# DOCTORAL DEFENSE

## From Quantum Transport In Semiconducting Nanowires To Hybrid Semiconducting-Superconducting Qubits

# Azarin Zarassi

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**Zoom ID: 977 5107 2659**

Non-department members:
Contact **doctoral candidate** or **advisor** for access.

**Research Advisor:**
**Dr. Sergey Frolov**

*Abstract:* A practical quantum computer demands a physical quantum bit (qubit) that is scalable, has a well-defined initial state, and brings together coherence with reliable control and read-out. A compelling idea is to put together a locally protected Majorana qubit with a superconducting qubit. The superconducting qubit is used to read out the Majorana states while the Majorana qubit may act as a quantum memory. This device paves the way to future generation of fault-tolerant quantum computers and is the beginning of many studies to exploit Majorana fermions. This thesis presents a series of studies on quantum transport in semiconducting nanowires coupled to superconductors to investigate various platforms for realizing Majorana fermions as well as gain an insight into interpretation of experiments aimed at detecting Majorana modes. These studies are followed by preliminary results from microwave measurements on superconducting circuits compatible with semiconducting-superconducting heterostructures.

We first evaluate the potentials of Ge/Si core/shell nanowires for realizing Majorana fermions by achieving induced superconductivity as well as estimating spin-orbit coupling and effective Landé g -factors. Next we explore the transport mediated by Andreev bound states formed in InSb nanowire quantum dots that exhibit a mirage of crowded Andreev spectrum. A subgap negative differential conductance is investigated together with the coalescing Andreev resonances at zero bias relevant for the correct interpretation of Majorana experiments done on the same structures. We close studies of semiconducting nanowires by exploring tunnel junctions in Sn-InSb nanowires that are prepared by in-situ shadowing using nearby nanowires as well as flakes. Tin shell is found to induce a hard superconducting gap persisting up to high magnetic fields. We observe two-electron charging effect from a small superconducting island of Sn-InSb. This effect is attributed to charge parity stability, which makes this hybrid superconducting-semiconducting nanowire system an intriguing candidate for superconducting and topological quantum circuits.

These Sn-InSb junctions are then used as the nonlinear element in a transmon qubit design where we observe a dispersive coupling between this nanowire Josephson junction and a superconducting resonator. We also present our progress towards building a magnetic field resilient superconducting circuit that allows integration with semiconducting and topological structures.

In the last chapter of the thesis, InSb semiconducting nanowires are utilized as shadow masks prior to superconductor deposition on an InAs two-dimensional electron gas system. We fabricate and study Josephson current properties in Josephson junctions made from these nanowires shadows. Our results point to highly transparent junctions that can be developed further for hybrid superconductor-semiconductor qubit systems.