Effect of Quantum Hall Edge Strips on Valley Splitting in Silicon Quantum Wells

Brian Paquelet Wuetz, Merrit P. Losert, Alberto Tosato, Mario Lodari, Peter L. Bavdaz, Lucas Stehouwer, Payam Amin, James S. Clarke, Susan N. Coppersmith, Amir Sammak, Menno Veldhorst, Mark Friesen and Giordano Scappucci

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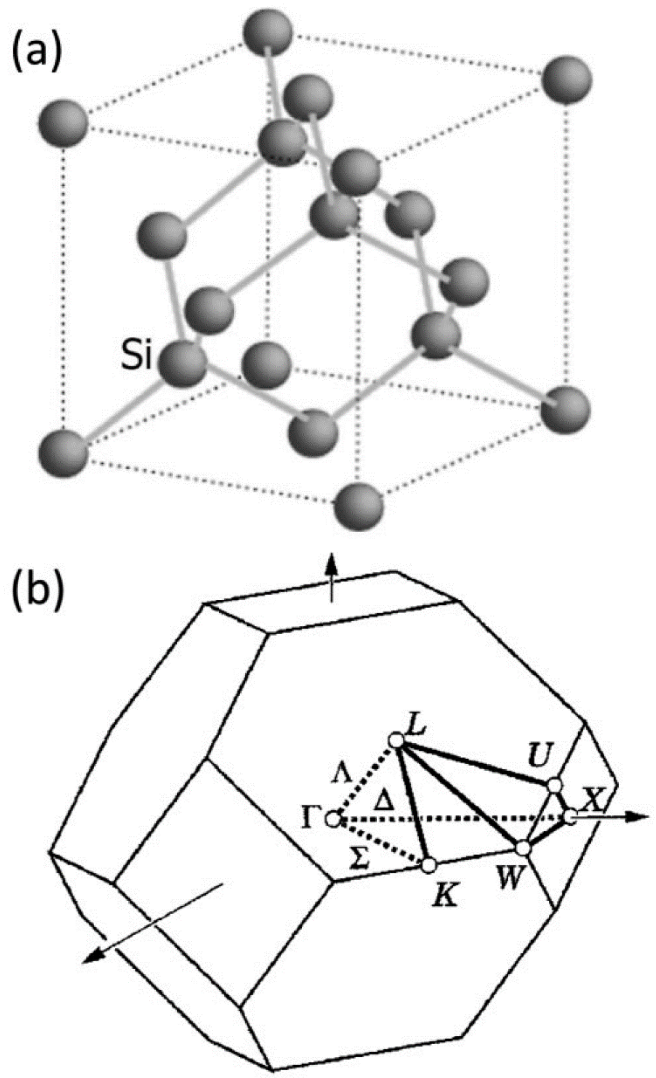
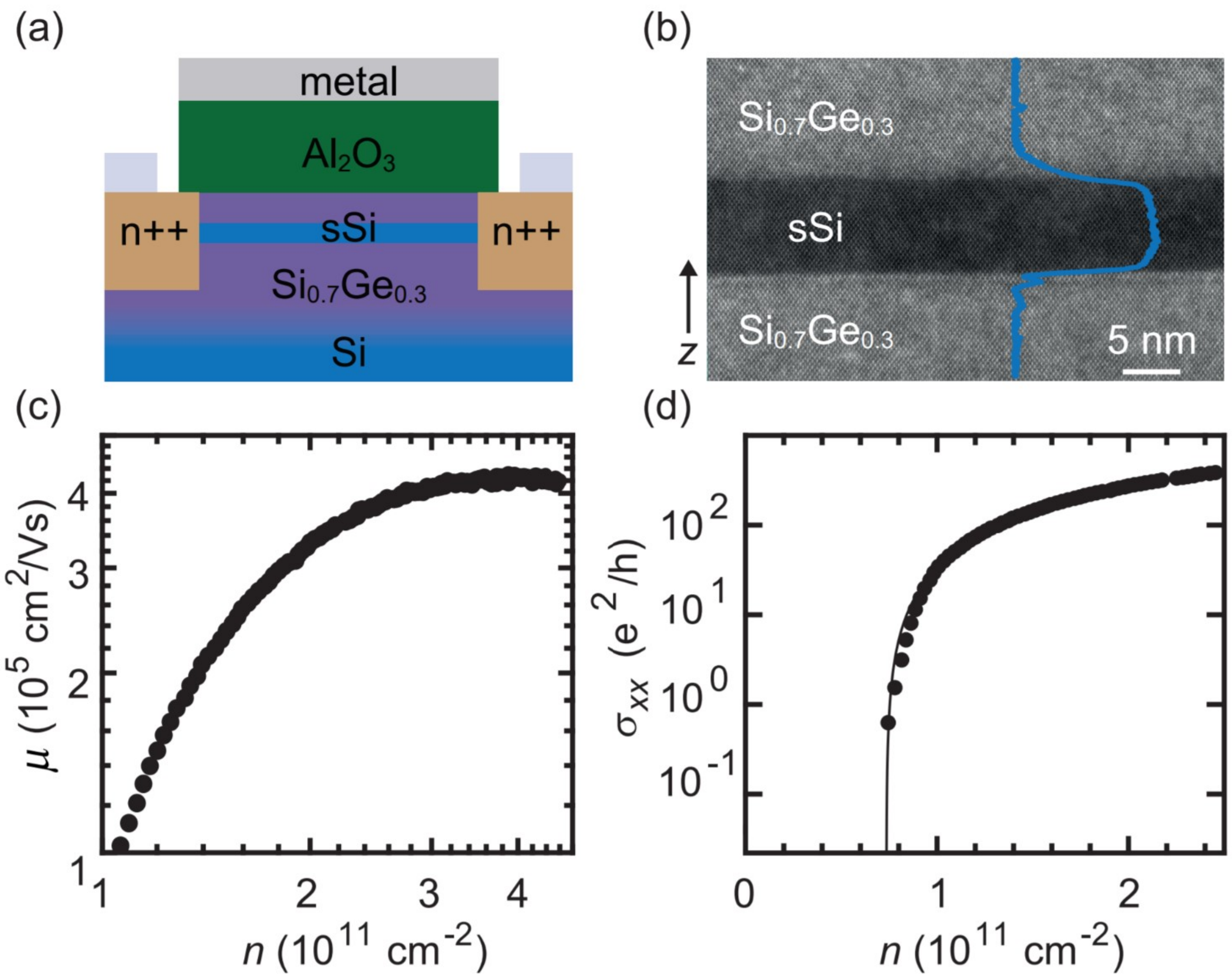
Motivation

