Nb/InAs Hybrid Heterostructures for Topological Quantum Computing

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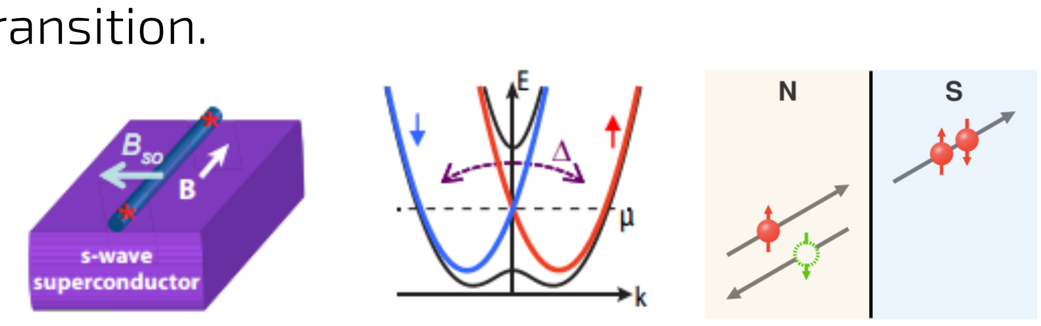
Introduction

We aim to develop Majorana fermion (MF) devices in 2D electron gases (2DEGs) present in InAs surface quantum wells (QWs) as a scalable approach to topological quantum computing. MF devices require:

- 1D wire of semiconducting material with strong spin-orbit interaction and a large g-factor
- Axially applied magnetic field
- Proximity superconductivity from an s-wave superconductor (SC)

in order to induce a topological phase transition.



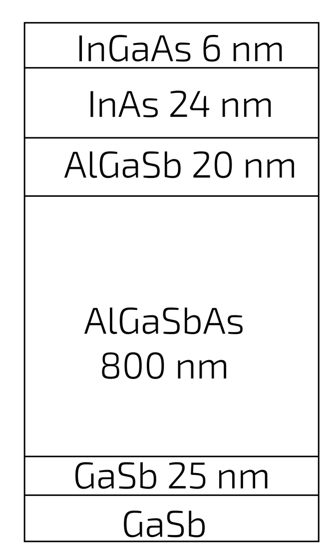
(a) Conceptual MF device.[1] (b) Energy dispersion diagram for a 1D semiconducting wire with Rashba spin orbit interaction (SOI). Magnetic field induces a Zeeman gap at k=0 and superconductivity induces a gap Δ.[1] (c) Schematic of Andreev reflection at a superconductor-semiconductor interface, an effect used to estimate Δ^*.

Our research encompasses the growth of III/V semiconductor heterostructures by molecular beam epitaxy, fabrication of devices using Waterloo's QNFCF facility, and characterization of material and device properties through low temperature transport experiments.

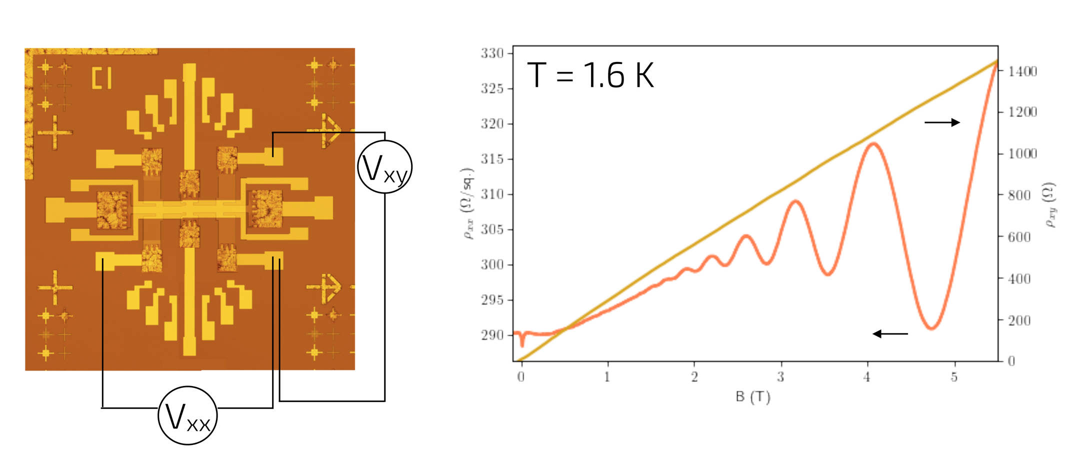
Characterization

Magnetotransport

The InAs QW heterostructure (right) is lattice matched and designed to host a 2DEG within the InAs layer. The thin InGaAs top barrier allows penetration of the 2DEG wave-function to the surface for compatibility with an epitaxial SC while affording some protection from the surface for improved transport mobility.

