Investigation of hybrid Josephson junctions for topological applications

InAs-based devices are studied, in combination with superconductors, for new topological applications. Low-temperature magnetotransport measurements on suspended InAs nanowires revealed important information on the intrinsic spin-orbit coupling. Side-gate tuning can be used to control spin-orbit length. We have inspected Josephson junctions with a high-mobility InAs quantum-well bridging two Nb superconductors. We demonstrate supercurrent flow with critical temperature up to 8.1 K and high critical field. Low-temperature transport shows clear quantum Hall plateaus, allowing for the study of the coexistence of superconductivity and quantum Hall effect. Superconducting quantum interference patterns can be tuned by external gates.

Recent experimental and theoretical activities focused on hybrid semiconductor/superconductor systems, aiming at the emergence of new topological states of matter, like Majorana fermions or parafermions. Hybrid superconductor/semiconductors with strong spin-orbit coupling offer a promising platform in this direction. Low-temperature transport measurements with a vector magnet on a suspended InAs nanowire (Fig. 1a) allowed to report a weak anti-localization signal (Fig. 1b) and to extract polar maps of spin-orbit length and coherence length. We demonstrated that the spin-orbit interaction is isotropic and can be controlled by external side gates [1,2].

Hybrid Josephson junctions (Fig. 2a) formed by an InAs quantum-well placed between two Nb contacts have been investigated as well. Transport measurements revealed a critical temperature up to 8.1 K and a high critical field (of the order of 3 T). Modulation of supercurrent amplitude is achieved by acting on side gates. Well-developed quantum Hall plateaus have been also observed (Fig. 2b). These samples therefore allow to study the coexistence of topological edge states and superconductivity [2,3].

We fabricated and investigated a hybrid trenched Josephson junction in which the width, area, and supercurrent of the two arms of a SQUID-like geometry can be independently controlled with high precision. We demonstrate wide tunability of interference patterns by electrostatic means, from a SQUID with narrow arms to a Fraunhofer pattern in an extended JJ [4]. These results pave the way for new device architectures with potential topological applications.

In parallel, theoretical activities on parafermionic models have been conducted. Microscopic descriptions of parafermionic chains, based on a tight binding model and on generalized hydrodynamic approaches have been inspected, discussing both equilibrium thermodynamic properties and non-equilibrium dynamics under temperature gradients. A deep theoretical understanding of the fundamental properties of parafermions will be useful in view of new experiments aiming at the detection of these elusive quasiparticles [5,6].

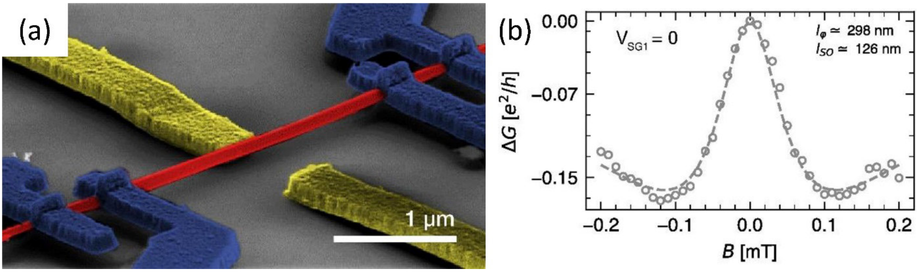

Fig. 1
(a) False-colored SEM image of a representative device with four-wire measurement setup. A suspended InAs nanowire (in red) is contacted with four ohmic contacts (in blue). Two lateral gate electrodes (in yellow) allow to induce tunable electric fields inside the wire and modulate the spin-orbit interaction. (b) The conductance correction ΔG(B) = G(B) - G(0) is shown as a function of magnetic field applied along the z-axis at zero external gate voltages $V_{SG1} = V_{SG2} = 0$. The peak at zero field is due to the weak anti-localization effect.

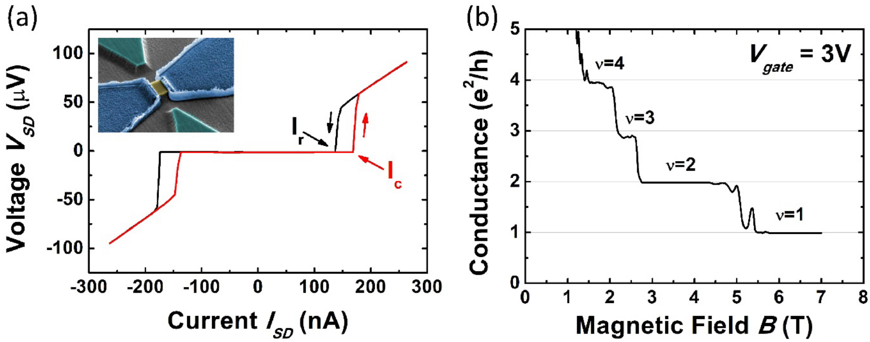

Fig. 2
(a) Source-drain voltage V_{SD} vs. source-drain current I_{SD} of InAs-based Josephson junction. The black (red) arrow shows the direction of the black (red) sweep. The inset shows a false color SEM image of the device. The mesa is yellow, side gates are green, niobium is blue. (b) Conductance (in units of e^2/h) as a function of magnetic field, showing well-developed quantum Hall plateaus already at 1.5 T.

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