- Si/SiGe as a leading contender for hosting qubits
  - Usually spin qubits
  - Valley states are a possibility, but valley splitting is usually small
- In this paper:
  - Investigation of dependence of valley splitting
    - Results in new model
  - Information about disorder at interface
- Short reminder about valleys in Silicon quantum wells [1]
  - Bulk silicon has 6-fold degeneracy
  - Lifted by strain, confinement and electric fields



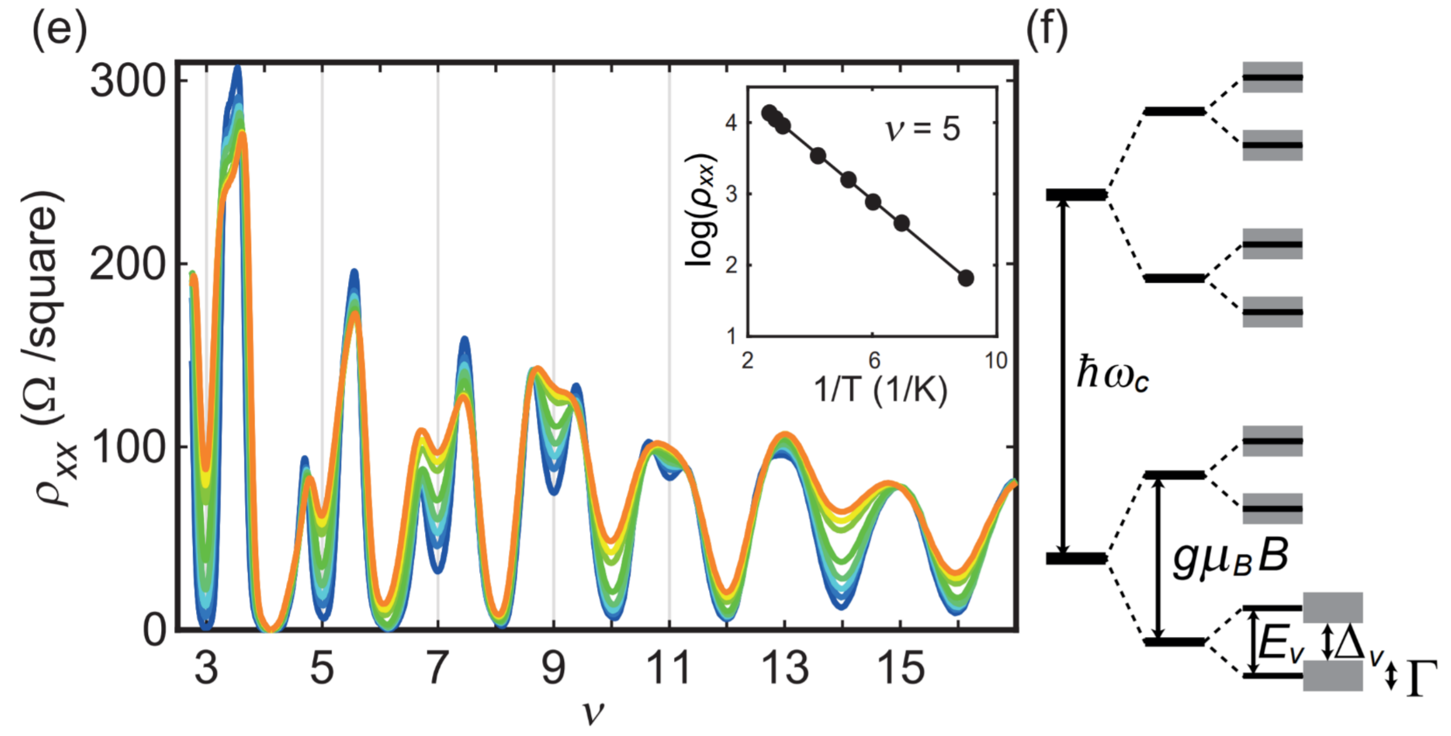
Device

- Si/SiGe heterostructure field effect transistor (H-FET)
    - 8 nm strained quantum well
- Measurements in dilution refrigerator (50 to 500 mK) with lock-in technique
- Electrons at top interface, density controlled by top gate
- Mobility $\mu = 4.2\text{e}5$ cm²/Vs @ $n = 4\text{e}11$ cm^{-2}
- Percolation density $=$ 7.3e10 cm-2
    - ➢ Activation energy measurable over many filling factors possible ($\nu = hn/eB$)



Hall Measurements

- Measurement of ρ_{xx} -> Shubnikov-de Haas (SdH) oscillations
- Extract mobility gap Δ_ν at odd filling factors
- Arrhenius plot: $\rho_{xx} \propto \exp\left(-\frac{\Delta_\nu}{2k_BT}\right)$



