker	Topic
08:00		*Breakfast*
09:00	Kenneth Burch	Macroscopic, Nonlocal Quantum Tunneling from a Magneto-Chiral Topological Superconductor
10:00	Kai Chang	From 2D ferroic semiconductors to ferroelectric valley valves
11:00		*Coffee*
11:30	Holger L. Meyerheim	Fermi surface chirality in a low-symmetry $TaSe_2$ monosheet
~12:30		*Closing remarks / Lunchboxes / Departure*

Abstracts

SUNDAY

Quantum Sensing of Quantum Matter: Probing electromagnetic nonreciprocity with the quantum geometry of photonic states

| Prineha Narang

University of California, Los Angeles, USA | *prineha@ucla.edu*

The integration of quantum materials with photonic platforms has seen enormous growth in recent years. Such devices offer enormous potential for developing advanced technologies for sensing and characterization by incorporating quantum and nonlinear effects into the dynamics of photonic modes. Here, we present such an integrated device – a superconducting cross resonator integrated with a quantum material that intrinsically breaks time-reversal symmetry. We show how the electromagnetic properties of the material are encoded in the dynamics of the photonic states and formulate a measuring protocol that can be used to sensitively measure small nonreciprocal responses in the material, e.g., through magnetic or chiral topological order. Our process tomography method utilizes the quantum geometry of photonic wavefunctions, and represents a concrete application of quantum metrology across a broad spectrum of experimental platforms including Fock states in optical cavities, or coherent states in microwave and THz resonators.

Biographical Sketch

Prineha Narang is a Professor in Physical Sciences, and in Electrical and Computer Engineering at the University of California, Los Angeles (UCLA). Prior to moving, she was an Assistant Professor of Computational Materials Science in the School of Engineering and Applied Science (SEAS) at Harvard University. Before starting on the Harvard SEAS faculty in 2017, Dr. Narang was a Fellow at HUCE, and worked as a research scholar in condensed matter theory in the Department of Physics at the Massachusetts Institute of Technology (MIT). She received an M.S. and Ph.D. from the California Institute of Technology (Caltech). Her group, the NarangLab, works across areas of quantum materials, non-equilibrium phenomena, and quantum information science. In 2023 she was appointed a U.S. Science Envoy by the State Department.

MONDAY

Analog computing with high precision and programmability enabled by memristors

| J. Joshua Yang

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While digital computing dominates the technological landscape, analog computing distinguishes itself with superior energy efficiency and high throughput. However, its historical limitation in precision and programmability has confined its application to specific and low-precision domains, notably in neural networks. The escalating challenge posed by the analog data deluge calls for versatile analog platforms. These platforms must not only exhibit exceptional efficiency but also sufficient reconfigurability and precision.

Recent breakthroughs in analog devices, such as memristors, have laid the groundwork for unparalleled analog computing capabilities. Leveraging the multifaceted role of memristors, we introduce memristive field-programmable analog arrays (FPAAs) [1], mirroring the functionality of their digital counterparts, field-programmable digital arrays (FPGAs). To elevate precision, we delve into the origins of reading noise, successfully mitigating it and achieving an unparalleled 2048 conductance levels in individual memristors—equivalent to 11 bits per cell, setting a record precision among diverse memory types [2]. Acknowledging the persistent demand for single or double precision in various applications, we propose and develop a circuit architecture and programming protocol [3]. This innovation enables analog memories to attain arbitrarily high precision with minimal circuit overhead. Our experimental validation involves a memristor System-on-Chip fabricated in a standard foundry, demonstrating significantly improved precision and power efficiency compared to traditional digital systems.

The co-design approach presented empowers low-precision analog devices to perform high-precision computing within a programmable platform. This demonstration underscores the transformative potential of analog computing, transcending historical limitations and ushering in a new era of precision and efficiency.

[1] Li, Y. et al. Memristive Field-Programmable Analog Arrays for Analog Computing. Advanced Materials, 2206648 (2023).

[3] Rao, M. et al. Thousands of conductance levels in memristors integrated on CMOS. Nature 615, 823-829 (2023).

[3] Song, W. et al. Programming memristor arrays with arbitrarily high precision for analog computing. Science 383, 903-910 (2024).

Biographical Sketch

J. Joshua Yang is the Arthur B. Freeman Chair professor of Electrical and Computer Engineering in the Ming Hsieh Department of Electrical and Computer Engineering. He joined USC in 2020, coming from the faculty of the University of Massachusetts, Amherst. Specializing in post-CMOS hardware for neuromorphic computing, machine learning, and artificial intelligence, he has published a number of groundbreaking research papers in these domains. His innovative work has led to the granting of over 120 US patents. He was recognized as a Distinguished Faculty lecturer at UMass, culminating in him receiving the UMass Chancellor's Medal (2020), the institution's highest honor. He contributes professional service to numerous international journals, conferences, and committees. He is the Associate Editor of *Science Advances* and the Founding Chair of the IEEE Neuromorphic Computing Technical Committee (2021). He currently serves as the director of an Air Force-funded *Center of Excellence* on Neuromorphic Computing at USC. Recognized as a Clarivate Highly Cited Researcher and listed among the Top Best Scientists in the Electronics and Electrical Engineering category by Research.com, he was elected Fellow of the IEEE (2022) and of the National Academy of Inventors (NAI) (2023), for his contributions to resistive switching materials and devices for nonvolatile memory and neuromorphic computing.

MemComputing, long-range order and efficient computation

| Massimiliano Di Ventra

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MemComputing is a new physics-based approach to computation that employs time non-locality (memory) to both process and store information on the same physical location [1]. Time non-locality is a remarkable feature since it can generate dynamical long-range order in the system even if its individual units are interacting locally. Long-range order means that the correlations between the machine units do not decay exponentially, rather algebraically, both temporally and spatially. A memcomputing machine then navigates its phase space by following specific trajectories (instantons) which showcase this long-range order, namely during dynamics the machine can change the values of just a few or as many variables in the problem specification as needed to reach the solution efficiently. I will discuss the physics behind MemComputing, its topological and geometrical aspects, and show many examples of its applicability to various combinatorial optimization problems, Machine Learning, and Quantum Mechanics, demonstrating its advantages over traditional approaches and even quantum computing. Work supported by DARPA, DOE, NSF, CMRR, and MemComputing, Inc. (http://memcpu.com/).

