TT 97: Superconducting Diodes and Ratchets

Time: Friday 9:30–12:00 Location: CHE/0089

TT 97.1 Fri 9:30 CHE/0089

Josephson Diode Effect of All-Metallic Lateral Junctions with Interfacial Rashba Spin-Orbit Coupling — •Maximilian Mangold[1,2], Lorenz Bauriedl[3], Johanna Berger[3], Chang Yu-Cheng[4], Thomas N.G. Meier[1,2], Matthias Kronseder[3], Pertti Hakonen[5], Christian H. Back[1,2], Christoph Strunk[3], and Dhavala Suri[1,6] — [1]School of Natural Sciences, Technical University of Munich, Garching b. Munich, Germany — [2]Center for Quantum Engineering (ZQE), Technical University of Munich, Garching b. Munich, Germany — [3]Department of Physics, University of Regensburg, Regensburg, Germany — [4]Pico Group, QTF Centre of Excellence, Department of Applied Physics, Aalto University, Aalto, Finland — [5]Low Temperature Laboratory, Department of Applied Physics, Aalto University, Espoo, Finland — [6]Centre for Nanoscience and Engineering, Indian Institute of Science, Bengaluru, India

The Josephson diode effect (JDE) is investigated in diffusive Josephson junctions incorporating only metallic materials. We find a magneto-chiral anisotropy in the JDE for devices with Fe/Pt and Cu/Pt weak links between Nb leads. The observed symmetry corresponds to Rashba spin-orbit coupling (SOC). In a simple Cu junction without a structural inversion asymmetry, the diode efficiency is finite, but field-angle independent. Our results suggest the generality of Rashba SOC for the JDE beyond the realm of high-mobility systems. Additionally, we observe an inverted hysteresis in the Fraunhofer patterns of all samples and explain it based on the critical state model of strongly pinned vortices without relying on SOC.

TT 97.2 Fri 9:45 CHE/0089

Giant anomalous Josephson effect as a probe of spin texture in topological insulators — Niklas Hüttner[1], Andreas Costa[1], Leandro Tosi[2], Michael Barth[1], Wolfgang Himmler[1], Dmitriy A. Kozlov[1], Leonid Golub[1], Klaus Richter[1], Jaroslav Fabian[1], Dieter Weiss[1], Christoph Strunk[1], and •Nicola Paradiso[1] — [1]University of Regensburg, Germany — [2]Grupo de Circuitos Cuánticos, Bariloche, Argentina

Topological-insulator surface states are chiral 2D electron systems with spin-momentum locking. Josephson junctions based on such states show nonreciprocal supercurrent features if time reversal symmetry is broken. For example, they show a finite phase at zero current, i.e., an anomalous Josepshon effect. I will present φ_0 measurements on junctions with HgTe nanowires as weak link. We detect an exceptionally large anomalous phase shift in the current-phase relation. We attribute this giant φ_0-shift to the single Fermi-surface contour of HgTe surface states, a key distinction from Rashba systems with two counteracting Fermi contours. By rotating the in-plane magnetic field, we probe the spin texture in momentum space. Interestingly, we find that the spin deviates by 19 degrees from the orientation perpendicular to the momentum. Our findings demonstrate that the anomalous Josephson effect provides a powerful and sensitive probe of the spin texture in chiral two-dimensional systems.

TT 97.3 Fri 10:00 CHE/0089

Josephson diode effect in superconducting hybrids with altermagnets — •Janus F. Niebuhr, Danilo Nikolić, and Matthias Eschrig — Institut für Physik, Universität Greifswald, Felix-Hausdorff-Straße 6, 17489 Greifswald

We present a systematic theoretical study of a ballistic Josephson junction consisting of a d-wave altermagnet (AM) placed between two conventional superconducting leads (S). The study is done by making use of the quasiclassical Green's function method considering two regimes of (i) a weakly and (ii) a strongly spin polarized altermagnet. The former regime in the limit of highly transmissive S/AM interfaces allows for an analytic treatment. The resulting Josephson current-phase relation (CPR) exhibits $0-\pi$ transitions. These significantly depend on the altermagnet's crystal orientation relative to the junction's axis by the display of a dominant second harmonic close to the transition. In the regime of strong spin polarization, the altermagnet is coupled to the superconductors via two spin-dependent interfaces, necessary for the creation of equal-spin triplets, which now entirely mediate the current. For a non-coplanar magnetization profile, a quantum-geometric phase emerges. This phase is coupled to spin and enters the Josephson CPR similarly to the phase difference. Consequently, depending on the altermagnetic crystal orientation, the CPR displays an anomalous Josephson effect, as well as a Josephson diode effect. Finally, we perform a harmonic analysis of the CPR discussing the effects in terms of the number of coherently transferred Cooper pairs across the altermagnet.

