InSb Surface Wells for Quantum Device Applications

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Introduction

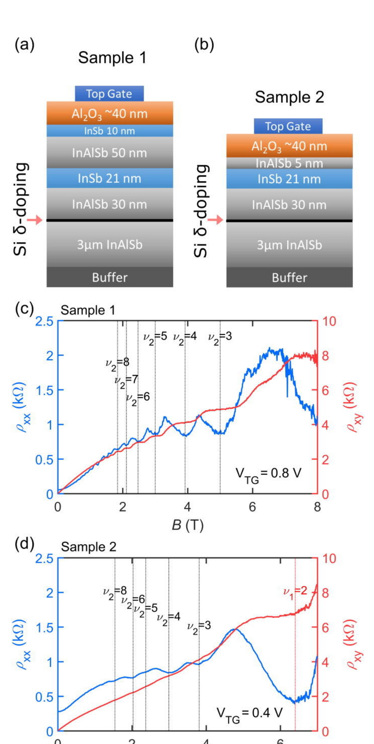
Amongst III-V binary semiconductors, Indium Antimonide (InSb) has:

- the smallest electron effective mass
- highest spin orbit coupling (SOI)
- largest Lande g-factor

Such material properties makes the pursuit of InSb QWs desirable for a number of quantum device applications, including quantum sensing, quantum metrology, and quantum computing.

High quality two-dimensional electron gases (2DEGs) in InSb QWs are difficult to realize partly due to highly mismatched lattice constants between the quantum well and available semi-insulating III/V substrates.

Given these limitations, reports of high quality InSb QWs are limited and commonly suffer from parasitic parallel conduction when using modulation dopants for 2DEG formation. (Right) Recent publication of an InSb near-surface QW considered "high quality" [1].

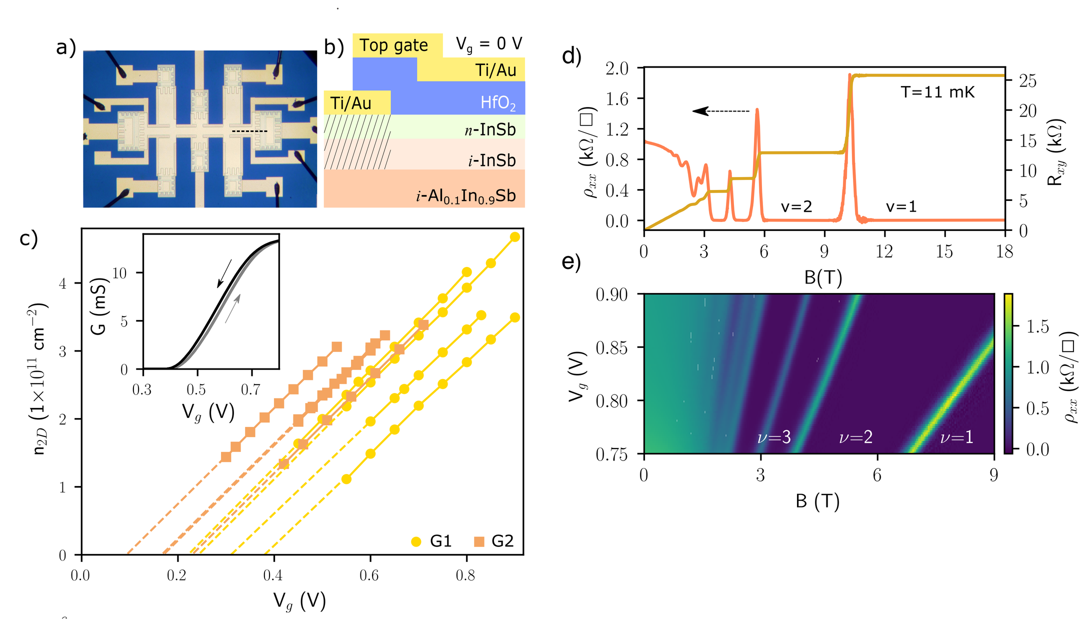


We present the transport characteristics of high-quality, gatetunable InSb 2DEGs in surface quantum wells grown on (001) SI-GaAs substrates. An n-InSb capping layer was used to realize reliable, low-resistance Ohmic contacts.

