SAND2018-1783C

Demonstration of a Hole Quantum dot in Ge/SiGe

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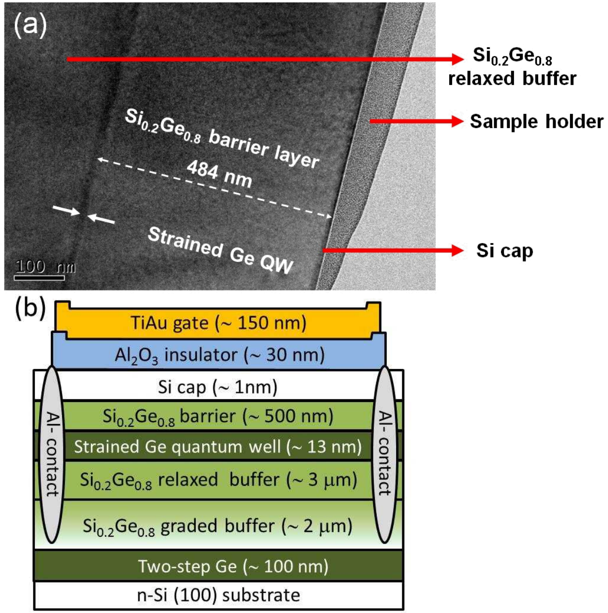
This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. DOE, Office of Basic Energy Sciences, user facility. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525

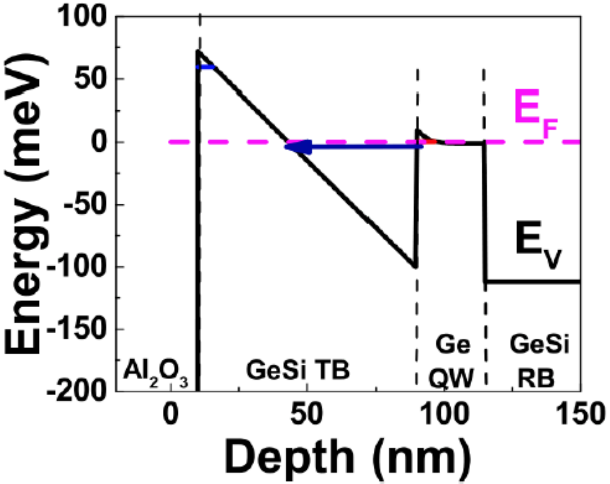
Motivation: Hole Spin Qubits

- Holes provide an alternate approach to spin based qubits
  - Recent demonstrations of hole spin manipulation in various systems
- Strained Ge/SiGe heterostructures are an attractive substrate
  - Low Disorder system
  - Absence of valley states (or near degenerate ground states)
  - All electrical control of spins through spin-orbit coupling
  - Small effective mass (~0.08 m_e)
  - Zero nuclear spin isotopes exist for Si and Ge
  - Weaker hyperfine interactions

Material System



The strained Ge layer splits the Light Hole and Heavy Hole bands by ~10 meV, leaving Heavy Holes as the ground state