[1] M. Di Ventra, MemComputing: Fundamentals and Applications (Oxford University Press, 2022).

Biographical sketch

Massimiliano Di Ventra obtained his undergraduate degree in Physics summa cum laude from the University of Trieste (Italy) in 1991 and did his PhD studies at the Swiss Federal Institute of Technology in Lausanne in 1993-1997. He is professor of Physics at the University of California, San Diego since 2004. Di Ventra's research interests are in condensed-matter theory and unconventional computing. He has been invited to deliver more than 350 talks worldwide on these topics including 16 plenary/keynote presentations. He has published more than 300 papers in refereed journals, 5 textbooks, and has 11 granted patents (7 foreign). He is a fellow of the American Association for the Advancement of Science, the American Physical Society, the Institute of Physics, the IEEE and a foreign member of Academia Europaea. In 2018 he was named Highly Cited Researcher by Clarivate Analytics, he is the recipient of the 2020 Feynman Prize for theory in Nanotechnology, and is a 2022 IEEE Nanotechnology Council Distinguished Lecturer. He is the co-founder of MemComputing, Inc. (http://memcpu.com/).

Quantum sensing of axion dark matter with a phase resolved haloscope

| Arnaud Théry

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Axions are hypothetical particles which do not belong to the standard model. They are credible candidates for dark matter in the Universe. Under a high DC magnetic field, an axion can decay into a photon of energy corresponding to the axion mass. Three-dimensional cavities in high magnetic fields can therefore serve as axion detectors, as first proposed by P. Sikivie in 1983. These devices, known as cavity haloscopes, are limited to a narrow range of accessible frequencies as opposed to the wide range of possible axion masses. Their sensitivity is also bounded by the standard quantum limit, which has slowed down the axion dark matter sensing efforts so far.

Our haloscope is different in concept from the existing platform, as it combines a superconducting circuit, an antiferromagnetic crystal, and a microwave cavity. It aims to detect the axion signal by measuring a phase shift of the microwave signal, which can outcast the standard quantum limit. Furthermore, the antiferromagnetic crystal provides a tunability, enabling in principle a large mass range.

In my talk, I will present our results concerning the physics of the superconducting circuit, the antiferromagnetic and the cavity modes. I will also show that our hybrid magnon-superconducting circuit-cavity platform is a scanning phase haloscope which should enable a substantial speed-up in the axion dark matter search.

Biographical sketch

Arnaud Thery is a PhD student at ENS Paris, in the group of Takis Kontos (in the hybrid quantum circuits group). His work focuses on quantum sensing with hybrid superconducting circuits and magnonics with applications for dark matter detection. Prior to this, Arnaud studied quantum physics and condensed matter at ENS de Lyon and worked at Institut Néel with Clemens Winkelmann on quantum thermodynamics and at Imperial College with Ortwinn Hess on numerical simulations of semiconductor lasers.

MONDAY

Skyrmionic spin textures in layered magnetic van der Waals compounds

| Abhay K. Srivastava

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Magnetic skyrmions and bubbles, nanoscopic vortex-like spin textures, have dominated research as they are considered memory bits for future memory devices. Several different crystals and thin film systems have been investigated over the years in search of various skyrmions and bubbles. Recently, a new class of materials, namely 2-dimensional (2D) materials, has gained interest after researchers demonstrated that high-quality monolayers of graphene can be obtained by simple exfoliation of the material. The addition of magnetic van der Waals (vdW) crystals to this family, capable of hosting such spin textures, has opened the door for fundamental research and the possibility of spintronics applications.

In this presentation, I will provide a brief introduction to the field of skyrmionics, followed by a discussion on the experimental realization of such spin textures using Lorentz Transmission Electron Microscopy and Magnetic Force Microscopy techniques. Finally, I will present our results on the investigation of two vdW compounds: Fe_3GeTe_2, which hosts Néel-type skyrmions resulting from a defect-driven Dzyaloshinskii-Moriya Interaction (DMI), and Fe_5GeTe_2, which hosts various kinds of spin textures depending upon the sample thickness.

Realization of a spin glass ground state in a layered 2D van der Waals material

| Banabir Pal

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The influence of critical dimensions on phase transitions has been a longstanding fascination within the scientific community. In particular, magnetism in the two-dimensional (2D) limit has always proved challenging, as the Mermin–Wagner theorem [1] predicts that at finite temperatures, thermal fluctuations in 3D Heisenberg spins destroy long-range magnetic order in 2D systems. However, recent experimental findings demonstrated that the magneto-crystalline anisotropy, dipolar interactions and the interfacial spin-orbit coupling give rise to stable ferro/antiferromagnetic (FM/AFM) ordering even in the 2D limit [2,3]. Subsequently, the magnetic phase space has expanded, uncovering a diverse array of magnetic ground states such as Ferro, Antiferro, Helical, and 2D XY magnets within 2D van der Waals materials [4,5,6]. While much attention is dedicated to uncovering ordered magnetic ground states in 2D magnets, this talk emphasizes the overlooked disordered magnetic ground states. Specifically, we discuss about the spin glass state, a complex quench-disordered magnetic phase characterized by conflicting spin interactions hindering long-range order emergence. Our focus centers on the realization of this glassy state in 2D van der Waals ferromagnets, specifically aimed at understanding the dynamics of glassy spin behavior.

[1] Mermin, N. D. & Wagner, H. Absence of Ferromagnetism or Antiferromagnetism in One- or Two-Dimensional Isotropic Heisenberg Models. Phys. Rev. Lett. 17, 1133-1136 (1966). https://doi.org:10.1103/PhysRevLett.17.1133

[2] Gong, C. et al. Discovery of intrinsic ferromagnetism in two-dimensional van der Waals crystals. Nature 546, 265-269 (2017). https://doi.org:10.1038/nature22060

[3] Huang, B. et al. Layer-dependent ferromagnetism in a van der Waals crystal down to the monolayer limit. Nature 546, 270-273 (2017). https://doi.org:10.1038/nature22391

[4] Bedoya-Pinto, A. et al. Intrinsic 2D-XY ferromagnetism in a van der Waals monolayer. Science 374, 616-620 (2021). https://doi.org:doi:10.1126/science.abd5146

[5] Bonilla, M. et al. Strong room-temperature ferromagnetism in VSe2 monolayers on van der Waals substrates. Nat. Nanotechnol. 13, 289-293 (2018). https://doi.org:10.1038/s41565-018-0063-9

[6] Deng, Y. et al. Gate-tunable room-temperature ferromagnetism in two-dimensional Fe3GeTe2. Nature 563, 94-99 (2018). https://doi.org:10.1038/s41586-018-0626-9

TUESDAY

Towards Quantum Computing with Spins on Surfaces

| Andreas Heinrich

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There is a strong international research effort in the area of quantum information science. Here, the concepts of quantum coherence, superposition and entanglement of quantum states are exploited. These concepts were originally shown with photons as well as atoms and ions in vacuum traps. Over the past two decades, many advances at studying such quantum coherence in solid-state and molecular architectures have evolved [1].