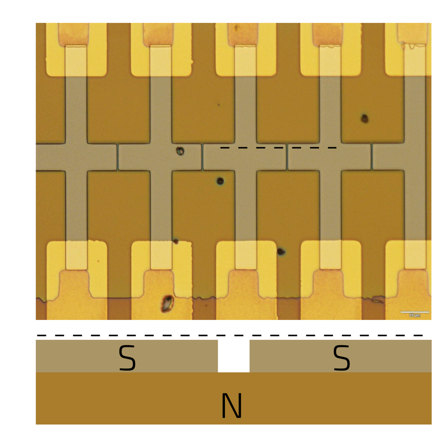


(Below) Hallbar devices are used to confirm the desired transport characteristics of the 2DEG. Measuring the longitudinal and Hall voltages, we obtain mobilities exceeding 10,000 cm^2/Vs at carrier densities near 1.5×10^{12} cm^{-2}. High density 2DEGs are desirable for improved Ohmic contact formation and measured mobilities are on par with competing platforms.

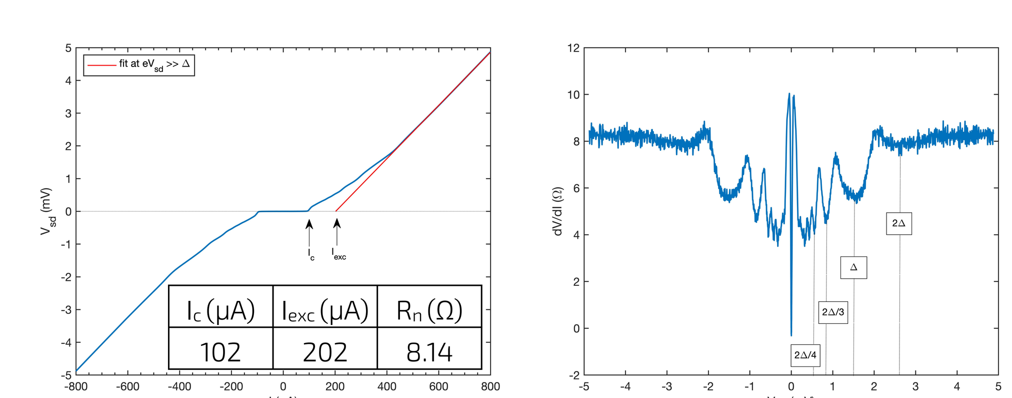


Superconductivity

Superconductor-semiconductor-superconductor (S-N-S) junctions are ideal devices for characterization of SN interfaces. The transparency of an SN interface dictates the strength of the induced superconducting gap Δ^* within the semiconducting layer, a critical element of future MF devices.



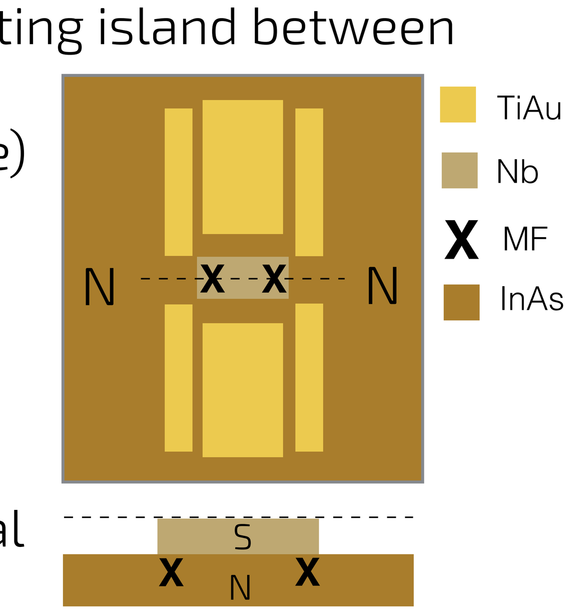
Our devices consist of Nb superconducting leads separated by a 200 nm gap wherein current must travel through the 2DEG. The electronic properties of the junction are determined from analysis of the IV curve (left). Once the bias current exceeds a critical value I_c, the junction will become resistive (finite voltage drop across sample) and a supercurrent will no longer be observed. Values of the critical current I_c, excess current I_{exc}, and normal state resistance R_n can be used to estimate the induced gap Δ^*= 1.11 meV. Additionally, from observation of multiple Andreev reflections Δ^* is confirmed (right).



Next Steps

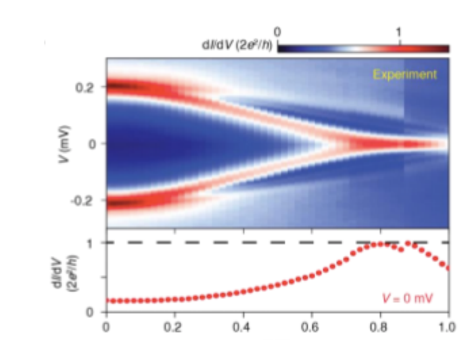
Majorana Devices

A Majorana device is formed by pattering a 1D "wire" in the 2DEG using electrostatic top gates. A superconducting island between normal conducting regions (N-S-N device) will host MF's at the ends of the wire. These non-abelian particles are topological protected against environmental decoherence making them ideal for quantum computation.



What are the signatures?

- Stable zero bias peak[2]
- Unitary limit
- Exponential protection



These signatures indicate that the system has entered a topological phase hosting MF's which are robust against changes in magnetic field, chemical potential and gate voltage.

1. V. Mourik et al, Science 336, 6084 (2012).
2. H. Zhang, et. al, arXiv:1710.10701 (2017).

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