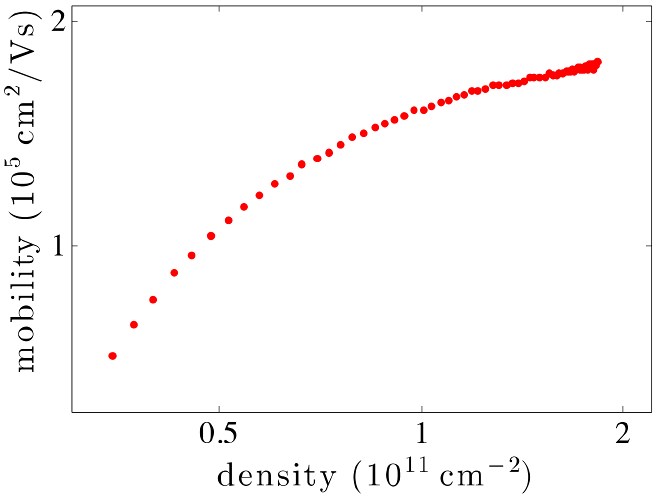


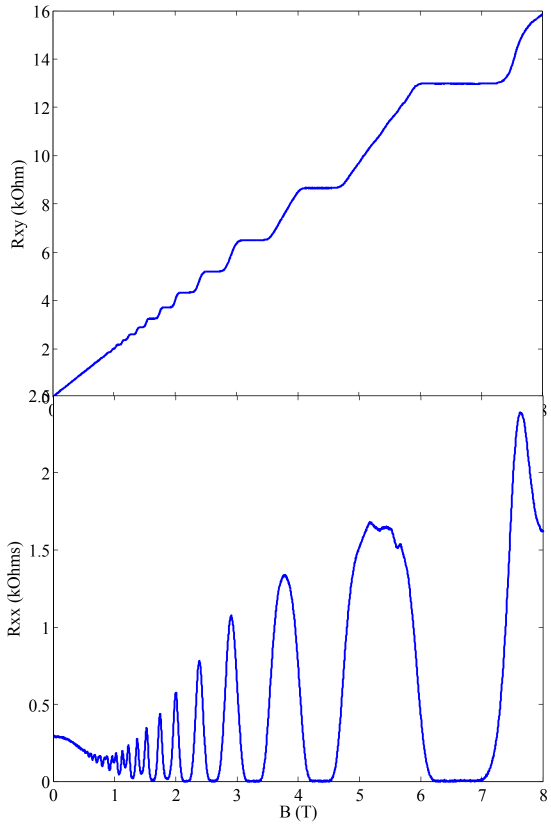
*Laroche, Lu et al., APL 2016 and T.M. Lu et al. APL 2017

Low Disorder Substrate

For 2DHG in 58 nm spacer sample
Density Range: 3 x10^{10} – 1.8 x 10^{11} cm^{-2}
Peak Mobility: ~2 x 10^{5} cm^{2}/Vs

g_{perp}~28
g_{par}~1.3
m*~0.08 m_e
Spin Orbit Length: 643 nm





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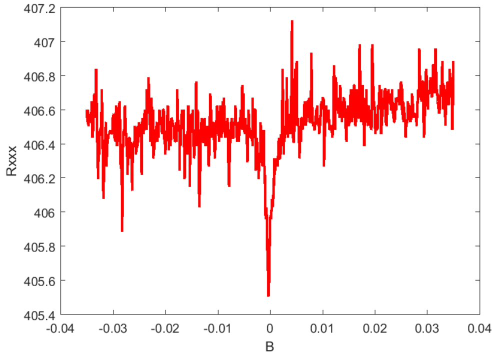
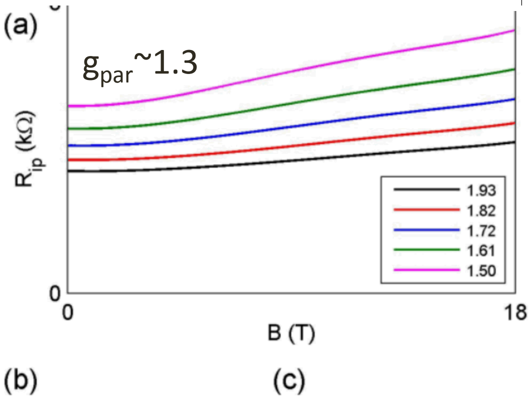
Material Properties

