High Transparency Induced Superconductivity in Field Effect Two-Dimensional Electron Gases in Undoped InAs/AlGaSb Surface Quantum Wells

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We report on transport characteristics of field effect two-dimensional electron gases (2DEGs) in 24 nm wide indium arsenide (InAs) surface quantum wells. InAs and InSb [1] quantum wells possess several desirable qualities for realizing topological qubits, including high electron mobility, strong spin-orbit interaction, small effective mass and large Landé g-factor. InAs has the additional property that its surfaces tend to pin the Fermi level in the conduction band, which can facilitate superconductor-semiconductor proximity effects. Two nominally identical heterostructures were grown by molecular beam epitaxy with the following sequence of layers, starting from a GaSb (001) substrate: a 25 nm GaSb nucleation layer, a 800 nm $Al_{0.80}Ga_{0.20}Sb_{0.93}As_{0.07}$ quaternary buffer, a 20 nm $Al_{0.8}Ga_{0.1}Sb$ bottom barrier, a 24 nm InAs quantum well, and a 6 nm $In_{0.75}Ga_{0.25}As$ cap layer.

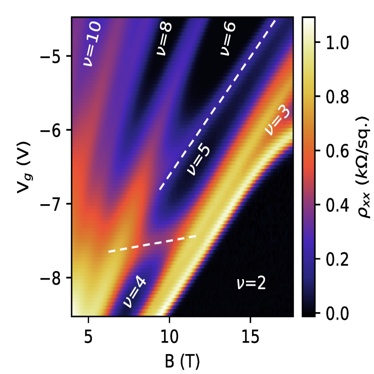

Fig. 1. Landau fan of Shubnikov-de-Haas (SdH) oscillations with densities ranging from $n_{2D} = 7.3\times 10^{11}$ cm^{-2} to $n_{2D} = 1.8\times 10^{12}$ cm^{-2}. White labels identify corresponding effective filling factors.

High-quality single-subband magnetotransport with clear quantized integer quantum Hall plateaus are observed to filling factor $\nu = 2$ in magnetic fields of up to B = 18 T, at electron densities up to 8×10^{11} cm^{-2}. Peak mobility is 11,000 cm^2/Vs at 2×10^{12} cm^{-2}. Large Rashba spin-orbit coefficients up to 50 meV·Å are obtained through weak anti-localization (WAL) measurements. The Landau fan diagram (Fig. 1), obtained by sweeping the top-gate at magnetic field increments, showcases the reproducibility and stability of gating characteristics with SiO_2 dielectric. Proximitized superconductivity is demonstrated in Nb-based superconductor-normal-superconductor (SNS) junctions, yielding 78-99% interface transparencies from superconducting contacts fabricated ex-situ (post growth), using two commonly-used experimental techniques for measuring transparencies. These transparencies are on par with those reported for epitaxially-grown superconductors; this result may dramatically expand the list of possible superconductors available for semiconductor-superconductor hybrid devices. The SNS junctions show characteristic voltages I_cR_n up to 870 μV and critical current densities up to 9.6 μA/μm, among the largest values reported for Nb-InAs SNS devices.

These high-quality SNS junctions are an essential step toward more complex devices for quantum computing applications. The SNS gap may be converted into a quasi-one-dimensional channel capable of hosting Majorana bound states (MBSs) by incorporating electrostatic top gates and quantum point contacts. These quasiparticles are of particular interest in quantum computing due to their non-Abelian exchange statistics, potentially facilitating fault-tolerant quantum computation with much lower overhead than is required for conventional qubit systems. This research is expected to accelerate the practical realization and manipulation of MBSs and may also find use in superconducting gatemon qubits and superconducting logic circuits.

References

[1] E. Annelise Bergeron et al., Field effect two-dimensional electron gases in modulation-doped InSb surface quantum wells, Appl. Phys. Lett. 122, 012103 (2023).