

Quantum transport in 2D electron systems in strained Si

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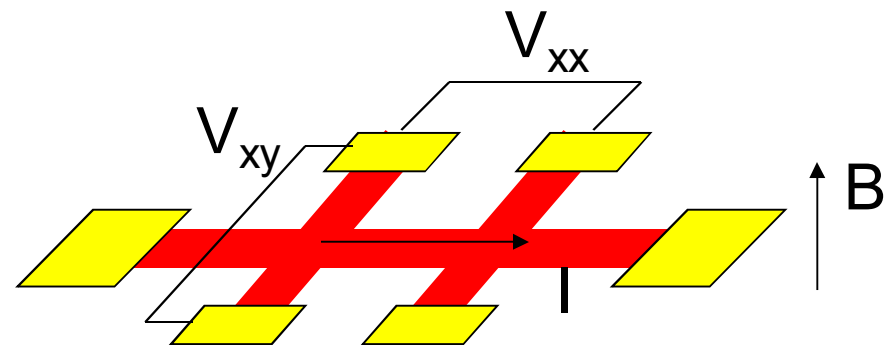


Outline

- Introduction
 - Quantum transport in high mobility 2DES
 - 2DES in strained Si
- QHE in (001) Si 2DES
 - IQHE and FQHE states in (001) Si
 - CF model in a two-valley system
- Gating on Si 2DES
 - Observation of 2D MIT
 - Gate-induced 2DES in undoped Si/SiGe
- Summary

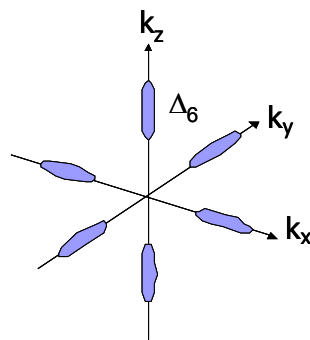
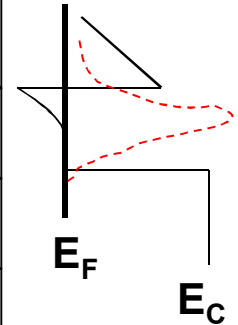
Transport in high mobility 2DES

- Quantum confined 2DES in semiconductor heterostructures
- Extremely clean system
 - $\mu > 3 \times 10^7 \text{ cm}^2/\text{Vs}$ and $l \sim 0.3 \text{ mm}$ in GaAs 2DES
- High magnetic field (Tesla) and low temperatures (milli-Kelvin)
- Strong e-e interaction physics
 - Fractional quantum Hall effect
 - 2D metal-insulator transition
 - Quantum Hall ferromagnetism
 - Stripes / bubbles / Wigner solids
-

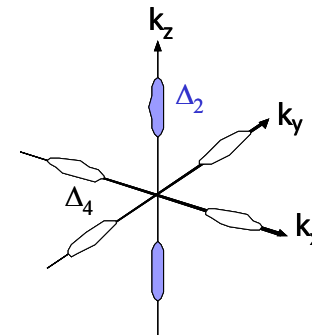
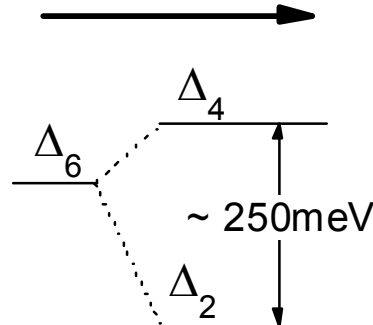


2DES in strained Si

- Clean 2DES in Si
 - High mobility ($>200,000$ cm^2/Vs) at relatively low density (10^{11}cm^{-2})
- Band structure parameter
 - Large/isotropic in-plane mass
 - Conduction band valleys