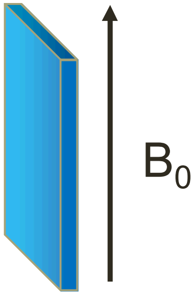
Parameters extracted from 2DHG

WAL: l_{SO}~640 nm



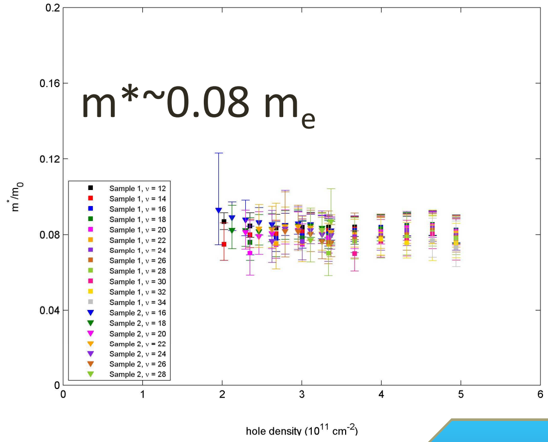
g_{par}~1.3

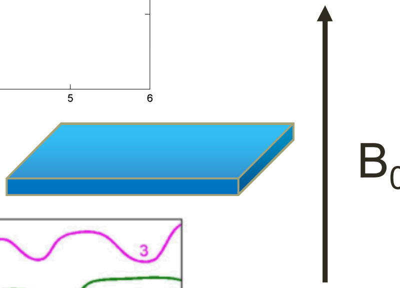


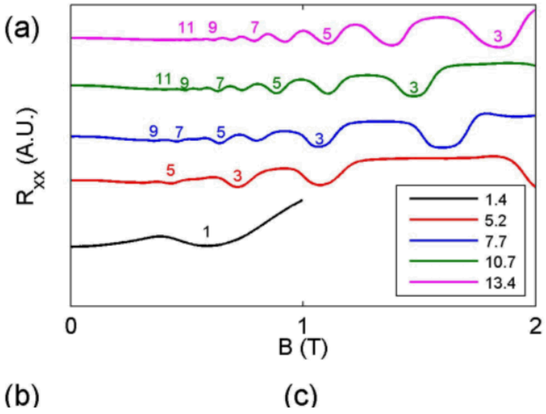


l_{SO} ~ 643 r

m*~0.08 m_e







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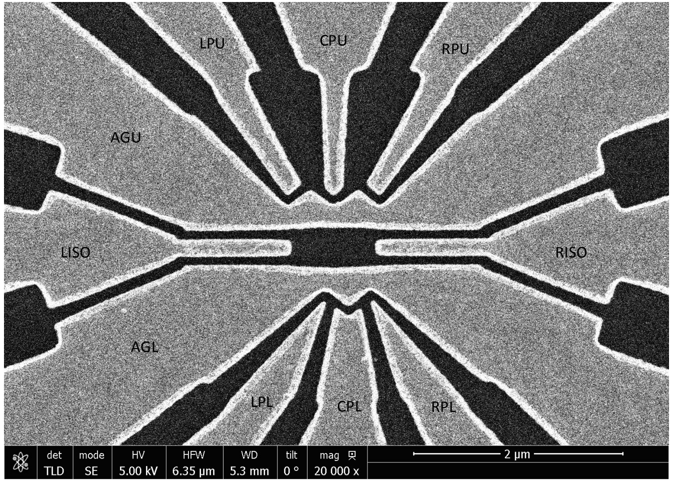
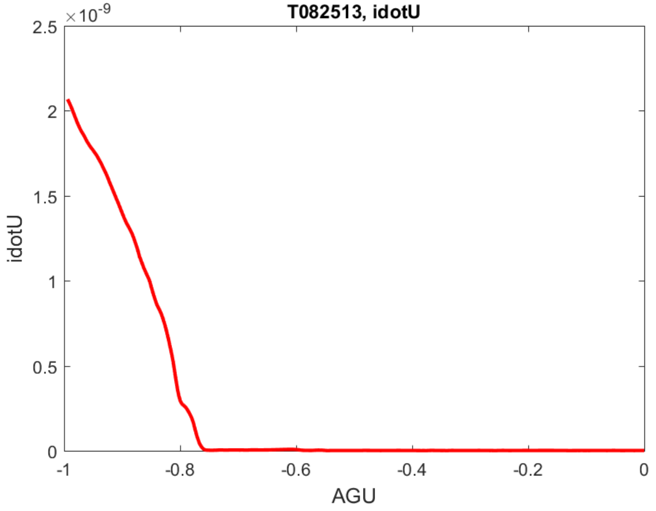
Device Structure

Single Metal Layer (110 nm Al_2O_3 oxide)