In this talk we will focus on quantum-coherent experiments in Scanning Tunneling Microscopy (STM). STM enables the study of surfaces with atomic-scale spatial resolution and offers the ability to study individual atoms and molecules on surfaces. In order to study qubits with STM, we recently learned how to combine STM with electron spin resonance [2,3]. Spin resonance gives us the means to quantum-coherently control an individual atomic or molecular spin on a surface. Using short pulses of microwave radiation further enables us to perform qubit rotations and learn about the quantum coherence times of our spins [4]. Finally, we will demonstrate multi-qubit operations with spins on surfaces and discuss their performance measures [5]. Future directions for improvements will wrap up the talk.

[1] Andreas J. Heinrich, William D. Oliver, Lieven M. K. Vandersypen, Arzhang Ardavan, Roberta Sessoli, Daniel Loss, Ania Bleszynski Jayich, Joaquin Fernandez-Rossier, Arne Laucht, Andrea Morello, "Quantum-coherent nanoscience", Nature Nanotechnology, 16, 1318-1329 (2021).

[2] Susanne Baumann, William Paul, Taeyoung Choi, Christopher P. Lutz, Arzhang Ardavan, Andreas J. Heinrich, "Electron Paramagnetic Resonance of Individual Atoms on a Surface", Science 350, 417 (2015).

[3] Yi Chen, Yujeong Bae, Andreas Heinrich, "Harnessing the Quantum Behavior of Spins on Surfaces", Advanced Materials 2023, 2107534 (2022).

[4] Kai Yang, William Paul, Soo-Hyon Phark, Philip Willke, Yujeong Bae, Taeyoung Choi, Taner Esat, Arzhang Ardavan, Andreas J. Heinrich, and Christopher P. Lutz, "Coherent spin manipulation of individual atoms on a surface", Science 366, 509 (2019).

[5] Yu Wang, Yi Chen, Hong T. Bui, Christoph Wolf, Masahiro Haze, Cristina Mier, Jinkyung Kim, Deung-Jang Choi, Christopher P. Lutz, Yujeong Bae, Soo-hyon Phark, Andreas J. Heinrich, Science 382, 87 (2023).

[6] Individual

Support from Institute for Basic Science (IBS-R027-D1) is gratefully acknowledged.

Biographical Sketch

Andreas Heinrich is a world-leading researcher in the field of quantum measurements on the atomic-scale in solids. He pioneered spin excitation and single-atom spin resonance spectroscopy with scanning tunneling microscopes – methods that have provided high-resolution access to the quantum states of atoms and nanostructures on surfaces. He has a track record of outstanding publications and invited talks and has established a strong network of global collaborations. As a consequence, Heinrich's work has received extensive media coverage worldwide. Heinrich spent 18 years in IBM Research, which uniquely positioned him to bridge the needs of industrial research and the academic world. This unique environment gave Heinrich extensive experience in presenting to corporate and political leaders, including the president of Israel and the IBM Board of Directors. Heinrich became a distinguished professor of Ewha Womans University in August 2016 and started the Center for Quantum Nanoscience (QNS) of the Institute for Basic Science (IBS) in January 2017. Under his leadership, QNS focuses on exploring the quantum properties of atoms and molecules on clean surfaces and interfaces with a long-term goal of quantum sensing and quantum computation in such systems. Heinrich is a member of the Korean and German Physical Societies as well as a fellow of the American Physical Society and the American Association for the Advancement of Science.

TUESDAY

Probabilistic Computing with p-bits: Optimization, Machine Learning and Quantum Simulation

| Kerem Çamsarı

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camsari@ucsb.edu

The slowing down of Moore's era has coincided with escalating computational demands from Machine Learning and Artificial Intelligence. An emerging trend in computing involves building physics-inspired computers that leverage the intrinsic properties of physical systems for specific domains of applications. Probabilistic computing with p-bits, or probabilistic bits, has emerged as a promising candidate in this area, offering an energy-efficient approach to probabilistic algorithms and applications [1-4].

Several implementations of p-bits, ranging from standard CMOS technology to nanodevices, have been demonstrated. Among these, the most promising p-bits appear to be based on stochastic magnetic tunnel junctions (sMTJ) [2]. sMTJs harness the natural randomness observed in low-barrier nanomagnets to create energy-efficient and fast fluctuations, up to GHz frequencies [4]. In this talk, we will discuss how magnetic p-bits can be combined with conventional CMOS to create hybrid probabilistic-classical computers for various applications. We will provide recent examples of how p-bits are naturally applicable to combinatorial optimization, such as solving the Boolean satisfiability problem [3], energy-based generative machine learning models like deep Boltzmann machines, and quantum simulation for investigating many-body quantum systems.

Through experimentally informed projections for scaled p-computers using sMTJs, we will demonstrate how physics-inspired probabilistic computing can lead to GPU-like success stories for a sustainable future in computing.