Bulk Si



Strained Si 2DES

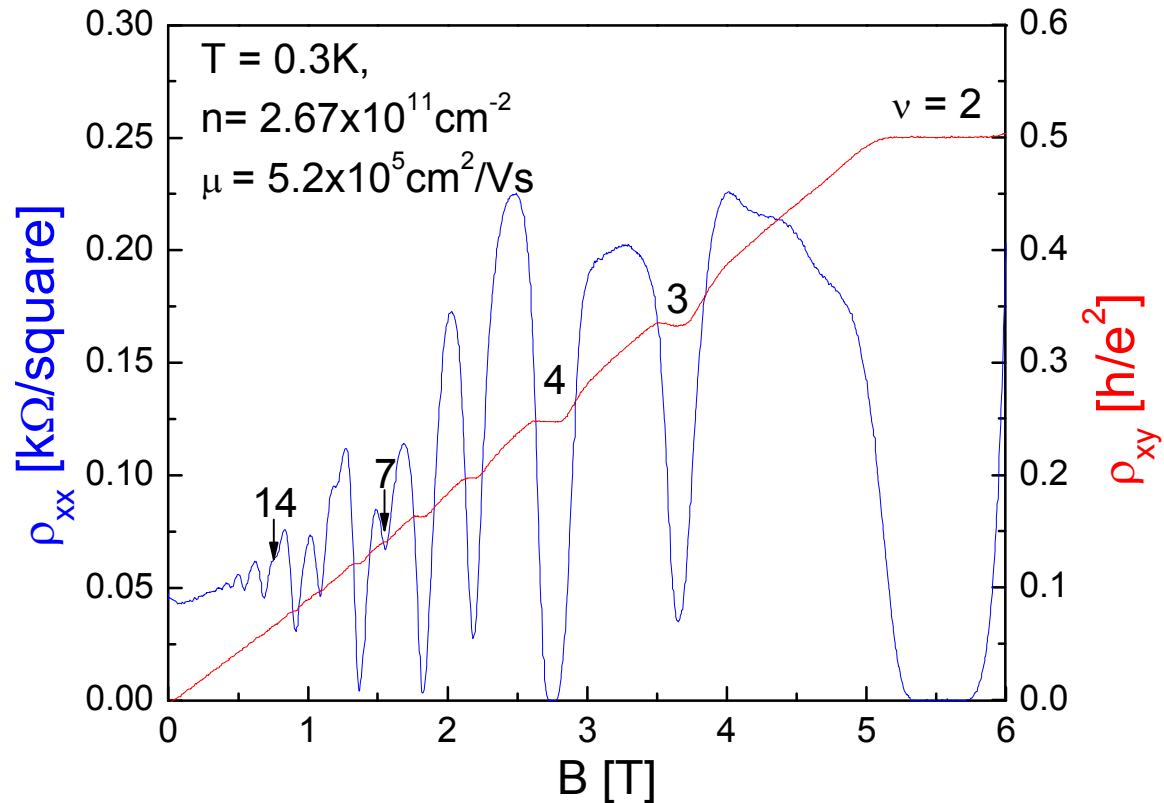
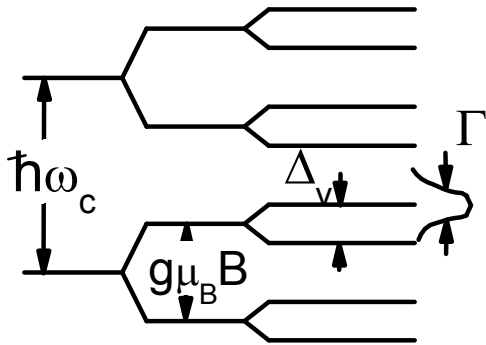
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IQHE in Si/SiGe

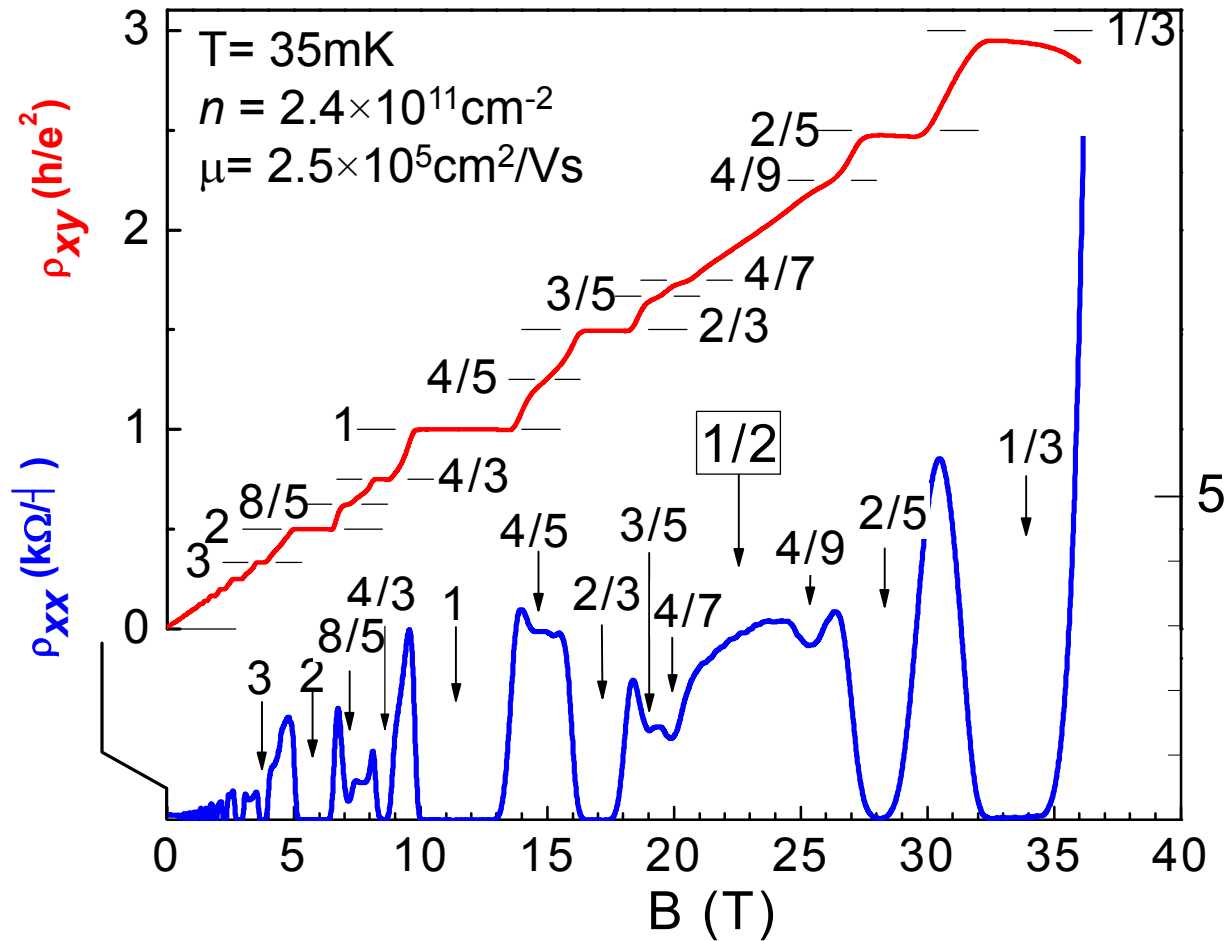
Energy scales in B-field

- Cyclotron: $\hbar\omega_c = \hbar eB/m^*$
- Spin: $E_Z = g^*\mu_B B$
- Disorder: $\Gamma \sim \hbar / \tau$
- Valley: Δ_v



