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Probing Interactions in Low-Dimensional Systems: Exciton Condensation in SiGe Bilayers

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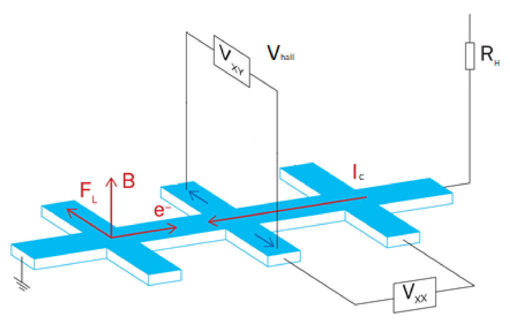
SiGe-based Bilayers

Undoped SiGe-based **quantum Hall bilayers** have been proposed as a platform for topological quantum computing[3] by utilizing the **spontaneous interlayer coherence (SIC)** that arises as a signature of indirect **exciton condensation** and for **valley splitting** tuning for the realization of long-lived Si spin qubits.

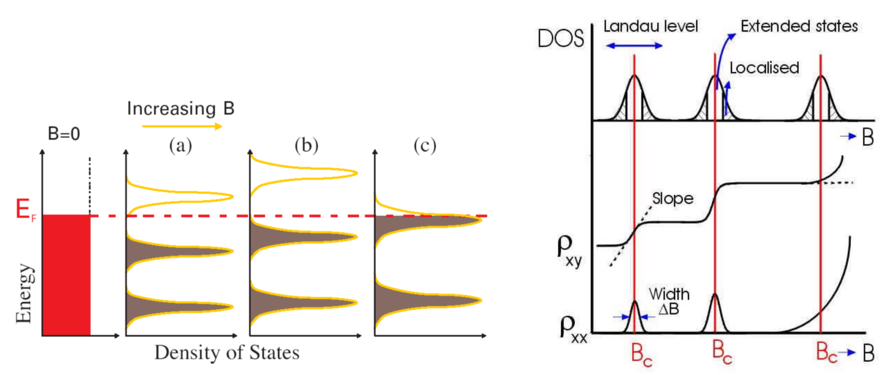
Quantum Hall Effect

At low T and high $B_\perp$ the Hall resistance, R_{xy}, exhibits steps that take on **quantized values** depending solely on **fundamental constants**, e and h:

$$R_H = \rho_{xy} = R_K/\nu = h/e^2\nu$$
$$[\nu_T = n_T/(eB/h)]$$



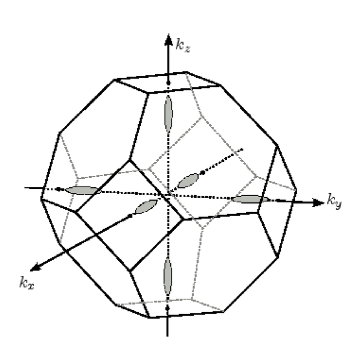
Measurement Scheme [1]



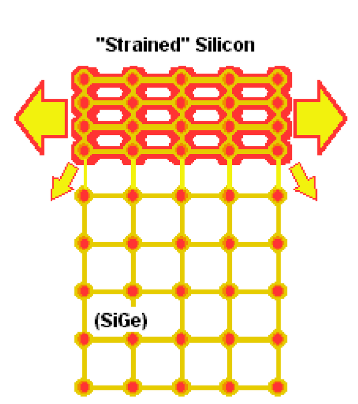
Density of States Schematic [TuDelft]

Valley Splitting

Through tensile strain and quantum confinement, the 6-fold valley degeneracy of bulk Si can be reduced to **2-fold.**