[1] S. Chowdhury, A. Grimaldi, N. A. Aadit, S. Niazi, M. Mohseni, S. Kanai, H. Ohno, S. Fukami, L. Theogarajan, G. Finocchio, S. Datta, K. Y. Camsari, A full-stack view of probabilistic computing with p-bits: devices, architectures and algorithms, IEEE Journal on Exploratory Solid-State Computational Devices and Circuits, (2023)

[2] W. A. Borders, A. Z. Pervaiz, S. Fukami, K. Y. Camsari, H. Ohno, S. Datta, Integer Factorization Using Stochastic Magnetic Tunnel Junctions, Nature, 573, 390-393 (2019)

[3] N. A. Aadit, A. Grimaldi, M. Carpentieri, L. Theogarajan, J. M. Martinis, G. Finocchio, K. Y. Camsari, Massively Parallel Probabilistic Computing with Sparse Ising Machines, Nature Electronics (2022)

[4] N. S. Singh, S. Niazi, S. Chowdhury, K. Selcuk, H. Kaneko, K. Kobayashi, S. Kanai, H. Ohno, S. Fukami and K. Y. Camsari, Hardware Demonstration of Feedforward Stochastic Neural Networks with Fast MTJ-based p-bits, IEDM (2023)

Biographical Sketch

Kerem Çamsarı is an Assistant Professor at the Department of Electrical and Computer Engineering at the University of California, Santa Barbara. His Ph.D. work established a modular approach to connect a growing set of emerging materials and phenomena to circuits and systems, a framework adopted by others. In later work, he used this approach to establish the concept of p-bits and p-circuits as a bridge between classical and quantum circuits to design efficient, domain-specific hardware accelerators for the beyond-Moore era of electronics. He is a founding member of the Technical Committee on Quantum, Neuromorphic, and Unconventional Computing within the IEEE Nanotechnology Council where he currently leads the Unconventional Computing section. For his work on probabilistic computing, he has received the IEEE Magnetics Society Early Career Award, a Bell Labs Prize, the ONR Young Investigator Award, and the NSF CAREER award. He has been named one of the Distinguished Lecturers of IEEE Magnetics Society for 2024 and he is a senior member of the IEEE.

Crystal Design of Altermagnets and 180° Electrical Switching of Néel Vector

| Cheng Song

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The altermagnet is an emerging magnetic phase with alternating spins and spin splitting band structure, thus combining the advantages of both antiferromagnets and ferromagnets [1-3]. However, as crucial components, the electrical detection and electrical 180o switching of the Néel vector as well as the corresponding spin-splitting, are very challenging. We demonstrated that in altermagnets Mn_5Si_3 [4,5] and CrSb [6], the unique anomalous Hall effect can be adopted for electrical readout of opposite Néel vectors. We proposed a new mechanism for the electrical 180o switching of the Néel vector via spin-orbit torques by designing asymmetric switching barriers and experimentally achieved it. It is made possible by the fixed chirality between Néel vector and tiny relativistic net moment due to the Dzyaloshinskii-Moriya interaction. Based on the novel readout and manipulation methods, we fabricated prototype devices that can accomplish robust write and read cycles. Control of crystal symmetry and the corresponding magnetic space group is introduced to obtain altermagnetism. In the CrSb films with magnetic mirror orthogonal to and glide mirror parallel to the film surface and other CrSb films with all magnetic mirrors and glide mirrors broken, we observe spontaneous anomalous Hall effect at room temperature. In the former, only field-assisted spin-orbit torque switching works. In the later, field-free full 180° SOT switching is realized. Such fertile switching modes are dependent on whether the Dzyaloshinskii-Moriya torque, a novel exchange-coupling torque induced by Dzyaloshinskii-Moriya interaction, is involved in driving the Néel vector switching.

[1] L. Šmejkal, J. Sinova, T. Jungwirth, Phys. Rev. X 12, 040501 (2022).

[2] H. Bai, C. Song, et al. Phys. Rev. Lett. 128, 197202 (2022)

[3] H. Bai, C. Song, et al. Phys. Rev. Lett. 130, 216701 (2023)

[4] L. Han, C. Song, et al. Sci. Adv. 10, eadn0479 (2024).

[5] L. Han, C. Song, et al. arXiv. 2403.13427.

[6] Z. Zhou, C. Song, et al. arXiv. 2403.07396.

Biographical sketch

Cheng Song completed his PhD at 2009 from Tsinghua University and Humboldt postdoctoral studies from University of Regensburg (Germany). He joined Tsinghua University as an assistant professor at 2011, and now is a full professor in Tsinghua University. He works mainly on spintronics, surface acoustic wave filters, and magneto-acoustic coupling. He has published more than 290 papers with the citation >13 thousand times (H-index 58). He received the State Natural Science Award and the State Scientific and Technological Progress Award, National Outstanding Youth Funds, Young Yangtze River Scholar, and now serves as Director of Chinese Materials Research Society-Youth Branch.

WEDNESDAY

Macroscopic, Nonlocal Quantum Tunneling from a Magneto-Chiral Topological Superconductor

| Kenneth S. Burch

Boston College, Chestnut Hill, USA | ks.burch@bc.edu

Magneto-Chiral topological superconductivity is a rare phase long pursued for error-free quantum computation. Its 1D chiral modes possess topologically protected long-range coherence well beyond that of the cooper pairs, which could be fruitful for quantum transduction and low-temperature spin transport. While evidence for such modes is mounting, unambiguous signatures, such as non-local transport via co-tunneling, remain elusive. I will describe our realization of 1D chiral hinge modes mediating the direct tunneling of electrons from source to drain in $FeTe_{0.55}Se_{0.45}$. Specifically, I will discuss our evidence that the non-local tunneling signatures are decoherence-free and emerge from this material's combination of surface magnetism, bulk topology, and superconductivity. Time remaining, I will discuss how these advances can be used for Majorana Circuits and future efforts in cryogenic spintronics.

Biographical sketch

Kenneth Burch has been a Professor of Physics at Boston College since 2014, running the Laboratory for Assembly and Spectroscopy of Emergence (LASE). Before arriving at BC, he was an assistant professor at the U. of Toronto for five years. He is a former Director's fellow at Los Alamos National Laboratory, where he performed ultrafast spectroscopy with A. Taylor. He was a graduate student of D. Basov studying the optical properties of magnetic materials at UCSD. He has made seminal contributions to developing novel techniques to understand and exploit quantum materials. This includes discovering the Axial Higgs Mode in a Charge Density Wave, the colossal bulk photovoltaic effect in a Weyl semimetal, modulation doping in 2D materials, fractional spin excitations in a potential Kitaev spin liquid, and he developed cutting-edge biosensors-based on graphene. His group also developed a cleanroom in a glovebox where all fabrication and heterostructure preparation is performed. He was named an APS fellow for his work, received the Lee-Asheroff-Riuchardson Prize, and the APS GMAG best dissertation award. The work also resulted in over 95 publications in high-impact journals, including *Nature*, *Advanced Materials*, *Nature Materials*, *Nano Letters*, *ACS Nano*, *Physical Review X*, *Biosensors and Bioelectronics*, multiple patents, and has been supported by NIH, NSF, DOE, ONR, AFOSR, ARO, BARDA, GRIP molecular and GINER Inc.