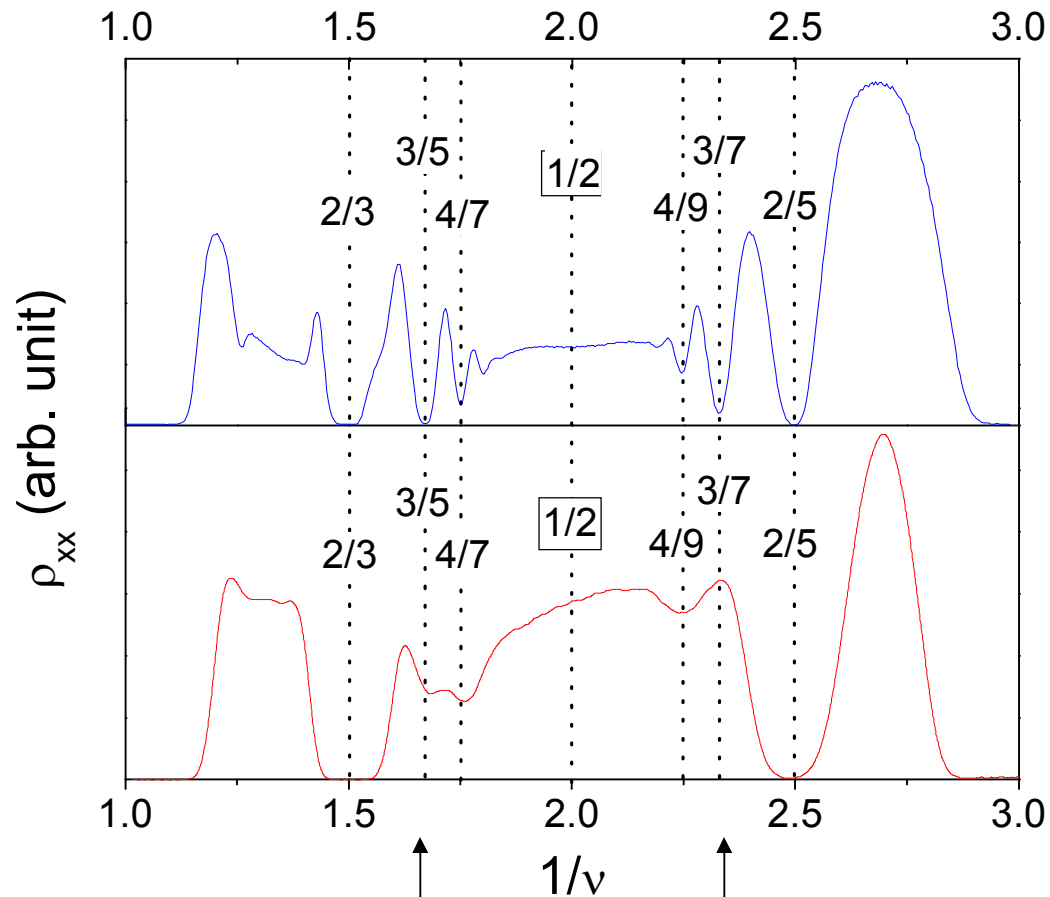
Sample from Y. Shiraki

FQHE in Si/SiGe



Sample from F. Schaffler

FQHE: Si vs GaAs



*Single-valley
GaAs/AlGaAs*

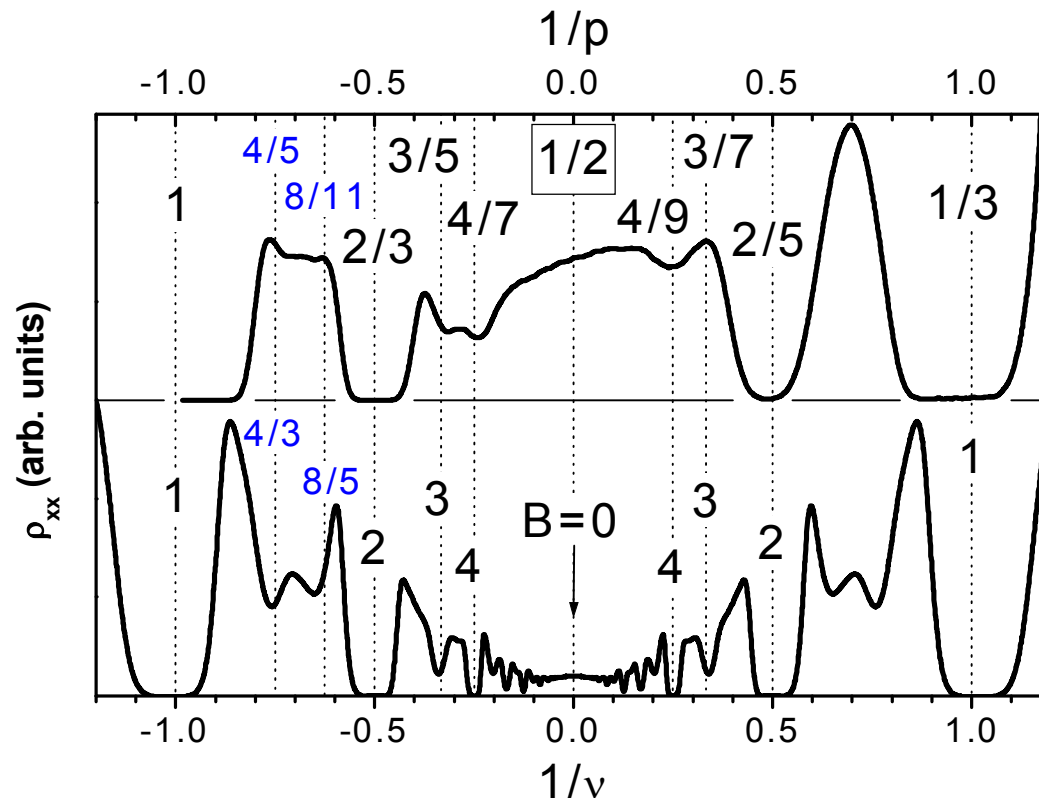
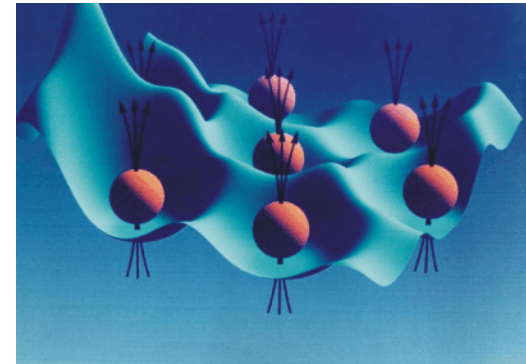
*Double-valley
Si/SiGe*

Weak $3/5$

Absence of $3/7$

Composite Fermion model

- Two flux quanta attached to each electron
- Reduced B field $B_{\text{eff}} = B - 2nh/e$
- IQHE of CFs at $p \Leftrightarrow$ FQHE of e's at $\nu = p/(2p \pm 1)$
- CF assumes its own valley degeneracy