Results

Magnetotransport

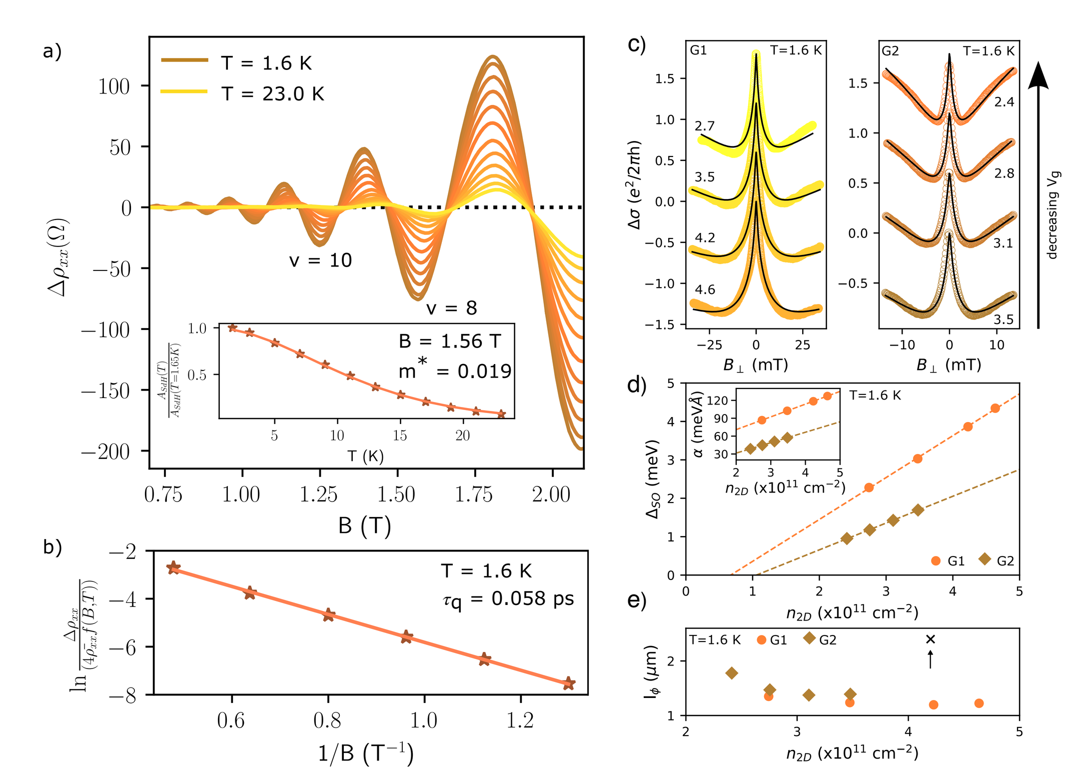
Magnetotransport measurements of (a) Hallbar devices are used to determine the electronic transport characteristic of the 2DEG. (b) An n-InSb capping layer produces reliable Ohmic contacts (< 1 kΩ) to a conductive InSb QW. (c) A top-gate induces a 2DEG with ideal gating characteristics up to a density of 4×10^{11} cm^{-2}.



(d, e) Magnetoresistance measurements confirm that intentional dopants in InSb are compatible with high quality single-subband 2DEGs as indicated by clear quantized integer quantum Hall plateaus observed to filling factor v = 1 in magnetic fields of up to B = 18 T. (e) The Landau fan, obtained by sweeping the top-gate at magnetic field increments, showcases the reproducibility and stability of gating characteristics. At densities near 2×10^{11} cm^{-2}, peak transport mobility exceeds 20,000 cm^2/Vs.

Properties of InSb

For application towards quantum devices, we've confirmed that the 2DEG inherits the material properties found in bulk InSb, such as the light effective mass and strong SOI.

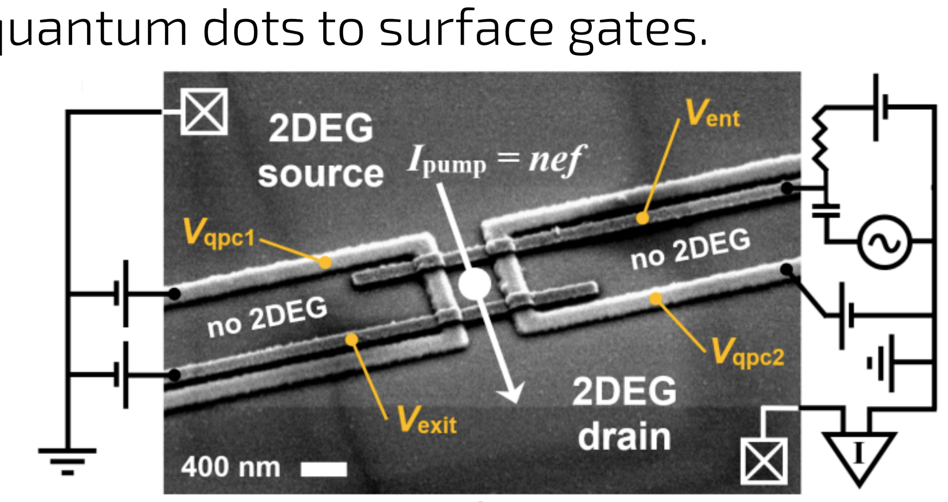


(a) An effective mass of $0.019m_e$ is determined from temperature-dependent magnetoresistance measurements and used to extract (b) a quantum lifetime of 0.058 ps. Remarkably, the quantum lifetime of our surface wells are similar to reports in deep InSb QWs. (c) Through weak anti-localization measurements, we've confirmed (d) Rashba spin-orbit coupling strengths up to 130 meVÅ and (e) phase coherence lengths > 1 μm.

Next Steps

Single Electron Pumps

The most commonly used pump architectures are GaAs/AlGaAs 2DEGs due to their small effective mass and silicon based architectures which offer stronger locally applied electric fields due to proximity of quantum dots to surface gates.



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Surface InSb heterostructures offer improved lateral electron confinement from electrostatic gating given:

- Proximity of the 2DEG to the surface
- Light effective mass.

We aim to design single electron pumps capable of operating at higher frequencies (GHz) due to these heterostructure design improvements.

1. Appl. Phys. Lett. 115, 012101 (2019)
2. Appl. Phys. Lett. 119, 114001 (2021).

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