From 2D ferroic semiconductors to ferroelectric valley valves

| Kai Chang

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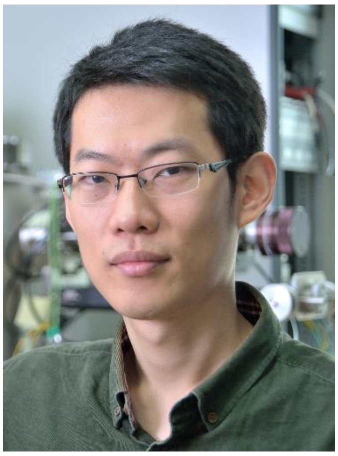
2D ferroelectric and ferromagnetic materials discovered in the recent decade have opened a new era for the construction and tuning of heterostructures for electronic and computing applications. Semiconducting 2D ferroic materials are especially interesting as their electronic structures deeply intertwine with the spontaneously broken symmetry, thus new freedoms like spin, orbital and electronic valleys are generated. In this talk, I will mainly focus on the development of group-IV monochalcogenide 2D ferroelectric semiconductors, from the discovery, ferroelectric mechanism, spin-valley correlation in the electronic structures, to the recently realized 2D lateral heterostructures and superlattices. The most interesting advancement is the design and in situ molecular beam epitaxial growth of a new type of ferroelectric valley valve device that is analogous to the classical spin valve, in which the transmission probability of electronic states is determined by the alignment of the polarization (magnetization) of two ferroic layers separated by a thin barrier. The mechanism of this ferroelectric valley valve relies on the polarization-tuned hole valleys in group-IV monochalcogenide ferroelectric semiconductors. The creation of such device is enabled by our ability of precisely controlling the growth mode of these materials, which eventually generates SnTe-PbTe monolayer superlattices with 2-nm wide material section, the narrowest ever 2D lateral superlattices to the best of our knowledge. Based on such structures, we plan to further develop novel non-volatile logic and storage devices, as well as topological qubits.



Biographical sketch

Kai Chang earned his Ph.D. in 2015 from Tsinghua University, focusing on the molecular beam epitaxial growth and scanning tunneling microscopy characterization of low-dimensional quantum materials. He worked as a postdoctoral staff in Max Planck Institute of Microstructure Physics from 2015 to 2019, and then joined Beijing Academy of Quantum Information Sciences (BAQIS) by the end of 2019. He is currently the executive president of BAQIS and the principal investigator of the Low-D Quantum Materials Team. His research focuses on the creation and electronic structure tuning of 2D ferroic heterostructures, involving 2D ferroelectrics, ferromagnets, superconductors and semiconductors, particularly on the design and construction of novel non-volatile logic/memory devices and topological qubits based on 2D ferroic semiconductors.

WEDNESDAY

Fermi surface chirality in a low-symmetry $TaSe_2$ monosheet

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Two-dimensional transition metal dichalcogenides containing heavy metals (Mo, W, Pt) are characterized by a non-trivial electronic structure and have found increasing interest as spin source materials. By contrast, bulk 2H-$TaSe_2$ has a trivial electronic structure and crystallizes in space group P63/mmc. In the ultra-thin film limit, TMDC films have been generally assumed to be rigid units with bulk-like symmetry. Here we show that this assumption is not justified which also leads to significant modifications of the electronic structure [1].

The $TaSe_2$ monosheet was prepared by an interface reaction after deposition of a sub-monolayer amount of Ta on a Bi_2Se_3 (0001) single crystal followed by annealing at 480°C. Surface x-ray diffraction experiments indicate that the two-dimensional $TaSe_2$ monosheet crystallizes in the hexagonal form but that the central Ta atom vertically relaxes out of the center of the prism formed by six selenium atoms downwards by 0.27 Å thereby leading to a reduction of the point group symmetry from D_{3h} to C_{3v}. Related to this structural relaxation, the electronic states at the Fermi surface acquire a chirality which is antiparallel to that of the topological surface state of the Bi_2Se_3 substrate near the $\overline{\Gamma}$ point. This indicates spin-momentum locking across the van der Waals gap at the $TaSe_2/Bi_2Se_3$ interface. Our approach provides a novel route to realize chiral 2D electron systems via interface engineering in van der Waals epitaxy that do not exist in the corresponding bulk materials.

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Poster abstracts

Twisted 2D all-antiferromagnetic tunnel junction

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Antiferromagnetic spintronics has much potential for high-density and ultrafast information devices. Magnetic tunnel junctions, a key spintronic memory component, that are typically formed from ferromagnetic materials, have seen rapid developments recently using antiferromagnetic materials (Nature 613, 490-495 (2023); Nature 613, 485-489 (2023)). Here, we demonstrate for the first time a novel twisting strategy for constructing all-antiferromagnetic tunnel junctions down to the atomic limit. Twisting two CrSBr bilayers, a two-dimensional antiferromagnet, a more than 700% nonvolatile tunneling magnetoresistance ratio is established at zero field with a van der Waals gap acting as the tunnel barrier. This considerable ratio is ascribed to a spin-filtering effect at the twisted interface, which is further confirmed by twisting two CrSBr monolayers. Our work shows that it is possible to push nonvolatile magnetic information storage to the atomically thin limit.

Phase coherent electrical transport in chiral topological metals

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The recent discoveries of topological phases, such as topological insulators and (semi)metals, have opened up new possibilities for the next generation of electronics. The wave-like nature of massless fermions at the mesoscopic scale in these phases provide new degrees of freedom of charge carriers such as chirality.[1] Understanding and developing strategies to manipulate it is essential to create efficient and low-noise spintronic devices. This poster introduces a new class of topological matter called chiral topological metals (CTM) and their fascinating electromagnetic responses. Its topological nature arises from multifold band crossing near the Fermi level at high symmetry points in the Brillouin zone. The collective behavior of the electrons near these crossings gives rise to chiral fermions. Topological metals can generate spin currents under longitudinal electric and magnetic fields due to the phenomenon known as the chiral anomaly.[2] However, these spin currents are localized, short-lived, and often masked by electrical transport in the trivial bulk bands. The poster aims to identify the charge transport in topological states in chiral topological metals and understand the influence of geometric chirality. It presents experimental strategies based on focused-ion beam crystal micro-sculpting and lateral Josephson junctions to study non-linearity and phase coherence of electrical transport along the low-miller crystal indices.

