Cos(2phi) Josephson Junction and Gate Controlled Josephson Diode in Proximitized InAs Supercurrent Interferometers*

Christian Schönenberger[1,2]
C. Ciaccia[1], R. Haller[1], A. C. C. Drachmann[2], C. Schrade[2], T. Lindemann[3], M. J. Manfra[3,4]

[1] *Quantum- and Nanoelectronics Lab, Department of Physics and Swiss Nanoscience Institute, University of Basel, Switzerland.*
[2] *Centre for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Denmark.*
[3] *Department of Physics and Astronomy, School of Electrical and Computer Engineering, and School of Materials Engineering, Purdue University, West Lafayette, Indiana, USA.*
[4] *Birck Nanotechnology Centre, Purdue University, West Lafayette, Indiana, USA.*

christian.schoenenberger@unibas.ch

Superconducting qubits with intrinsic noise protection offer a promising approach to improve the coherence of quantum information. Crucial to such protected qubits is the encoding of the logical quantum states into wavefunctions with disjoint support. Such encoding can be achieved by a Josephson element with an unusual charge-4e supercurrent emerging from the coherent transfer of pairs of Cooper-pairs. We demonstrate the controlled conversion of a conventional charge-2e dominated supercurrent to a charge-4e dominated one in a superconducting quantum interference device (SQUID) consisting of gate-tuneable planar Josephson junctions realized in a InAs two-dimensional electron gas proximitized by a nearby superconducting Al film evaporated in-situ. We investigate the ac Josephson effect of the SQUID and measure a dominant photon emission at twice the fundamental Josephson frequency together with a doubling of the number of Shapiro steps, both consistent with the appearance of charge-4e supercurrent [1]. Our results present a step towards protected superconducting qubits based on superconductor-semiconductor hybrid materials.

Using the same material system, we also demonstrate that by tuning the higher harmonics of Josephson junctions allows to engineer the superconducting diode effect [2]. The Josephson Diode (JD) is a non-reciprocal circuit element that supports a larger critical current in one direction than in the other. This effect has been gaining a growing interest because of promising applications in superconducting electronic circuits with low power consumption. The effect can only appear if time-reversal symmetry and inversion symmetry is broken together. In a DC-SQUID geometry the former is achieved by applying a phase bias induced by the flux in the loop and the latter by tuning the two junctions in an asymmetric regime. While in earlier work the asymmetry was created through asymmetric loop inductances, this is realized here by tuning the transparency of the two Josephson junctions asymmetrically.

References

[1] C. Ciaccia et al., Phys. Rev. Research 5 (2023) 033131.
[2] C. Ciaccia et al., Comm. Phys. 7 (2024) 41.

*This research was supported by the Swiss Nanoscience Institute (SNI), the Swiss National Science Foundation through grants Nos. 172638 and 192027, and the QuantEra project SuperTop. We further acknowledge funding from the European Union's Horizon 2020 research and innovation program, specifically (a) from the European Research Council (ERC) grant agreement No. 787414, ERC-Adv TopSupra, (b) grant agreement No. 828948, FET-open project AndQC, and (c) grant agreement 847471, project CO-FUND-QUSTEC. C. Schrade acknowledges support from the Microsoft Corporation.