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Gating at high-B / low-T

- Density control
 - Back gate
 - Front gate: Schottky barrier
 - Front gate: band insulator as gate dielectric (oxide, nitride...)
- Reliable gating for quantum transport
 - Leakage current
 - Gate hysteresis / interface states
 - Homogeneity of 2DES under gating
 -

Gating on doped Si/SiGe

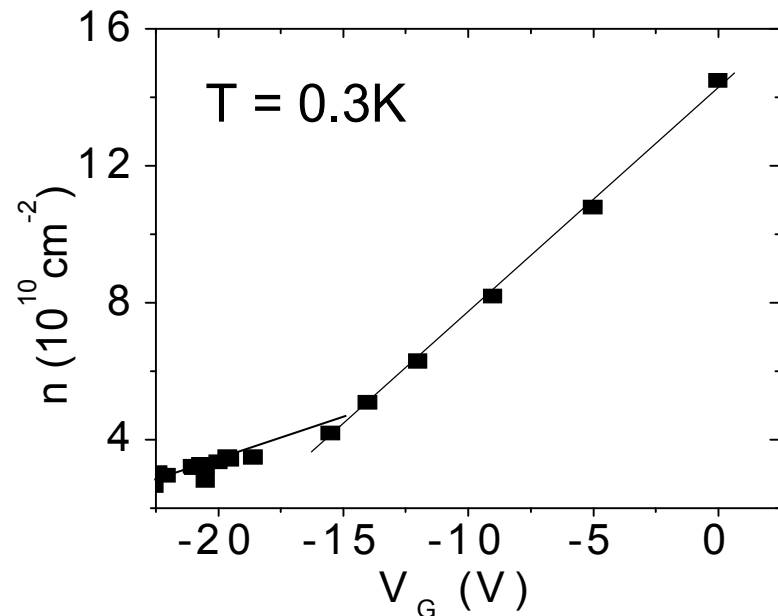
Al Gate
300nm PECVD SiO ₂
Si/SiGe cap
n+ doping
SiGe spacer
<i>Strained Si QW</i>
SiGe buffer / Si substrate