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Energy-dependent Spin Hall Effect in Non-collinear Antiferromagnet Mn_3Ir an Mn_3Ge

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Non-collinear antiferromagnets (NC-AFMs) have highly interesting properties resulting from their chiral spin structure and topological band structure. This allows for properties that, in many ways, resemble ferromagnets (FMs) even though they have negligible magnetization. Among them, the spin Hall effect (SHE) that converts electrical current to spin current and its inverse counterpart, inverse spin Hall effect (ISHE), are key effects for potential spintronic applications including spin-orbit torque (SOT) magnetization manipulation (Hu et al., Nat. Commun. 13, 4447(2022)) and THz generation (Li et al., Nature 578, 70-74(2020)). The energy dependence of the SHE and ISHE is very important in determining the origin of these phenomena for which there have been theoretical calculations (Kim et al. Nat. Phys. 10, 549–550 (2014)), but also is highly desired for all-AFM spintronic devices including hot electron transistors that, in principle, have higher operating speeds.

Here, we determine the energy-dependence of the ISHE in the non-collinear antiferromagnets Mn_3Ir and Mn_3Ge. Using a magnetic tunnel junction (MTJ), one of the most important spintronic devices today, a voltage bias applied across the tunnel barrier thereby tunes the energy of the injected tunneling electrons. Using this method, we can then directly measure the energy dependence of the spin Hall effect and the spin Hall angle (SHA). We find a significant bias dependence of the SHE in both Mn_3Ir and Mn_3Ge, which is consistent with the theoretical calculations.

Enhanced spin-orbit torques from proximity-induced magnetization at ferromagnetic/heavy metal interfaces

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Spin-orbit torques (SOTs) that are generated at interfaces between a spin current generating heavy metal layer and a ferromagnetic layer serve as a prime mechanism for realizing current-induced switching of magnetization. Enhanced SOTs can improve the performance of spintronic devices such as magnetic random-access and racetrack memories. Herein, by inserting atomically thin dusting layers composed of Pd and Rh at a heavy metal/ferromagnet interface, we find that both the anti-damping-like and field-like SOTs are significantly enhanced by more than two and seven times, respectively, for Pd, but rather decreased for Rh. This enhancement is attributed to a large proximity induced magnetic moment (PIM) in Pd which is absent for Rh. This work emphasizes the role of interface engineering for enhanced spin current generation and transmission and provides a route for pursuing highly efficient spintronic devices.

Reversal of anomalous Hall effect and octahedral tilting in $SrRuO_3$ thin films via hydrogen spillover

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Iontronics has garnered great attention due to the emergence of intriguing physical phenomena in oxide thin films whose structural and physical properties are strongly intertwined [1,2]. Hydrogen spillover can be employed as a novel technique for inserting hydrogen ions into the thin films that can result in new physical phenomena. Here, we demonstrate the sign reversal of the anomalous Hall effect (AHE) and the suppression of octahedral tilting in strongly correlated $SrRuO_3$ (SRO) thin films through hydrogen spillover [3]. While various research groups have previously suggested the emergence of the topological Hall effect (THE) possibly attributed to skyrmion formation in SRO thin films via inversion symmetry breaking [4,5], our results indicate that inhomogeneity of AHEs in a thin film can exhibit THE-like hump features even in the absence of the skyrmion formation. Additionally, we unveil diverse changes in physical properties such as increased resistance and suppression of magnetization via hydrogenation. Our findings provide a new approach to tailor the lattice symmetry and associated physical phenomena in correlated oxide thin films.

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Multi-core memristor from racetrack memory

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The current induced manipulation of mobile domain walls in nanoscopic magnetic wires and their electrical detection are keys to the development of domain wall based memory and logic devices that go beyond today's binary technologies. A racetrack device with a single domain wall is functionally equivalent to a memristor in which the output signal is proportional to the position of the boundary core. In such device, analogue-like output can be achieved upon the current induced motion of the domain wall which can be a platform for neuromorphic computing. A commonly known memristor or resistive switching memory cell possesses a single boundary core that separates physical states (e.g., doped vs. undoped or conducting vs. insulating or formation vs. rapture). Racetrack devices, however, can possess multiple mobile domain walls in a single racetrack cell, in contrast to conventional memristors. As a result, the racetrack with multiple domain walls can generate highly complex time-signal outputs upon operation. Here we discuss how multiple mobile domain walls can be effectively traced with high resolution (~ 40 nm) in the racetracks. We introduce a multi-core memristor model to describe the dynamics of domain walls. We strongly believe that racetrack can be an excellent platform for neuromorphic devices with higher-order complexity.

Revealing ion dynamics in epitaxial T-Nb_2O_5 thin films during Li-ionic gating

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Ionic gating has garnered considerable attention due to emergent physical phenomena such as insulator-metal transitions, emergent superconductivity and magnetism via ion migrations into or out of films. However, its electrochemically driven responses are sluggish compared to conventional field-effect transistors, which hinders the diverse potential applications. Therefore, a profound understanding of the kinetics and dynamics of ion intercalation into materials is crucial for advancing fast ionic gating devices. We previously reported rapid and colossal insulator-metal transitions in epitaxial T-Nb2O5 thin films, featuring vertical ionic transport channels that promote fast Li ion migration [1] Here, we elucidate defect-accelerated ion dynamics in epitaxial T-Nb2O5 thin films during ionic gating using optical interferometric scattering microscopy (iSCAT) [2]. By employing iSCAT [3], we observe that the optical contrast of the thin film changes into rectangular-shaped domains in the early stage of Li ion insertion. Scanning transmission electron microscopy (STEM) revealed the formation of vertical anti-phase boundaries in the T-Nb2O5 thin films, likely accelerating the Li ion migration along the vertical pathways. These defect-driven fast ion migrations may open new avenues for designing and developing fast ion gating devices.