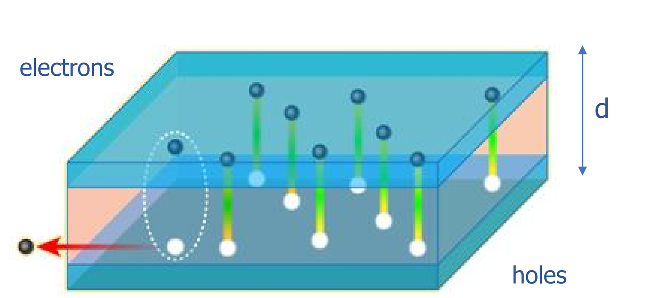
Si 1st Brillouin zone



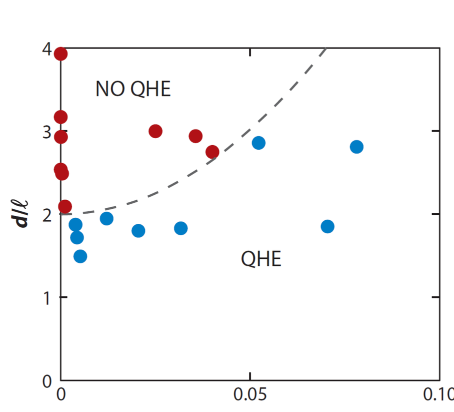
Strained Si [2]

SIC

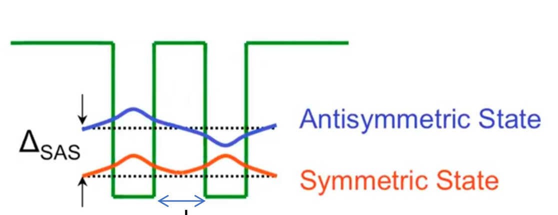
When 2 parallel 2DESs are brought close together, a **coherent** many-body state of matter that occurs solely due to Coulomb interactions at the **limit of low interlayer tunneling**.



Exciton Condensate [3]



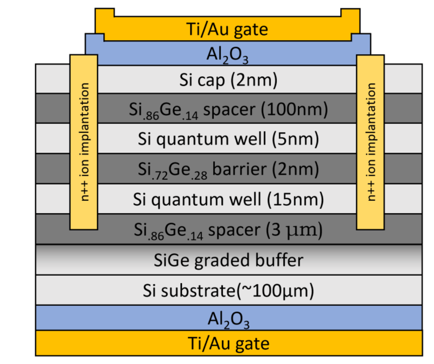
ν_T = 1 phase diagram [4]



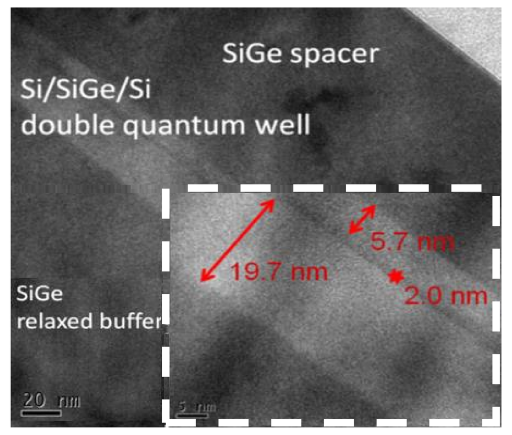
Single Particle Tunneling Gap [5]

SiGe Device Fabrication

A **dual-gated** bilayer Si/SiGe device, fabricated using standard photolithographic techniques, allows independent control of the density in both layers.



Layer Skematic [7]



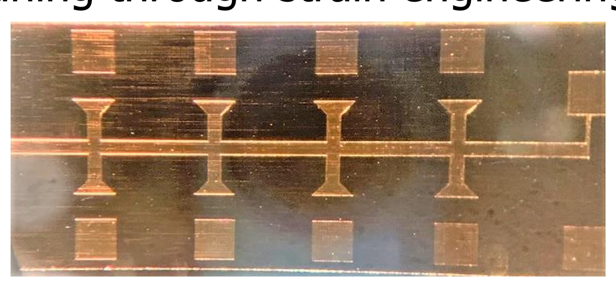
SiGe Bilayer [6]

Characteristics

- Consistent **front & back** gating capabilities
- Large material **mobility & low disorder** @ low T
- n_{Hall} 6.8 x 10^{10} cm^{-2} to 3.42 x 10^{11} cm^{-2}
- μ_{Hall} up to 3.08 x 10^5 $cm^2/(V \cdot s)$
- Effective-mass tuning through strain engineering

Measurements

- Low-frequency (~9-50 Hz) lock-in amplifiers
- **four-point geometry** w/ constant excitation current (~1-50 nA)

