Master thesis Project

Josephson physics of high-transparency quantum conduction channels in 2D Germanium

Two-dimensional (2D) Ge-based heterostructures have recently been put to the forefront of quantum technologies in particular for their high mobility and as a platform for hole spin qubit architectures. Additionally, 2D-Ge forms high transparency contacts to superconductors (S), offering a promising platform for hybrid superconductor / semiconductor physics [1]. This could have promising applications for combining superconducting with spin-based qubits.

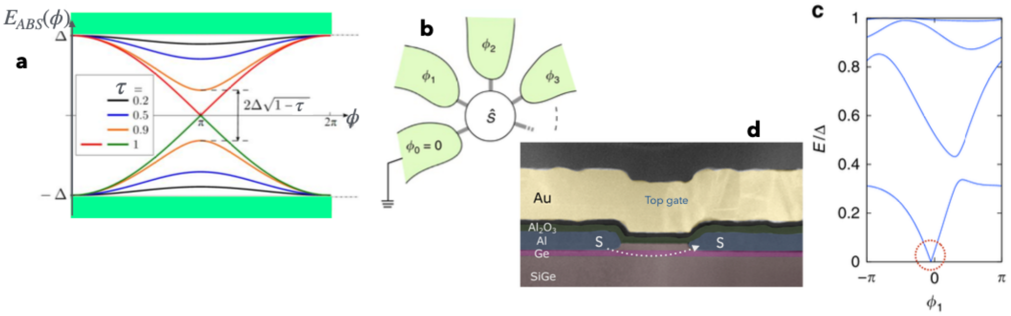

Figure 1: (a) ABS energies versus phase for different transparencies. As $\tau \to 1$, the Andreev gap closes at $\phi = \pi$.(b) Schematics of a multiterminal Josephson junction with relative phases applied and (c) ABS energies which can be driven to a topological ground state transition (red circle) (from [2]). (d) Transverse cut of a S-Ge-S junction, with length of bout 200 nm.

In short (few 100 nm long) S-Ge-S junction, the Josephson effect (dissipationless current flow) can be realized. Electronic transport is governed by only few conduction channels with conductance $G=\tau\, G_Q$, where $G_Q=2e^2/h$ is the quantum of conductance and $0<\tau<1$ is the channel transmission. In the superconducting state, each channel leads to a so-called Andreev bound state (ABS), which carries the supercurrent. In ballistic junctions with transparencies $\tau \to 1$, the ABSs can have intriguing properties which are the object of this project. So far, Al/Ge contacts have been successfully realized at the laboratory but the transmission seems to be limited to ~ 0.7.

The first step of this Master project will consist in fabricating and investigating 2D-Ge Josephson junctions based on new superconducting materials which form contacts to Ge with $\tau \to 1$. The next step consists in moving to 3- and 4-terminal Josephson junctions in 2D-Ge. Here, the ABS are more complex and can be varied by the quantum phases in each superconducting lead, which can lead to topologically distinct ground states [2]. You will study the dc transport properties of multi-terminal junctions and confront the results to theory [3].

This internship can be pursued with a PhD thesis in the frame of which the above-described structures will be investigated using microwave rather than dc transport techniques.

[1] Leblanc *et al.,* arXiv:2405.14695 (2024)., [2] Riwar *et al.,* Nature Commun. **7,** 11167 (2016)., [3] Mélin *et al.,* Phys. Rev. Research 5, 033124 (2023).

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