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[2] H. Han†, D. Kim† et al, in preparation

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Reduced decay of Josephson coupling across ferromagnetic weak links in junctions with spin-orbit coupling spacers

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The spin-rotation effect required for generation of S=1 triplet Cooper pairs has been predicted theoretically in superconducting-ferromagnetic (SC/FM) hybrid heterostructures with spin-orbit coupling (SOC).[1,2] In this study, we experimentally investigate overlap SC/NM/FM/NM/SC Josephson junctions (JJs), where NM are materials with strong and weak SOC and FM has perpendicular magnetic anisotropy. We find that the decay rate of Josephson coupling is smaller in JJs with strong SOC indicating the presence of $S=1$ spin-triplet correlations. We also identify key technical challenges in establishing spin-polarized supercurrent in these systems and propose solutions.

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Computational elements based on coupled VO2 oscillators via tunable thermal triggering

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Computational technologies based on coupled oscillators are of great interest for energy efficient computing [1, 2]. A key to the development of such technologies is the tunable control of the interaction strength between the oscillators. Thus far, such coupled oscillators have been accomplished by additional external electronic components [3-5]. Here we show that the synchronization of closely spaced vanadium dioxide (VO_2) oscillators can be controlled via a simple thermal triggering element that itself is formed from VO_2. We demonstrate active tuning of coupled oscillation states via a thermal cell that is placed between adjacent VO_2 devices. The tuning process allows us to control amplitude, frequency and phase of coupled VO_2 oscillators. The assisted frequency synchronization process between two coupled VO_2 oscillators is similar to the signal propagation from pre-synaptic neurons to post-synaptic neurons via releasing neurotransmitter. Biological plausibility and functionality of two spiking neuron models (Hodgkin-Huxley model and leaky-integrate-and-fire model) realized by VO_2 oscillators are demonstrated. Together with Racetrack memory as synapse, we illustrate the idea that networks of thermally coupled oscillators can be readily applicable to novel computational techniques such as artificial neural networks.

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Enhanced Spin Hall Efficiency by Oxygen Ion Irradiation

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Spin-orbit torque (SOT) plays a key role for contemporary spintronic devices. Typically, SOT based magnetic devices consist of ferromagnetic (FM) and spin Hall source (typically heavy metal, e.g., Pt) bilayer system, where the charge current flowing through heavy metal layer is converted into spin current, transfer spin angular momentum to the adjacent FM layer, and induces magnetization reversal effectively. Therefore, achieving high spin Hall efficiency stands as a crucial factor for spintronic applications advancement, such as racetrack memories and SOT magnetic random-access memory (SOT-MRAM).

In this study, we employed oxygen ion irradiation to enhance spin Hall efficiency. Through harmonic Hall measurements, current-induced magnetization switching, and current induced domain wall motion, we systematically investigate how the spin Hall efficiency and domain wall motion properties are evolving upon irradiation of oxygen ion to the spin Hall layer. We found out that the ion irradiation on Pt enhances the spin Hall efficiency by 25 % and switching current density from 4.9 to 4.2 x 10^{11} A/m^2. In contrast, we observe an increase in threshold current density for domain wall motion (from xx to YY). Our findings not only propose and demonstrate an approach to achieve energetically efficient SOT switching devices but also provides us insights into the correlation between SOT switching and domain wall motion efficiencies. This understanding allows us to develop advanced spintronic applications.

Interface engineering of synthetic antiferromagnets for energy-efficient domain-wall memory applications

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The efficiency of current-induced domain wall motion in nanoscopic magnetic racetrack devices results from the combination of complex interfacial interactions which arise in synthetic antiferromagnetic (SAF) multilayered thin films. Therefore, investigating the role of the interfaces in these films, and engineering their properties, is of paramount importance to reduce the energy consumption in domain-wall-based electronic devices.

Here we show that sophisticated interface engineering can be used to dramatically improve the efficiency of state-of-the-art domain-wall-based devices. Firstly, we introduce engineered spin Hall layers to boost the spin-orbit torque in ferromagnetic multilayers and consequently reduce the threshold current density to operate racetrack devices. Secondly, we engineer synthetic antiferromagnetic multilayers to improve the exchange coupling strength, which consequently allows to reach higher domain wall speed and mobility. We evaluate the potential performance of nanoscopic (100-nm-size), single-domain-wall memory devices from engineered SAF films. We found relevant improvements in both the writing energy and latency, potentially leading to sub-10-fJ and sub-1-ns writing operations.

Our work demonstrates that careful interface engineering can drastically boost the efficiency of current-induced domain wall motion, which is of significant importance for lowering the energy consumption and allowing fast operation in domain-wall-based memory and logic technology.

Combining ferromagnetic Josephson junctions and magnetic racetracks

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Proximity effect at superconductor-ferromagnet interfaces leads to interesting phenomena such as unconventional odd-frequency Cooper pairing [1,2]. These “spin-triplet” Cooper pairs carry a spin-momentum and are speculated to influence magnetization under certain conditions [3]. Experimental demonstration of this effect is currently lacking, but in principle could revolutionize the field of superconducting spintronics.

Controlled manipulation of domain walls in magnetic racetracks using spin-polarized current has led to the promise of low-cost, high-performance and reliable non-volatile memory [4]. However, the high current density involved can lead to excessive energy consumption and heating. Studies show that replacing conventional room-temperature devices with superconducting devices could lead to significant energy savings along with improving reliability and performance [5].

In our work, we take the first steps to combine ferromagnetic Josephson junctions and magnetic racetracks. We study different methods for generating triplet currents: non-collinear ferromagnetic layers [6], spin-orbit coupling layers combined with ferromagnetic layers [7], and non-collinear antiferromagnets [8]. We explore possible ways to inject triplet Cooper pairs into a hybrid geometry to study the influence on magnetization in the future.

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Control of AHE and generation of long-range supercurrents in non-collinear AFM Mn_3NiN

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Chiral antiferromagnets have recently emerged as a viable alternative to ferromagnets in spintronics devices, owing to their enhanced storage density and faster spin dynamics. An interesting member of this family is Mn_3NiN, a non-collinear antiferromagnet (AFM) with a cubic antiperovskite structure. Below its transition temperature (TN ~ 250 K), Mn_3NiN undergoes an AFM phase transition and displays interesting phenomena like large anomalous Hall effect (AHE), anomalous Nernst effect and giant piezomagnetism [1]. With temperature, Mn spins rotate within the (111) plane, transitioning between the high symmetry configurations of Γ^{5g} and Γ^{4g} [2]. Notably, non-zero anomalous Hall conductivity (AHC) is observed only in Γ^{4g} configuration. Our investigation reveals that introducing a Ni deficiency in the system can constrain Mn spin rotation, thereby sustaining AHC across the entire temperature range below T_N. Furthermore, we show that Ni deficient Mn_3NiN films can be switched electrically using spin orbit torque mechanism. Additionally, our ongoing research delves into the generation of spin triplet supercurrents by interfacing Mn_3NiN with a superconductor, elucidating the role of Berry phase in converting spin singlet Cooper pairs to spin triplet counterparts [3].