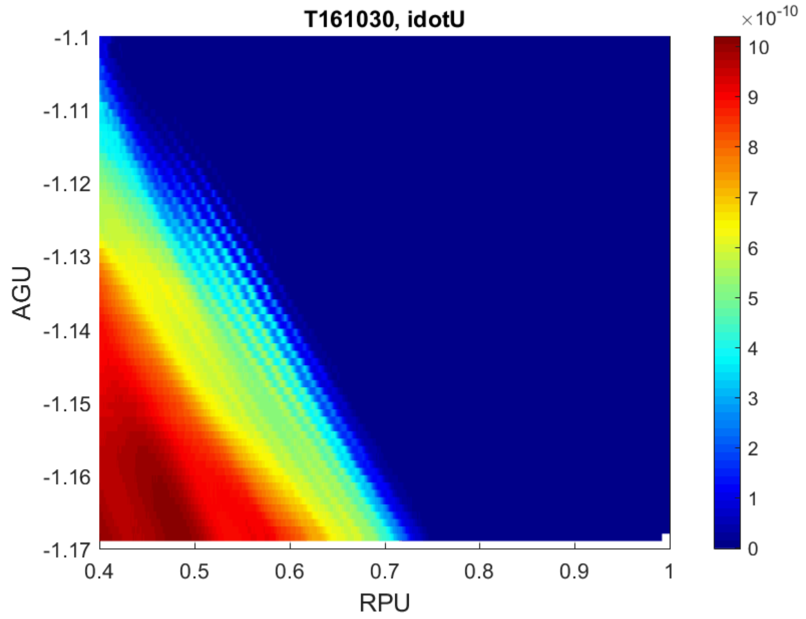
Device Design similar to Si/SiGe in Lu et al. APL (2016)

Typical Threshold curve

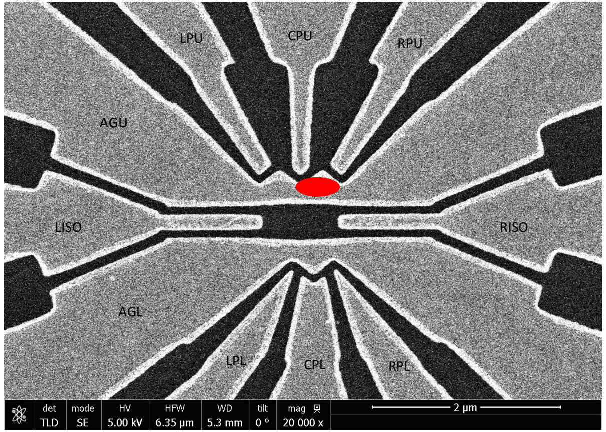


Device Tune up

Single metal layer Ge/SiGe Device



T=30 mK

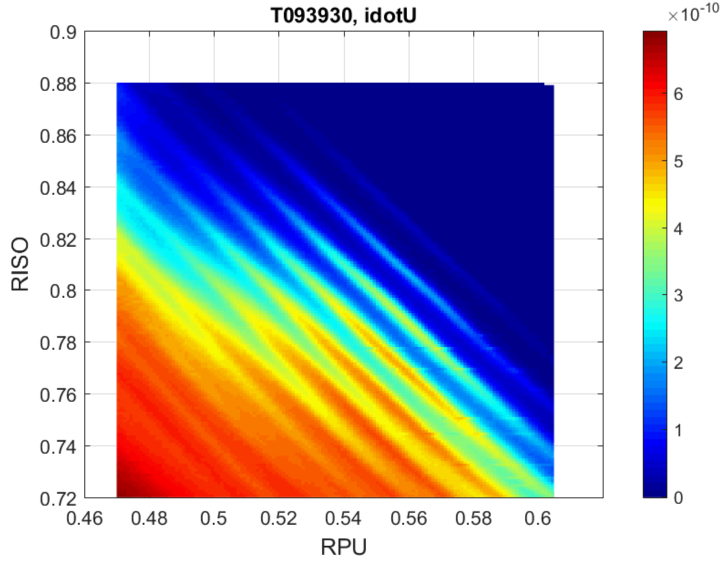


C_{AGU}=53.3 aF
C_{RPU}=10.3 aF
C_{CPU}=5.09 aF
C_{RISO}=8.51 aF

Top gate capacitance similar to that expected from lithographic dimensions (55 aF)