Sample from F. Schaffler

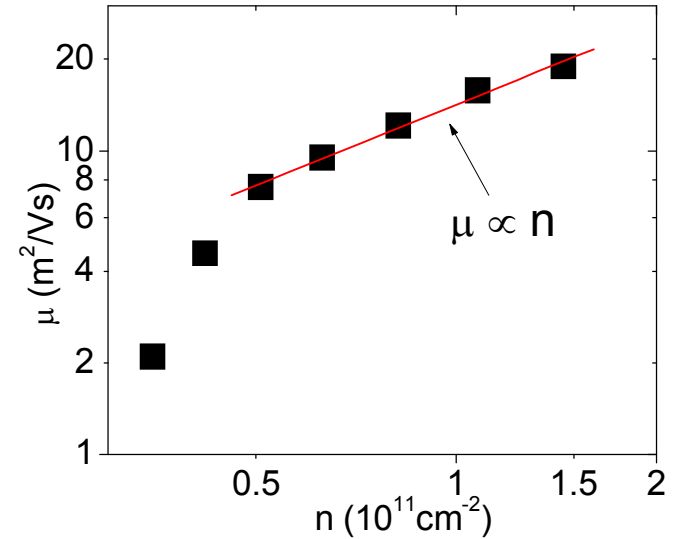
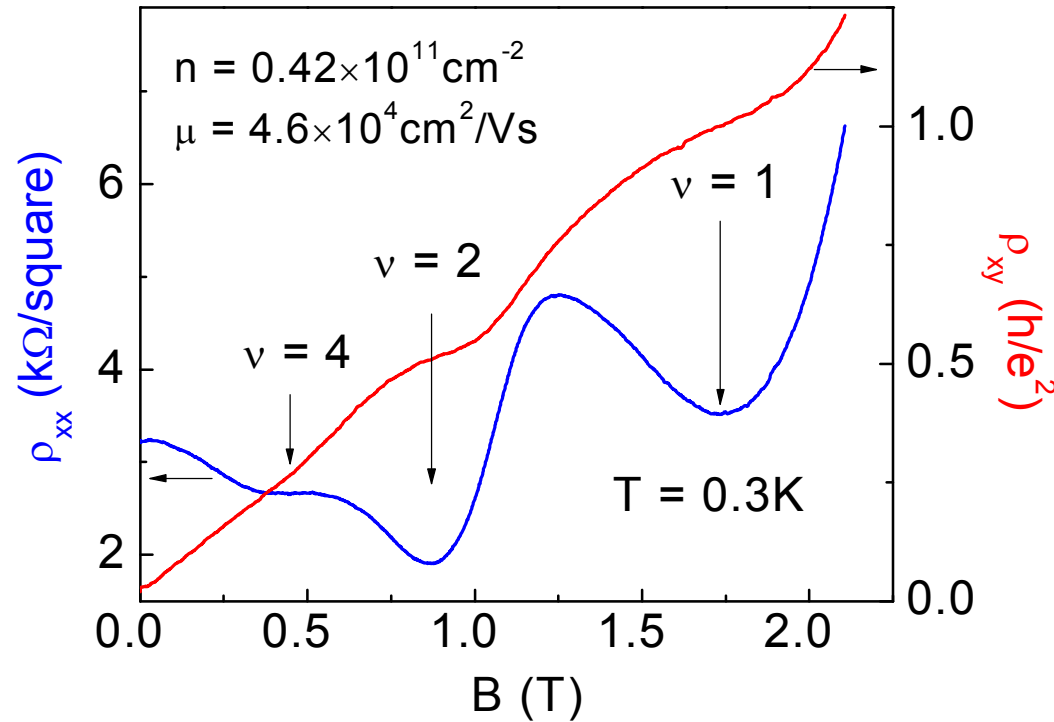
Starting material (at $V = 0$)