TT 97.4 Fri 10:15 CHE/0089

Field-Free Superconducting Diode and Topological FFLO States in Altermagnetic Shiba Chains — •Dibyendu Samanta and Sudeep Kumar Ghosh — Indian Institute of Technology, Kanpur 208016, India

The superconducting diode effect (SDE), characterized by a directional asymmetry in the critical supercurrents, typically requires external magnetic fields to break time-reversal symmetry-posing challenges for device integration. Here, we demonstrate a field-free realization of the SDE in a helical Shiba chain proximitized by a d-wave altermagnet. Using a self-consistent Bogoliubov-de Gennes approach, we uncover a topological Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) superconducting state hosting tunable Majorana zero modes at the chain ends. This state, stabilized by the interplay between the exchange coupling of magnetic adatoms and the induced altermagnetic spin splitting, can be tuned by an applied supercurrent. Crucially, the same FFLO phase supports strong nonreciprocal supercurrents, achieving diode efficiencies exceeding 45% without applied magnetic fields. The d-wave altermagnet simultaneously breaks time-reversal and inversion symmetries via momentum-dependent spin splitting, enabling both topological superconductivity and the field-free SDE in a junction-free setting. Our findings establish Shiba chain-altermagnet heterostructures as a scalable platform for supercurrent-tunable topological superconductivity and intrinsic, field-free superconducting diodes for dissipationless quantum technologies.

TT 97.5 Fri 10:30 CHE/0089

Current pulse manipulation of the superconducting diode effect in FeSe — •Roemer Hinlopen[1], Linus Holeschovsky[1], Rebecca Nicholls[2], Nigel Hussey[2,3], Carsten Putzke[1], and Philip Moll[1] — [1]Max Planck Institute for Structure and Dynamics of Matter, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]University of Bristol, HH Wills Laboratory, Tyndall Avenue, BS8 1TL Bristol, UK — [3]High Field Magnet Laboratory (HFML-FELIX) and Institute for Molecules and Materials, Radboud University, Nijmegen 6525ED, Netherlands

The superconducting diode effect (SDE) has seen a surge in popularity in recent years for its potential technological applications. However, switching the sign of the SDE usually relies on reversing the polarity of the applied magnetic field on specifically designed device architectures which break the necessary symmetries. In this talk, we present a new means of control for the intrinsic SDE through microsecond current pulsing. We use focused ion beam (FIB) machining to create single crystalline devices of the strongly correlated nematic superconductor FeSe. We observe a clear intrinsic diode effect with effiency up to 30 %, which remains observable to a record applied magnetic field of 12 T. Our central result is that by sending intense microsecond current pulses through the device, we can deterministically manipulate the sign and strength of this SDE. This finding opens a new channel to control the SDE in devices and potentially realise a zero-field switchable device in the future.

15 min. break

TT 97.6 Fri 11:00 CHE/0089

Nonreciprocal Magnon Fluxonics — •Oleksandr Dobrovolskiy — Cryogenic Quantum Electronics, EMG and LENA, Technische Universität Braunschweig, Braunschweig, Germany

Fluxon dynamics controls the magneto-resistive response of superconductors (S) and becomes nonreciprocal under symmetry break [1]. Magnons - the quanta of spin waves in magnetic materials - are attracting increasing attention as information carriers [2]. In my talk, I will introduce magnon fluxonics as a subdomain of superconducting spintronics. I will discuss nonreciprocal spin-wave dynamics in dipole-coupled superconductor/ferromagnet heterostructures, focusing on two effects. (i) Within the "ratchet window", the application of an AC current to S enables magnon bandgap tuning during one half-wave, while the bandgap frequencies remain constant during the other. This effect arises from the Doppler shift and the nonlinear spin-wave dispersion. (ii) At higher velocities, on the order of a few km/s, the moving vortex lattice excites magnons unidirectionally along the direction of vortex motion. This regime occurs when the wavevector (momentum) and frequency (energy) of the magnons match those of the fluxons, thereby fulfilling the Cherenkov resonance condition [3]. These results demonstrate how the well-studied superconducting diode or ratchet effects can enrich other research areas and enable new functionalities of nonreciprocal steering and unidirectional generation of spin waves.

[1] Kochan & Strunk, Nat. Electr. 8 (2025) 380.
[2] Chumak et al., IEEE Trans. Magnet. 58 (2022) 0800172.
[3] Dobrovolskiy et al., Nat. Nanotechnol. (2025). https://doi.org/10.1038/s41565-025-02024-w.