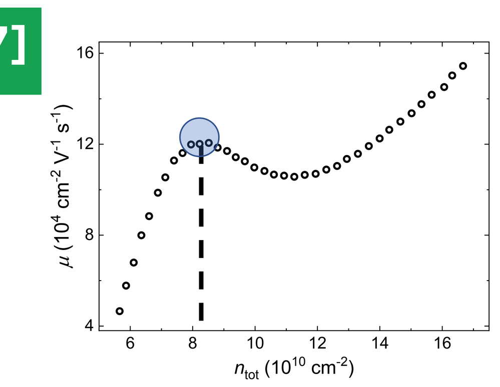


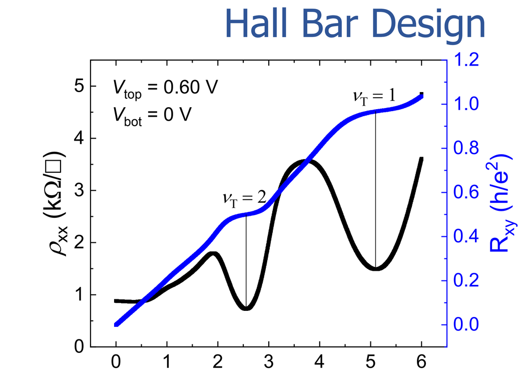
Hall Bar Design

Key Results[7]

$n_{crossover}$

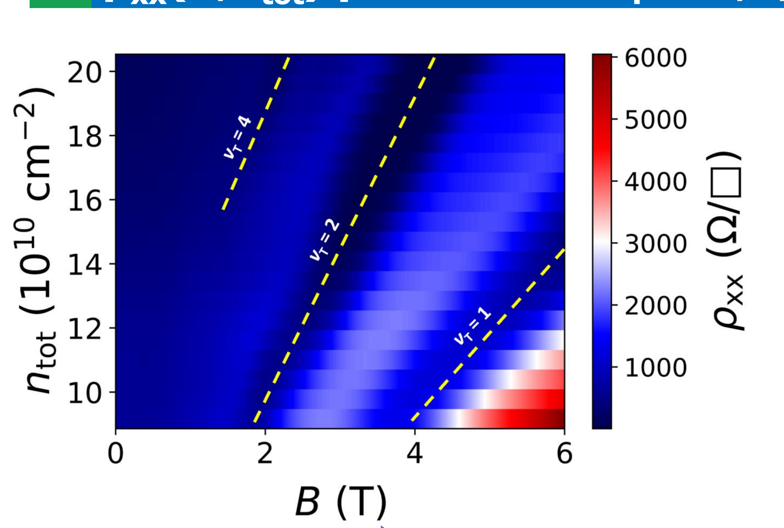
Bilayer behavior is observed due to increased scattering.