Coulomb Blockade

Single metal layer Ge/SiGe Device

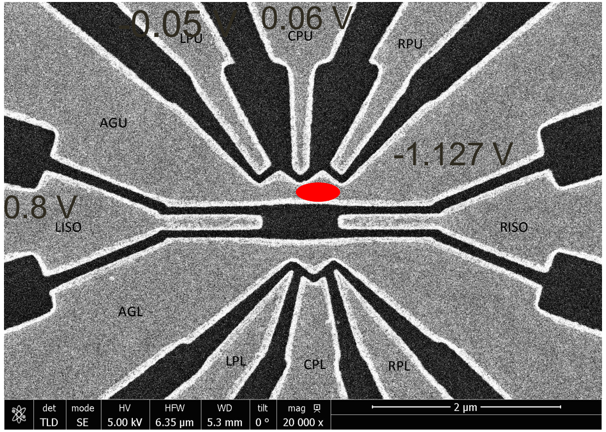


V_{AGU}=-1.127 V

V_{CPU}=0.06 V

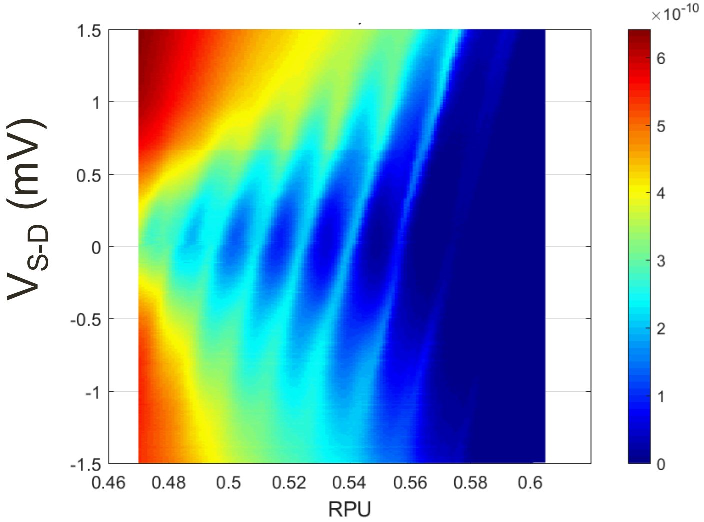
V_{LISO}=0.8 V

V_{LPU}=-0.05



Lower gates grounded

Coulomb Diamonds

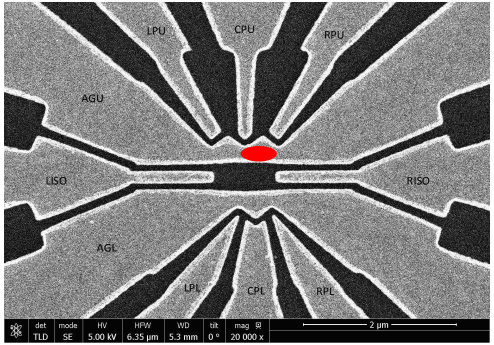


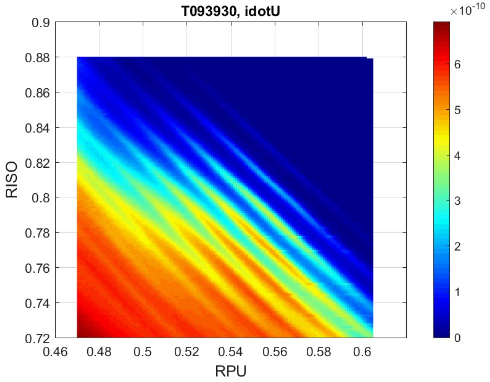
Addition energy expected from capacitances
E_{add} = 1.7 meV

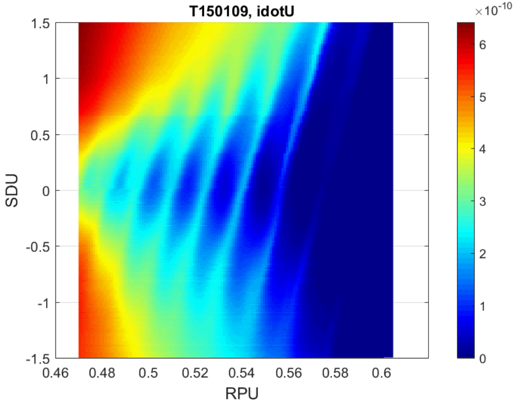
Increasing charging energy indicates we have achieved the low hole occupancy regime

Conclusions

- Strained Ge/SiGe heterostructures are a compelling system for hole spin qubits
- Ge/SiGe heterostructures are a low-disorder material system (μ~200,000 cm^2/Vs)
- Demonstrated Lithographic Quantum Dot operation in a single metal layer device
- Achieved low hole regime