TT 97.7 Fri 11:15 CHE/0089

Spin-wave-induced giant ratchet effect in superconductor-ferromagnet heterostructures — •Anton Pokusinskyi and Oleksandr Dobrovolskiy — Cryogenic Quantum Electronics, EMG and LENA, Technische Universität Braunschweig, Germany

Superconducting vortex ratchets enable directed motion of magnetic flux quanta under zero time-average forces and thus act as rectifiers in superconducting circuits. Recent diode realizations exploiting asymmetric edge barriers in superconducting NbN and V/EuS microstructures have achieved ratchet efficiencies of 35-50% [1-3]. However, their tunability remains limited by fixed geometries or magnetic-field reversal, constraining scalability and dynamic control. Here, we theoretically predict a tunable giant ratchet effect in superconductor-ferromagnet heterostructures, arising from the coupling between moving fluxons and spin waves—collective precessions of spins in the ferromagnetic layer. Our modeling, based on time-dependent Ginzburg-Landau simulations under the experimental conditions of [4], demonstrates that spin-wave excitation enables dynamic control of vortex motion, offering a pathway toward reconfigurable superconducting ratchets and fluxonic devices.

[1] Ingla-Aynes et al., Nat. Electron. 8 (2025) 411
[2] Castellani et al., Nat. Electron. 8 (2025) 417
[3] Porrati et al., Small Methods e01430 (2025)
[4] Dobrovolskiy et al., Nat. Nanotechnol. (2025). https://doi.org/10.1038/s41565-025-02024-w.

TT 97.8 Fri 11:30 CHE/0089

Tunable Nonreciprocity in 3D Superconductor Nanoarchitectures — •Igor Bogush and Oleksandr Dobrovolskiy — Cryogenic Quantum Electronics, EMG and LENA, Technische Universität Braunschweig, Germany

Nonreciprocity lies at the heart of superconducting diodes and ratchets, key elements for designing low-dissipative computing devices [1]. However, achieving precise control over the directionality and strength of nonreciprocity is challenging, as it requires local tuning of superconductor properties or applied stimuli. Here, we show that the geometry of curved thin superconductor membranes introduces a new degree of freedom, enabling vortex-motion synchronization [2] and nonreciprocity tunable via the magnetic field direction. In such membranes, only the component of the magnetic field normal to the surface exerts a driving Lorentz force on vortices, while the tangential component is less relevant. Using a conformal approach for time-dependent Ginzburg-Landau simulations [3], we predict that in cap-shaped superconductor membranes, the magnetic field induces effective pinning whose location can be controlled by adjusting the field direction. Even without a pinning potential, this controllable symmetry breaking induces nonreciprocal vortex dynamics and vortex ratchet behavior. These results highlight the geometry in thin curved membranes as a parameter that enhances the tunability of superconducting phenomena in rectifiers and other fluxonic devices.

[1] Plourde, IEEE Trans. Appl. Supercond. 19 (2009) 3698
[2] Bogush et al., Phys. Rev. B 111 (2025) 214510
[3] Bogush et al., Comp. Phys. Comm. 315 (2025) 109736

TT 97.9 Fri 11:45 CHE/0089

Steering of Vortex Jets in Anisotropic Pinning Fields — •Ekaterina Pribytova[1] and Oleksandr Dobrovolskiy[2] — [1]Brno University of Technology, Czechia — [2]Technische Universität Braunschweig, Germany

Understanding how Abrikosov vortices penetrate and move in superconductor films is crucial for fluxonics, which treats vortices as quantized information bits. So far, vortex steering was achieved for their global dynamics across the entire superconductor constriction. Here, we take a different approach of local vortex dynamics [1]: vortices are injected via an edge defect (notch) and guided through a washboard pinning potential (WPP). The resulting arrangement of vortices is a diverging jet rather than a periodic lattice. Numerical modeling via the time-dependent Ginzburg-Landau equation [2] reveals that vortex jets can be focused, deflected, and directed toward given points along the edge opposite to the notch. The underlying vortex steering mechanism is based on the competing vortex-vortex, vortex-current, and vortex-pinning interactions [1]. In return, beyond their potential for fluxonic logic gates, steered vortex jets offer a tool for probing these interactions. Specifically, the vortex jet's opening angle estimates the magnetic penetration depth, while its deflection from the current-normal direction reveals the WPP strength. These results demonstrate the predictive power of TDGL modeling for nanoengineered fluxonic circuits and complement the analytical and experimental results.

[1] Bezuglyj et al., Phys. Rev. B 105 (2022) 214507.
[2] Bishop-Van Horn, Comput. Phys. Commun. 291 (2023) 108799.