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Non-collinear spin structure in rare-earth ion doped nickel ferrite

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Metallic systems offer tremendous potential for spintronic applications which highly relies on spin currents. However, it is often difficult to create pure spin currents using magnetic metals due to charge current leading to high damping and dissipation. Recently, Zn/Al-substituted nickel ferrite ($Ni_{0.65}Zn_{0.35}Al_{0.8}Fe_{1.2}O_4$, NiZAF) was realized to serve as potential system for low-damping spintronics. Although ferrites are abundantly used as magnetic materials, thus far the detailed spin structure in ultra-thin films remained elusive. Only a few studies were carried out which proposed the presence of non-collinear magnetism in nanosized spinels [1] and in rare-earth garnets [2]. Large-size rare earth elements with high SOC and large paramagnetic moment (~10 μ_B) are expected to distort the lattice and modify the magnetic ordering. Here we present a thorough analysis of the atomic and magnetic spin structure of thin (5 nm) films of NiZAF doped with 5-10% Dy. X-ray absorption fines structure experiments reveal, that Dy^{3+} ions occupy octahedral sites within the spinel structure, thereby coupling antiferromagnetically with Fe-ions at tetrahedral sites as concluded by Dy concentration dependent x-ray magnetic circular dichroism (XMCD) experiments at the Fe-$L_{2,3}$ edge. Evidence for a non-collinear spin structure below 200 K is provided by SQUID, MOKE and XMCD experiments as well as by resonant soft x-ray magnetic scattering data collected at Fe-L_3 edge.

This work is supported by DFG under grant MO-4198/2-1 (463310690) and FWF project I-5384.

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Near-field imaging of Verwey transition in magnetite

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The quest for finding the underlying cause of metal to insulator transition in strongly correlated materials has been debated over the years. Magnetite serves as a paradigm for the study of such phenomenon. Recent studies suggest that the Verwey transition occurs due to the formation of electron nematic order, giving rise to a trimeron lattice order in the insulating phase via electron-phonon coupling. However, trimeron order, influenced by strain and disorder, may present a different perspective when probed at the nanoscale during this first-order percolation-type phase transition. Notably, existing studies have predominantly focused on the global aspects of the transition. To bridge this gap, we leverage the unique capabilities of near-field imaging to investigate the phase coexistent state with nanometer-scale resolution in real space.

In this poster, we present the abilities of scanning near field optical microscopy in probing local optical, electronic and chemical properties of a material, thereby offering a direct route to real-space visualization and investigation of local charge carrier density and mobility, ferroelectricity, moiré patterns and more. Additionally, we present the findings from our exploration of the intermediary phase regime in magnetite during the Verwey transition.

Novel spin Hall effect materials and artificially engineered magnetic thin film heterostructures for energy-efficient spintronic memories

| Peng Wang, Andrea Migliorini, Rana Saha, Jaechun Jeon, Ke Gu, Hakan Deniz, Ilya Kostanovskiy, Arthur Ernst, See-Hun Yang, Holger Meyerheim, Stuart S.P. Parkin*

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The discovery of novel materials with superior properties is a key factor to promote the progress of highly energy-efficient spintronic memories, which are urgently needed to satisfy the increasing demand for data storage. Of special interest are new materials that convert charge current into spin currents with high efficiency. These could impact two distinct classes of spintronic memories, namely magnetoresistive random-access memories (MRAMs), that are already in mass production, and racetrack memories that have great potential for high density and high performance, non-volatile memory-storage devices. For the latter chiral non-collinear spin textures such as domain walls and skyrmions are the basic storage elements. I will detailedly introduce our work about energy efficient racetrack memories, which is going to be put industrial application in a visible time point and our findings about magnetic bubbles and Néel skyrmions in intermetallic thin films.

Long range supercurrent across 2D van der Waals antiferromagnet Josephson junctions

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Traditional superconducting Josephson Junctions (JJs) have been widely used in quantum computing and spintronics is always the basic of the memory device. The combination of spintronics and JJs has the potential to generate spin-polarized supercurrents, which holds significant importance in the development of new low-energy-dissipation quantum chips. Moreover, the proximity effect between superconductors and magnets may induce triplet superconductivity near the interface, potentially enhancing superconductivity and coherence length in JJs. Therefore, this project aimed to fabricate long-range correlated magnetic JJs using pristine interfaces within two-dimensional (2D) heterostructures. In our experiments, in-plane JJs based on the 2D superconductor NbSe2(S) and 2D antiferromagnetic metal GdTe3(AFM) exhibited superconductivity even when the minimum separation between the superconducting layers approached 600 nm. Additionally, we find a conspicuous superconducting diode effects in this S/AFM/S junction. These present promising avenues for the development of novel quantum devices. Furthermore, in tunnelling junctions with proximity effects, we observed evidence of superconducting enhancement, such as an increase in the superconducting critical field. These findings offer a new way to study the mechanism of superconducting pairing with spin-polarized electrons.

Nonlinear optical characterization on few layer NiI_2

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The discovery of atomically thin van der Waals ferroelectric and magnetic materials has ignited interest in the exploration of 2D multiferroics, holding the potential to unveil captivating magnetoelectric interactions and foster the development of advanced spintronic devices. Concurrently, the thinning of layered multiferroics originating from spin, such as NiI2, emerges as a natural avenue toward realizing 2D multiferroicity.

Utilizing polarization-resolved second harmonic generation (SHG) measurement, we found that above the helimagnetic transition temperature, both quadrupole and surface states contribute to the SHG signal. Conversely, below the helimagnetic transition temperature, NiI2 undergoes a magnetic phase transition from antiferromagnetic to helimagnetic state, accompanied by a structural phase transition from $\overline{3}m$ point group to C_2 point group, as indicated by the pronounced anisotropy of the polarized modulated reflection spectrum. Furthermore, we have observed that the magnetic dipole significantly influences the SHG signal, thus breaking the mirror symmetry of the SHG pattern.

Notes