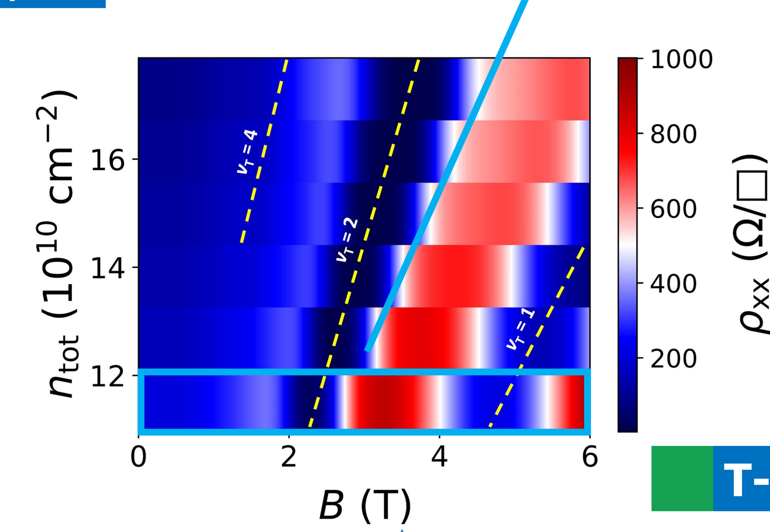




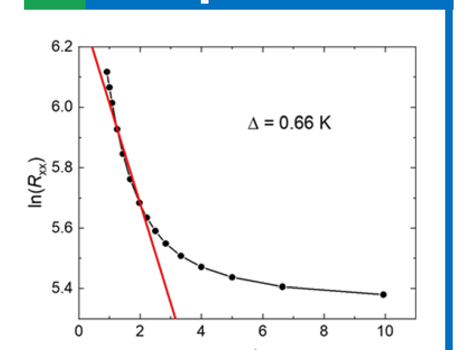
QHE

$\rho_{xx}(B,n_{tot})$ plateaus at ν_T = 1,2,4





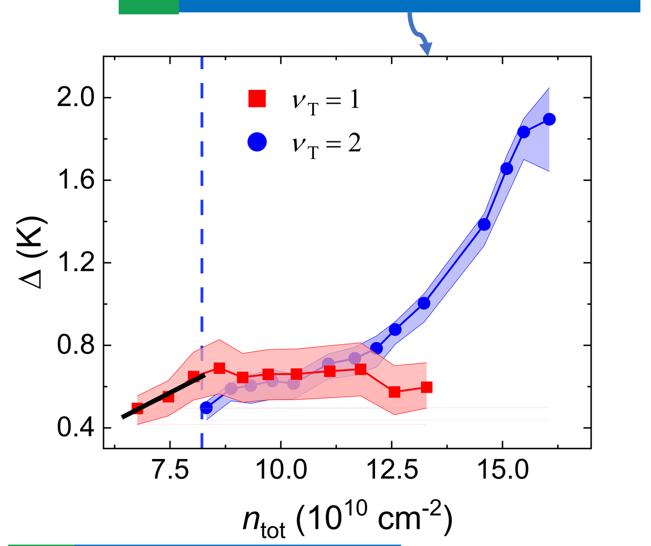
T-dependence



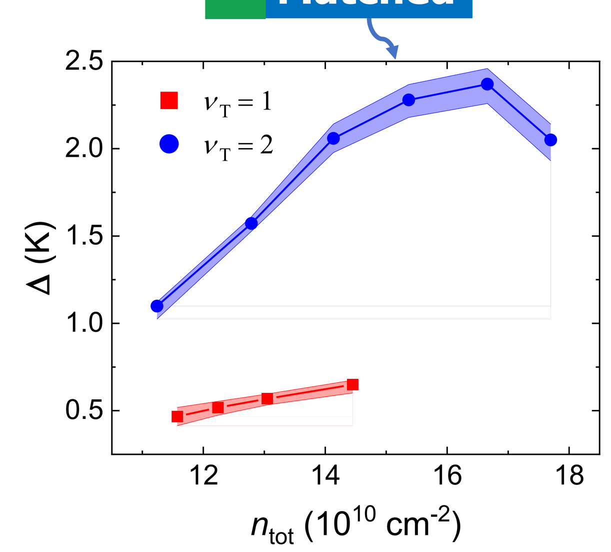
Arrhenius Plot

$\rho_{xx}(T) = \rho_0 e^{-\Delta/2T}$

Variable Imbalanced



Matched



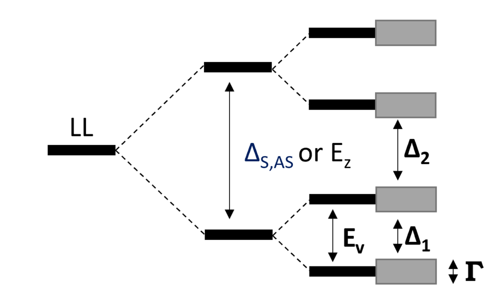
Key Findings $\Delta_{1,2}(n_{tot})$ non-linear evolution for ν_T = 1,2

Single Layers: Disorder broadening, Γ ≈ 0.327 K and linear coefficient, c_B ≈ 0.29 K/T

Analysis[7]

Schrödinger-Poisson (SP) simulations were used to reproduce tunneling behavior through $n_{crossover}$, and the even energy splittings, E_{2n}. When considering the **degeneracies** of our system, we can attribute ν_T to either interlayer effects or valley splitting.