Valley Splitting

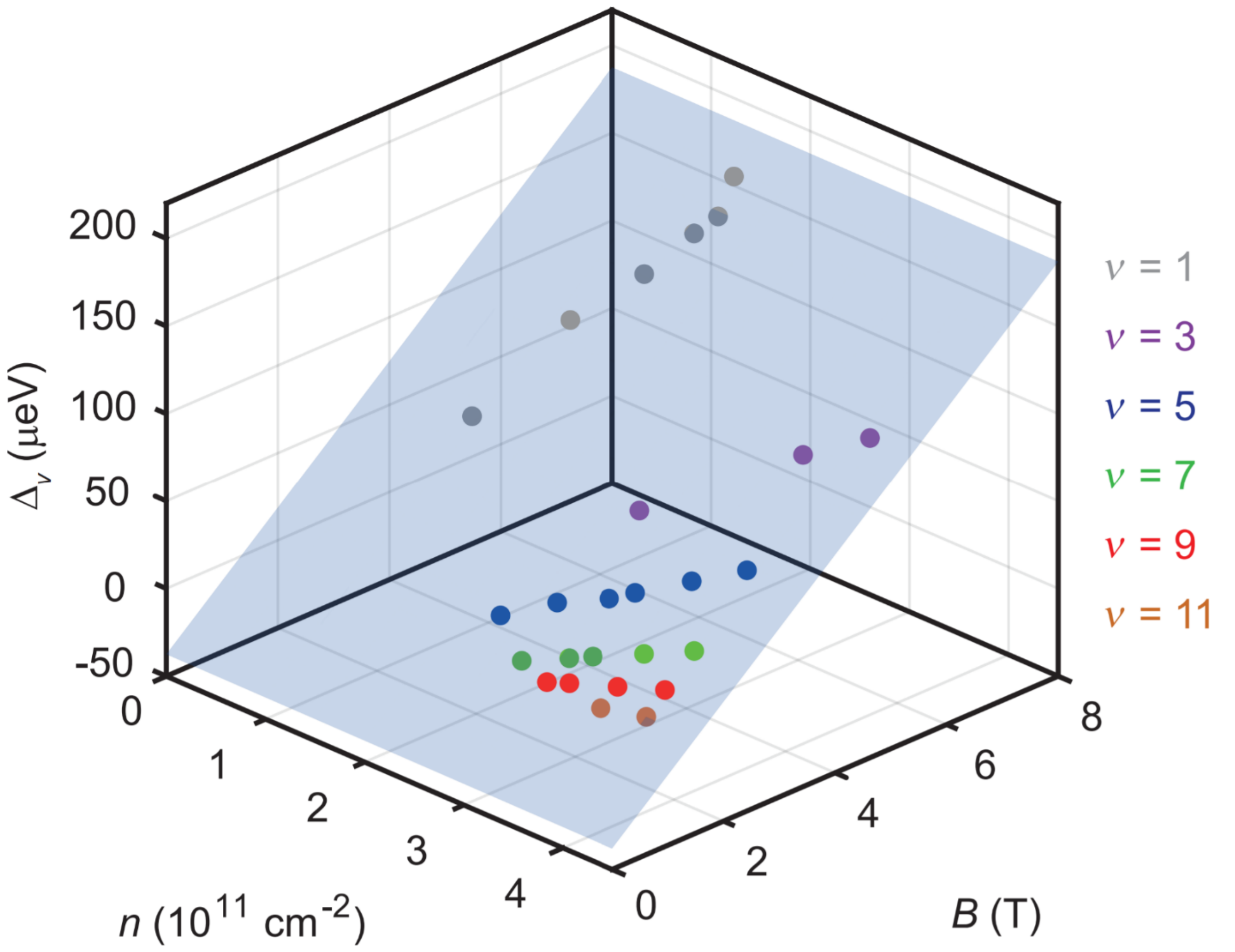
- Data fitted to plane $\Delta_v = c_B B + c_n n - \Gamma$
  - $c_B = 28.1 \pm 1.2\ \mu$eV/T
  - $c_n = 0.1 \pm 2.5\ \mu$eV/10^{11}cm^{-2}