$$n = 1.45 \times 10^{11} \text{ cm}^{-2}$$

$$\mu = 1.9 \times 10^5 \text{ cm}^2/\text{Vs}$$

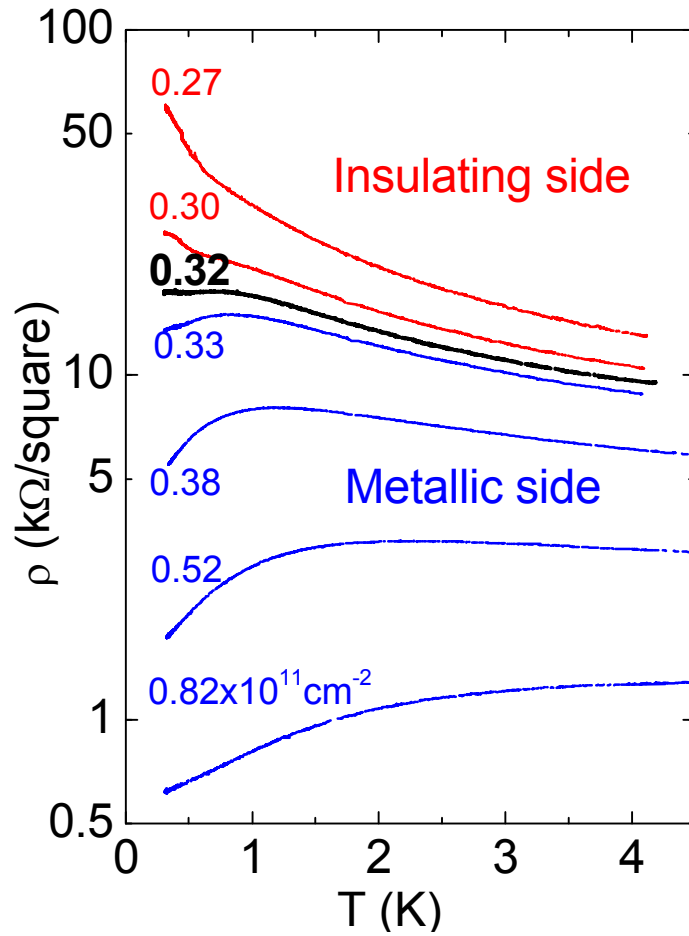


Gating on doped Si/SiGe



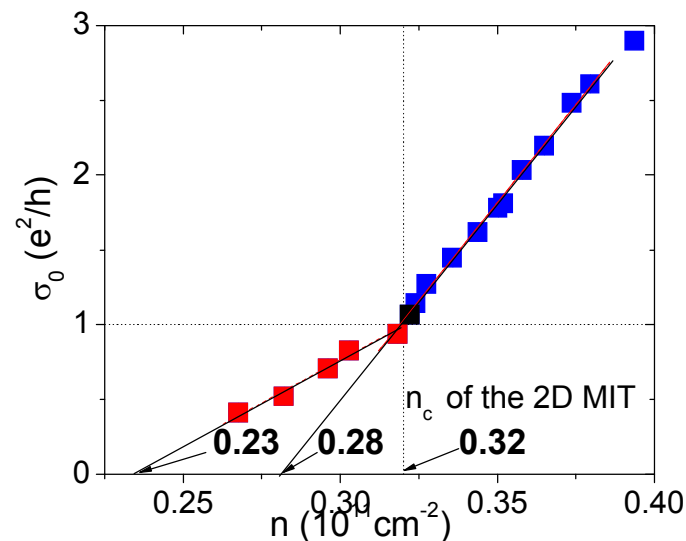
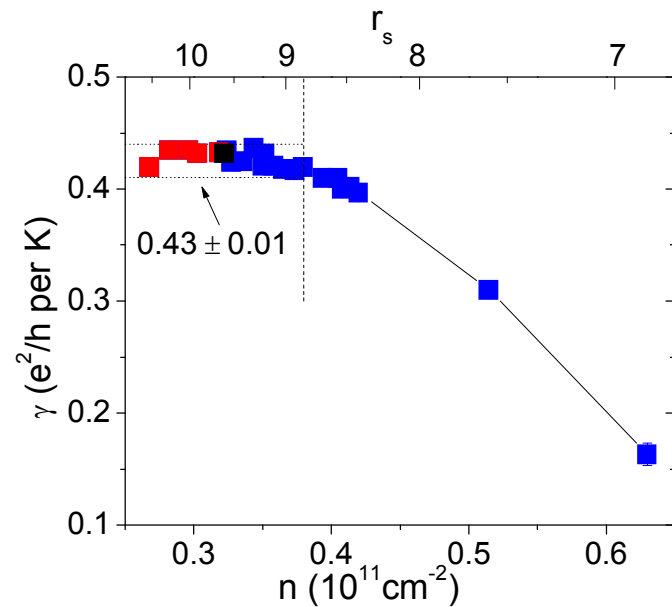
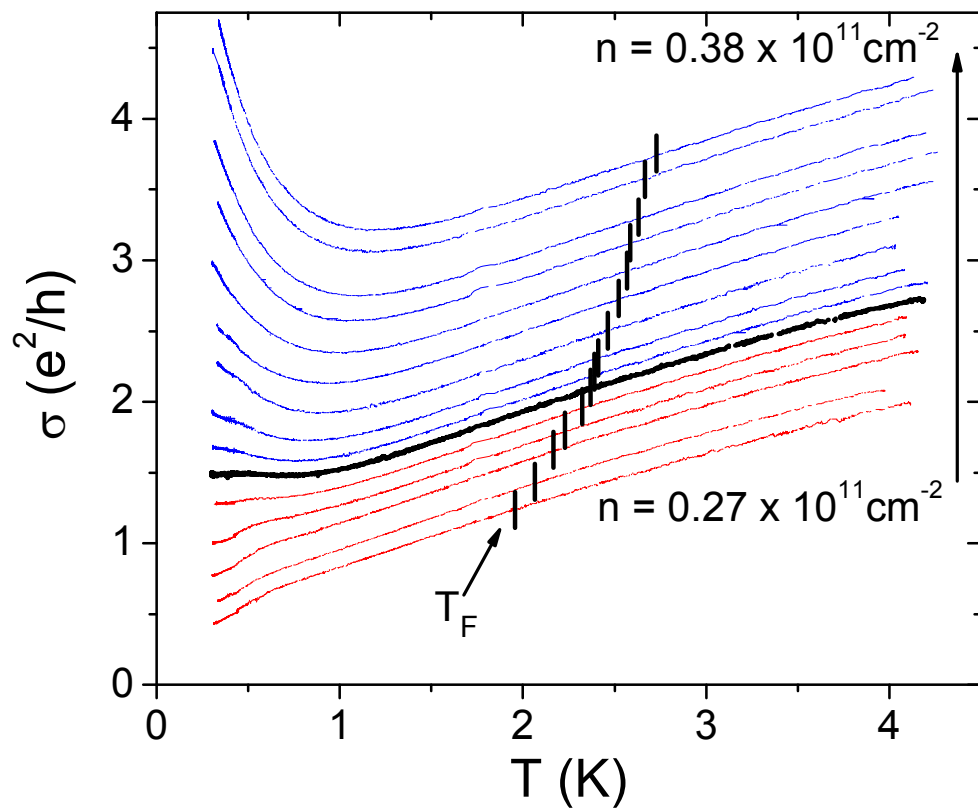
- No gate leakage
- No hysteresis at 4K
- Homogeneous 2DES at low n

