A Ge quantum dot monolithically embedded in a metal-semiconductor heterostructure: from single-hole transport to proximity induced superconductivity

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ABSTRACT:

Metal-semiconductor-metal heterostructures are an attractive platform for both fundamental studies of low-dimensional nanostructures as well as future high-performance low power dissipating nanoelectronic and quantum devices. Most notably, they provide enormous potential for a vast array of key components for quantum computing such as SQUIDs, oscillators, mixers and amplifiers. Related to its inherently strong spin-orbit coupling and the ability to host superconducting pairing correlations, Ge is emerging as a versatile material to realize devices capable of encoding, processing, or transmitting quantum information.

Here, we demonstrate that utilizing a thermally induced exchange reaction between single-crystalline Ge nanowires and Al pads, monolithic Al-Ge-Al

nanowire heterostructures with ultra-small Ge segments contacted by self-aligned, quasi-1D, crystalline Al leads can be fabricated without lithographic constraints. High-resolution transmission electron microscopy and energy dispersive X-ray spectroscopy proved the composition and perfect crystallinity of these metal−semiconductor nanowire heterostructures. Integrating such nanowire heterostructures as active channels in electrostatically gated field-effect transistor devices, provides a platform for the systematic investigation of electrical transport mechanisms in ultra-scaled Ge channels.

Conducting low temperature (400 mK) DC spectroscopy measurements, we report highly gate-tunable hole transport from a completely insulating regime, through a low conductive regime, that exhibits properties of a single-hole transistor, to a superconducting regime, resembling a Josephson field-effect transistor. The experimental proof of exchanging cooper-pairs between superconducting Al leads through a gate-tunable Ge channel, resulting from the superconducting proximity effect, is the first demonstration of superconductivity induced in an intrinsic Ge channel. The realization of a Josephson field-effect transistor with a high junction transparency in the supercurrent regime allows us to study the sub-gap transport mediated by Andreev states. The presented results establish Ge quantum dots monolithically embedded in Al-Ge-Al nanowire heterostructures as a highly promising platform for hybrid superconductor-semiconductor devices for the study of Majorana zero modes and key components of quantum computing such as gatemons or gate tunable SQUIDS.