  - $\Gamma = 37.5 \pm 10.2\ \mu$eV

- g-factor ≈ 1.8

➢ Δ_v is linar in B, independent of n

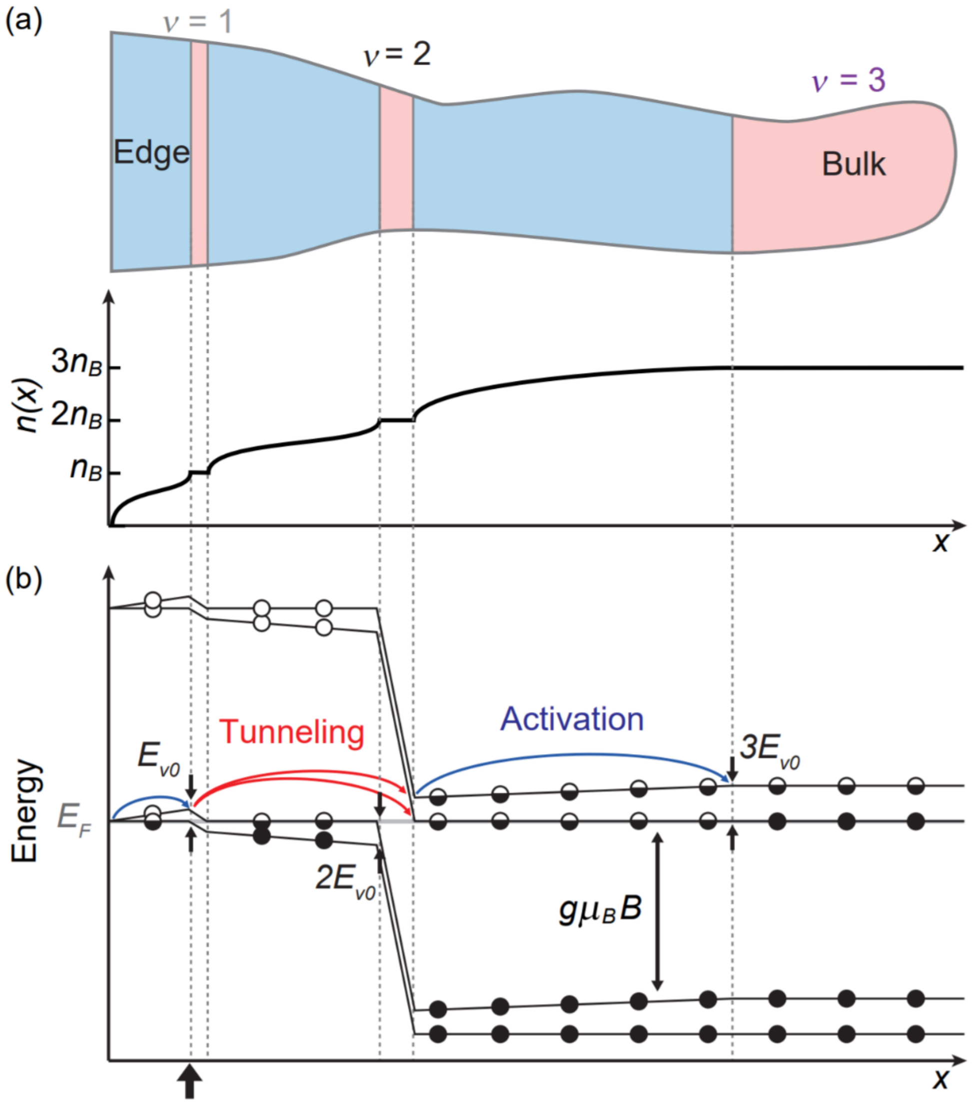
- Conventional theory: $E_v \propto E_z = \mathrm{en}/\epsilon$ [2]

