Hybrid Josephson junctions (JJs) realized in superconductor - semiconductor heterostructures

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Semiconductor-superconductor hybrid structures ranging from quasi 1D-nanowires to 2D electron gases (2DEGs) serve as a platform to study interactions between confined electronic states and superconductivity, including phenomena such as Andreev Bound States and Majorana Fermions. Realizing highly transparent interfaces in these systems is essential for the exploration of their physics. Traditionally, hybrid materials like epitaxial Al on InAs have dominated due to their high-quality interfaces achieved through in-situ deposition. However, their relatively small superconducting gap and limited operating range in temperature and magnetic field have motivated exploration of alternative superconductors.

In this work, we present a novel hybrid material platform based on Nb, NbTi and NbTiN as superconductors, leading to a larger superconducting gap and enhanced resilience to magnetic fields. A significant challenge in combining III-V semiconductors with Nb-based superconductors lies in the formation of amorphous interfaces. To address this, we introduced a thin Al interlayer, which provides an epitaxial connection between shallow InAs 2DEGs and the superconducting thin films deposited via magnetron sputtering. Guided by scanning transmission electron microscopy, we optimized the material stack, achieving a highly crystalline interface with a well-defined epitaxial relationship.

Transport measurements of Josephson junctions fabricated from this hybrid material show an induced superconducting gap, nearly five times higher than typical Al-based hybrids and only twice smaller than bulk Nb. This result demonstrates the formation of a highly transparent interface and establishes the potential of Nb-based hybrids as a high-quality material platform for advanced superconducting devices. Furthermore, 2DEG platforms allow for versatile device geometries beyond standard two-terminal designs. Recent advancements in multi-terminal Josephson junctions have revealed rich physics, including spin-splitting effects, ground-state parity transitions, and synthetic Andreev band structures, potentially hosting topological states.

This work highlights the pivotal role of interface engineering in hybrid systems and introduces a robust methodology to maximize the induced superconducting gap, opening pathways for exploring novel quantum phenomena in semiconductor-superconductor platforms.

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