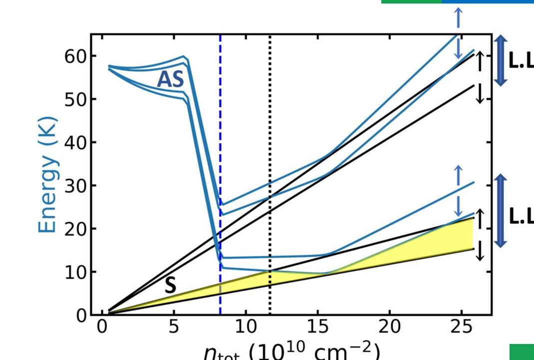
Fan Diagrams

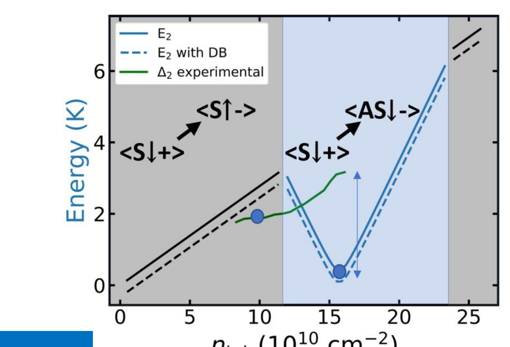


$$\Delta_2 = E_2 - E_1 - \Gamma = E_2 - \Delta_1 - 2\Gamma$$

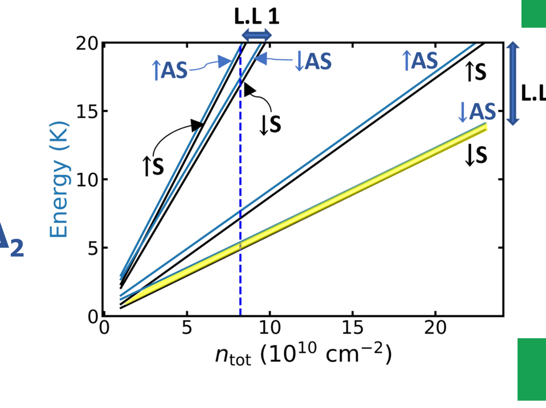
- **Neither Δ_{SAS}, spin splitting, nor LL spacing alone reproduces Δ_2.**
- **Large enhancement of Δ_2 in the variable imbalanced regime due to decreased Δ_{SAS}.**

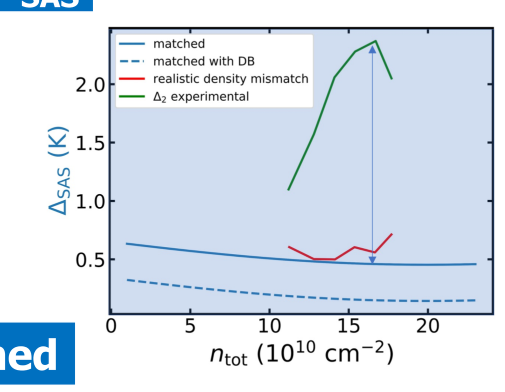
Variable Imbalanced





E_z & Δ_{SAS}





Matched

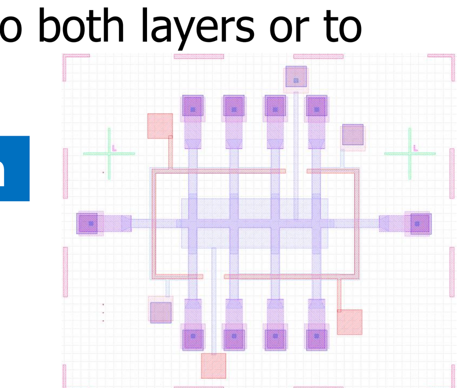
Future Work

Future Si/Ge devices will be fabricated in-house at UF's **Nanoscale Research Facility (NRF)** in hopes of realizing independent contacts to both layers or to Ge wells.