2D metal-insulator transition

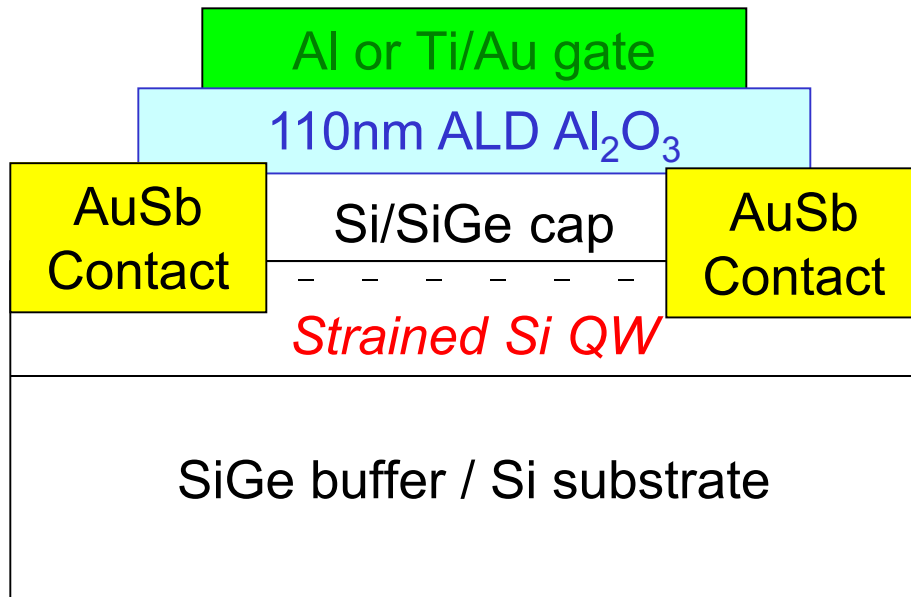


- Observation of 2D MIT
 - Lowest $n_c \sim 0.32 \times 10^{11} \text{ cm}^{-2}$ in Si system ($0.8 \times 10^{11} \text{ cm}^{-2}$ in clean Si-MOSFETs)
- Strong interaction physics
 - $r_s = l_{e-e} / a_B \sim 10$
 - $E_c / E_F \sim 20$

Near the transition



Gating on undoped Si/SiGe

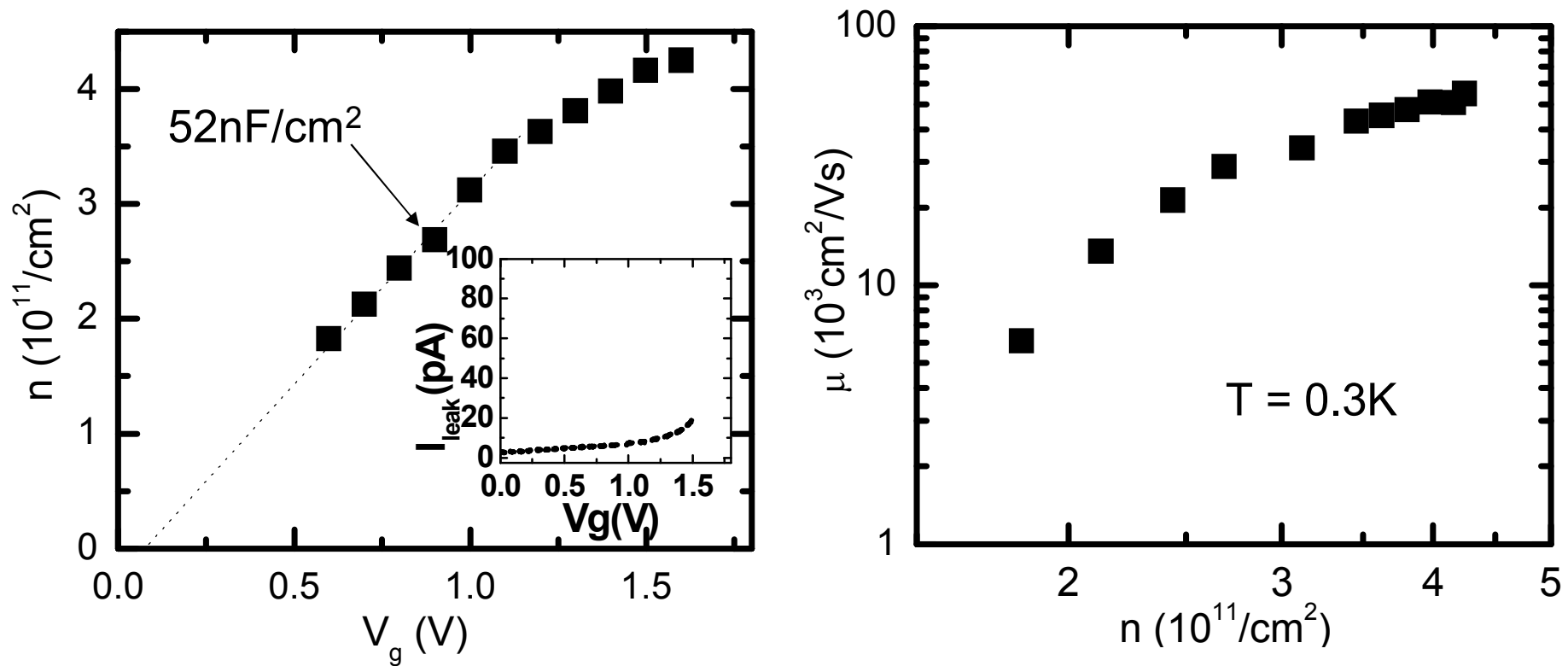


- No intentional doping
- Vertical overlap between gate and AuSb Ohmic contacts
- Atomic layer deposited Al₂O₃ as gate dielectric
- QW ~ 10nm; Si/SiGe cap ~ 50nm

