

Hybrid superconductor-semiconductor Josephson junctions for quantum technologies

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After a brief review of the NQSTI activities at CNR-Nano, I will focus on our work on InSb nanoflag-based Josephson junctions.

High-quality III–V narrow bandgap semiconductor materials with strong spin–orbit coupling and large Landé g-factor provide a promising platform for next-generation applications in the field of high-speed electronics, spintronics, and quantum computing. InSb stands out due to its narrow bandgap, high carrier mobility, and small effective mass, making it very appealing in this context. In fact, this material has attracted tremendous attention in recent years for the implementation of topological superconducting states. An attractive pathway to obtain two-dimensional (2D) InSb layers is the growth of freestanding single-crystalline InSb nanoflags¹.

We demonstrated fabrication of ballistic Josephson-junction devices based on these InSb nanoflags with Ti/Nb contacts that show gate-tunable proximity-induced supercurrent and sizable excess current². The devices show clear signatures of subharmonic gap structures, indicating phase-coherent transport in the junction and a high transparency of the interfaces.

The high quality of the devices enabled the observation of the Josephson diode effect in these Josephson junctions³. When subjected to an in-plane magnetic field, these devices enter a non-reciprocal transport regime, manifesting an asymmetry between positive and negative critical currents. The degree of asymmetry varies with the angle between the in-plane field and the current direction, exhibiting a pronounced temperature dependence. Our data demonstrate that these devices can work as Josephson diodes, with dissipation-less current flowing in only one direction. Under microwave irradiation, we observe half-integer Shapiro steps that are robust to temperature, suggesting their possible nonequilibrium origin⁴. Our results demonstrate the potential of ballistic InSb nanoflag Josephson junctions as a valuable platform for understanding the physics of hybrid devices and investigating their nonequilibrium dynamics.

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