Engineered Josephson diode effect in kinked Rashba nanochannels

Mattia Trama[1,2], Alfonso Maiellaro[1,3,4], Jacopo Settino[5], Claudio Guarcello[1,3], Francesco Romeo[1,3], Roberta Citro[1,3,4]

1. *University of Salerno, Department of Physics, via Giovanni Paolo II, 132 I-84084 Fisciano, Italy*
2. *Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany*
3. *INFN, Sezione di Napoli, Gruppo collegato di Salerno, via Giovanni Paolo II, 132 I-84084 Fisciano, Italy*
4. *CNR-SPIN, via Giovanni Paolo II, 132 I-84084 Fisciano, Italy*
5. *Dipartimento di Fisica, Università della Calabria, Via P. Bucci Arcavacata di Rende (CS), Italy*

Abstract: The superconducting diode effect in kinked Rashba Josephson junctions is tunable via geometry and magnetic field, achieving 46% efficiency. Moreover a vast phenomenology of sub-gap states makes it suitable for application to topological quantum devices.

The superconducting diode effect (SDE) [1], analogous to unidirectional charge transport in semiconductor diodes, is distinguished by a nonreciprocal, dissipationless flow of Cooper pairs. This phenomenon arises from symmetry-breaking mechanisms and the quantum properties of superconductors. We investigate the geometric control of the SDE in a kinked nanostrip Josephson junction (JJ) (Fig. 1a) formed in a two-dimensional electron gas (2DEG) with Rashba spin-orbit coupling (RSOC) [2]. The kink geometry and an out-of-plane magnetic field offer a novel approach to tuning transport properties.

Our phase diagram reveals a geometry- and field-tunable diode effect, with diode efficiency peaking at 46% (Fig. 1b), notably near the topological phase transition where trivial zero-energy Andreev bound states (ABSs) evolve into Majorana bound states (MBSs). This synergy between geometric modulation and topological phases enables optimized SDE performance in nanoscale devices.

Additionally, we uncover an anomalous Josephson effect, characterized by a non-zero current at zero phase difference (φ_0-junction behavior), linked to RSOC and geometric asymmetry. Distinct transport regimes are governed by subgap quasiparticle states, including ABSs, zero-energy ABSs, and MBSs, each contributing uniquely to the current-phase relation.

This combination of geometric control and RSOC establishes a versatile platform for nonreciprocal superconducting transport and paves the way for designing high-efficiency superconducting diodes, with implications for advanced quantum technologies and energy-efficient nanoelectronics.

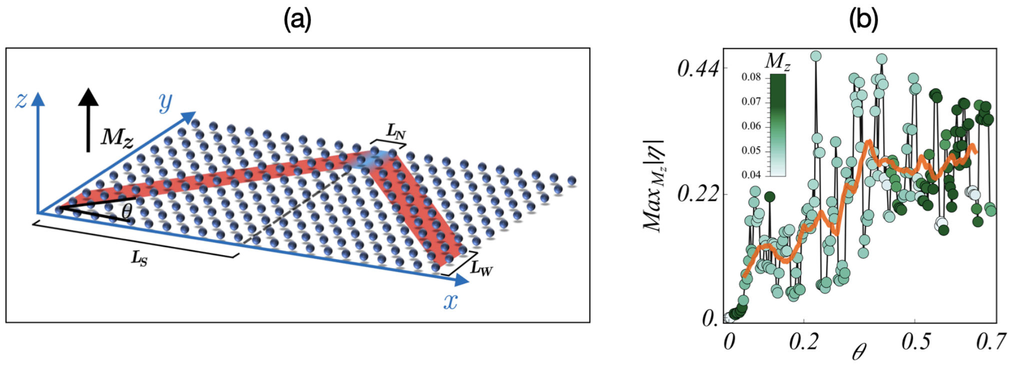

Fig. 1 (a) Schematic representation of the kinked Josephson junction realized over a square lattice. The red area is the superconducting region, while the blue one is the region in the normal state; M_z is the external magnetic field, and θ is the kink angle. (b) Maximum value of the superconducting diode efficiency with the applied magnetic field M_z as a function of the kinked angle θ. The orange line is the mobile average over a window 25 points.

References

[1] M. Nadeem, M. S. Fuhrer, and X. Wang, "The superconducting diode effect", Nat. Rew. Phys. **5,** 558 (2023).
[2] A. Maiellaro, M. Trama, J. Settino, C. Guarcello, F. Romeo and R. Citro, "Engineered Josephson diode effect in kinked Rashba nanochannels", SciPost Phys. **17**, 101 (2024).