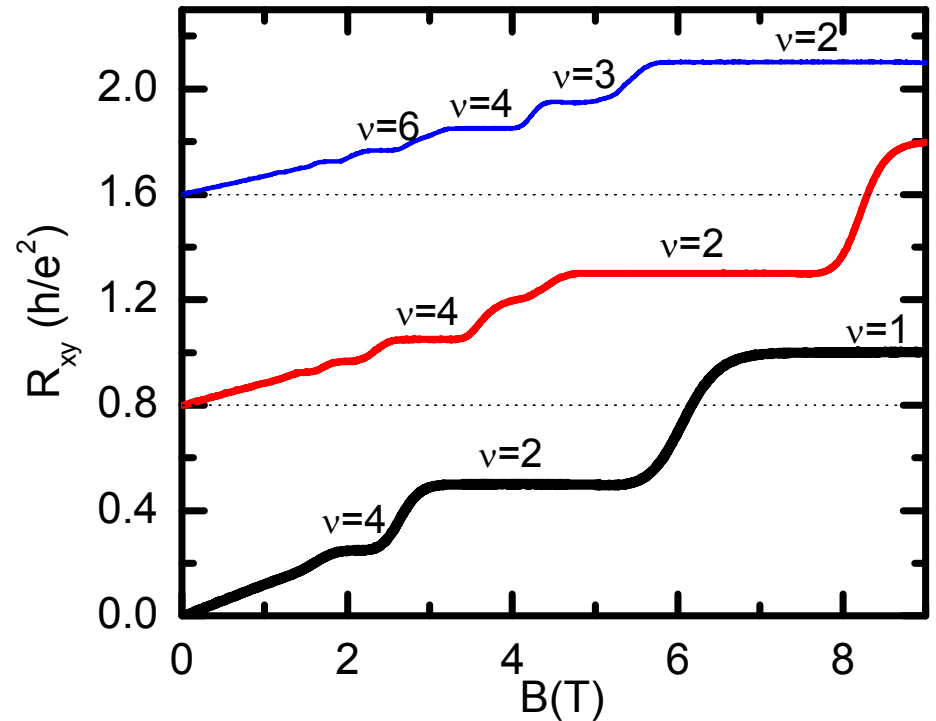
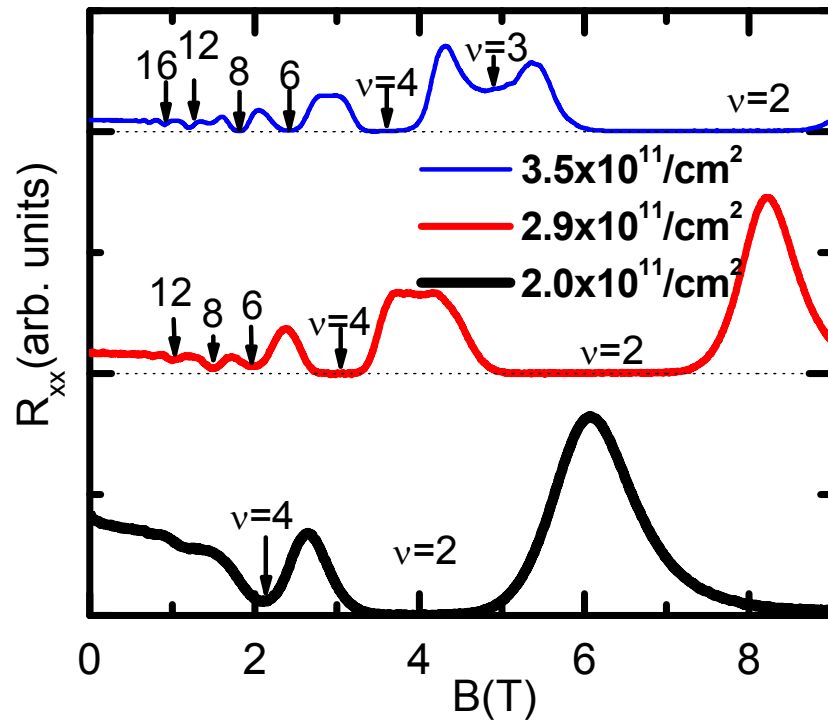
Sample from Y.H. Xie

Gate-induced 2DES

- Capacitively induced 2DES (55nF/cm for ideal capacitor)
- Mobility limited by background impurities



Gate-induced 2DES



- High quality 2DES without remote ionized impurity scattering
- Potential for future 2D physics

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- High mobility 2DES in strained Si
- Quantum Hall physics in Si 2DES
 - Energy scales in B-fields
 - IQHE and FQHE states
 - Composite Fermions with valley degeneracy
- Gated Si/SiGe for transport study
 - Apparent 2D MIT at low electron density
 - Capacitively induced 2DES in undoped Si/SiGe