- New proposal: activation energy is determined near edges of the 2DEG, not in the bulk



Theoretical Model

- Quantum Hall regime: alternating strips of compressible (C) and incompressible (I) strips
- I: $n_B = \frac{eB}{h}$ quantized density of filled Landau level (until $n = \nu_{Bulk} n_B$)
- C: desity varies monotonically, charge distribution screens electric fields parallel to 2DEG (edge = 0, centre = bulk value)
- Non-zero longitudinal resistance only when electrons transit across the width of the Hall bar (perpendicular to Source/Drain)
  - ➢ Excitation above Fermi level E_F needed
- Activation energy in this model: E_{v0} (change in valley splitting associated with density change $\Delta n = n_B$)
- Leads to conduction due to long valley-state lifetimes

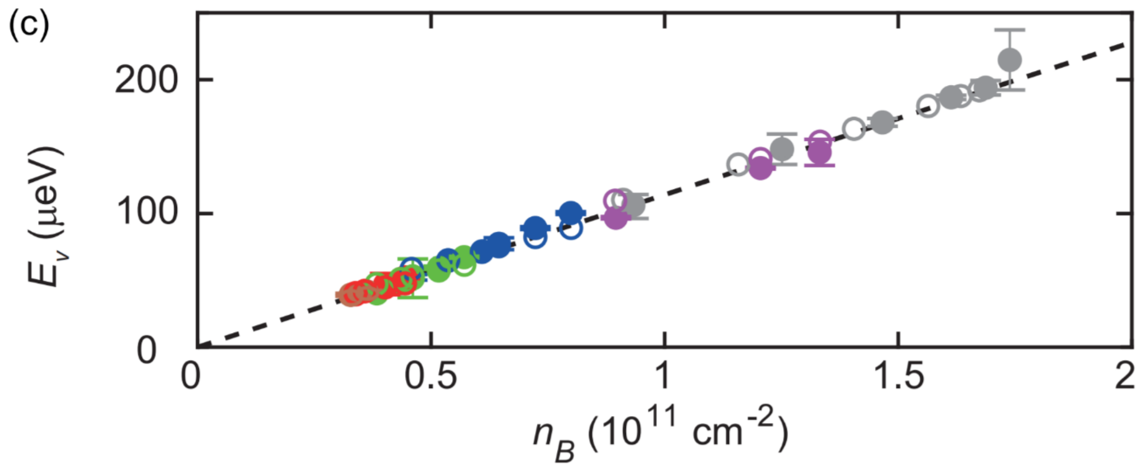


Comparison to Theory

- Solid circles: Data
- Hollow circles: Thomas-Fermi simulation
- Dashed line: expected value of valley splitting for near ideal Si quantum well top-interface [2]

- Agreement with simulation: model represents data
  - Valley splitting is not density dependent

- Agreement with theory: atomic scale disorder does not suppress valley splitting
  - Clean interface



[2] Friesen et al., Phys. Rev. B 75, 115318 (2007)

Summary

- Measurement of valley splitting over multiple filling factors in Si/GeSi quantum wells
- Valley splitting depends linearly on B, independent of n
- New model: E_{v0} is determined at the edge, not in the bulk