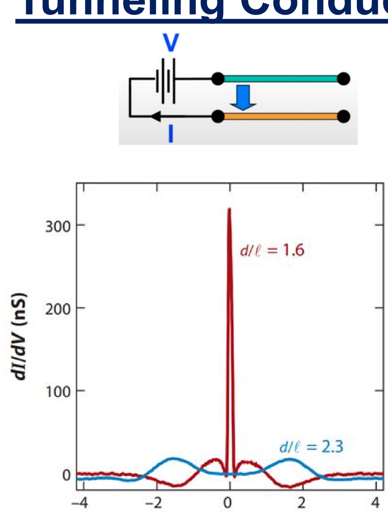
Independent Contacts

A scheme for independently contacting **both layers simultaneously** can unlock a host of new measurements:

Mask Design

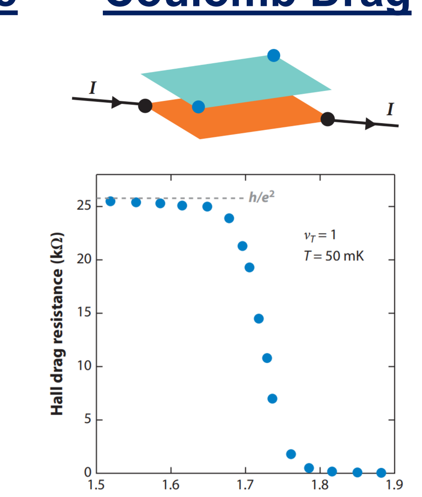


Tunneling Conductance



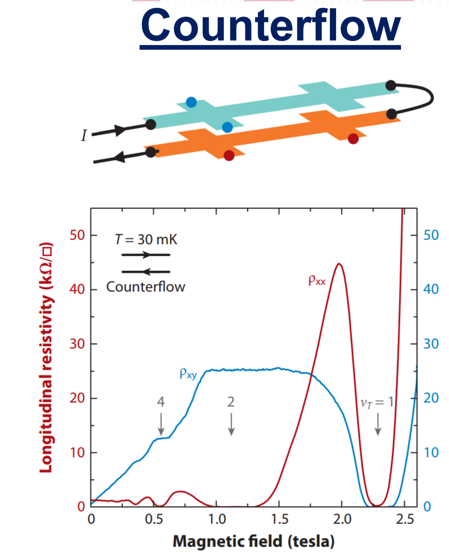
[8]

Coulomb Drag



[9]

Counterflow



[10]

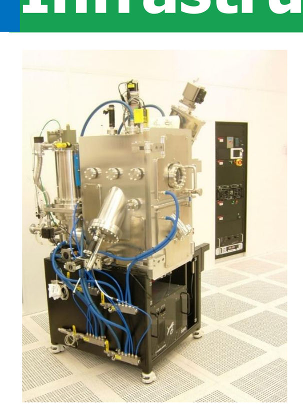
Key Conclusions

- **Signature of exciton condensation: ν_T = 1 and large excitation gaps, Δ.**
- **Large valley splitting at low B or spontaneous valley polarization.**

Outlook

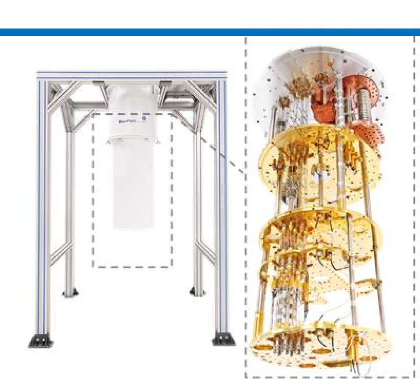
Fabricating a SiGe bilayer with **independent contacts** to both layers will unlock a host of measurements to further study the signatures of SIC: **tunneling conductance**, **Coulomb drag**, and **counterflow** measurements.

Infrastructure and Crew



Nanofabrication is done at UF's NRF.

Left: E-beam evaporator, PVD
Right: Karl Suss MA6



New cryo-free Blue Fors system capable of reaching T ~ 10 mK & B_z = 6 T

Current crew: (top right to back left)

Rebika Makaju, Chris Cravey, Davis Rash, Harith Kassar, Dominique Laroche, Mert Daloglu, Suyang Cai, and Davis Chen

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Acknowledgement

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