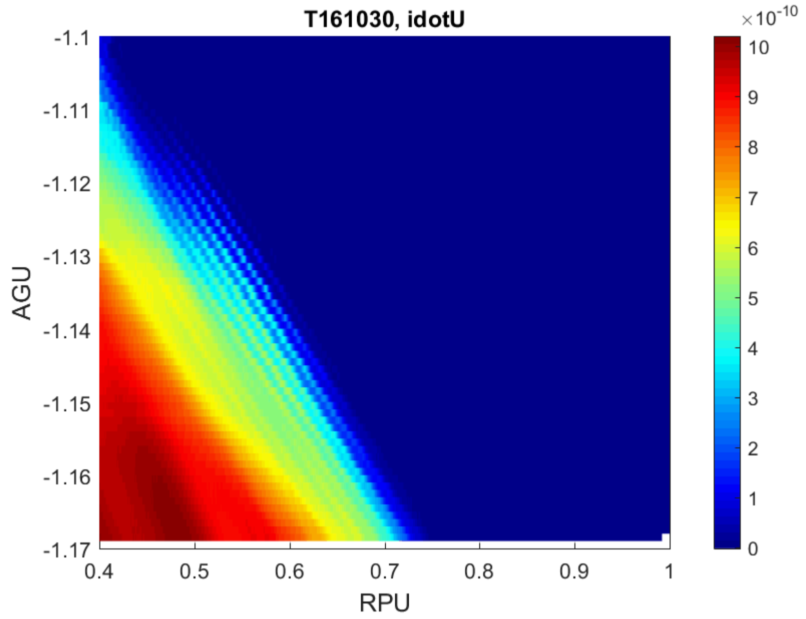


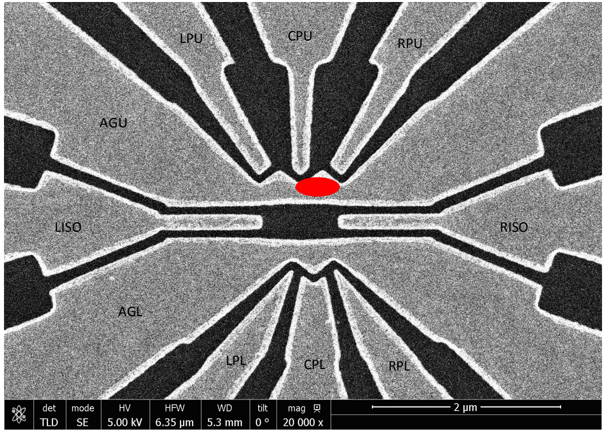


Backup Slides

Device Tune up

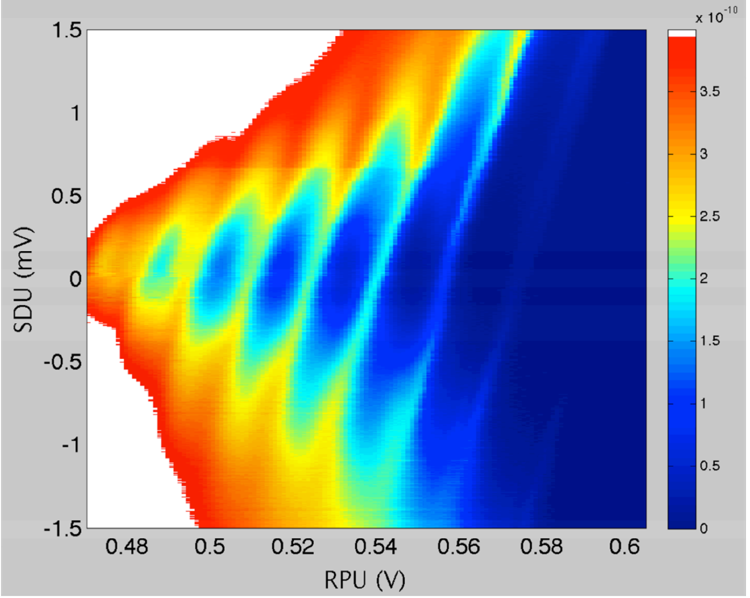
Single metal layer Ge/SiGe Device





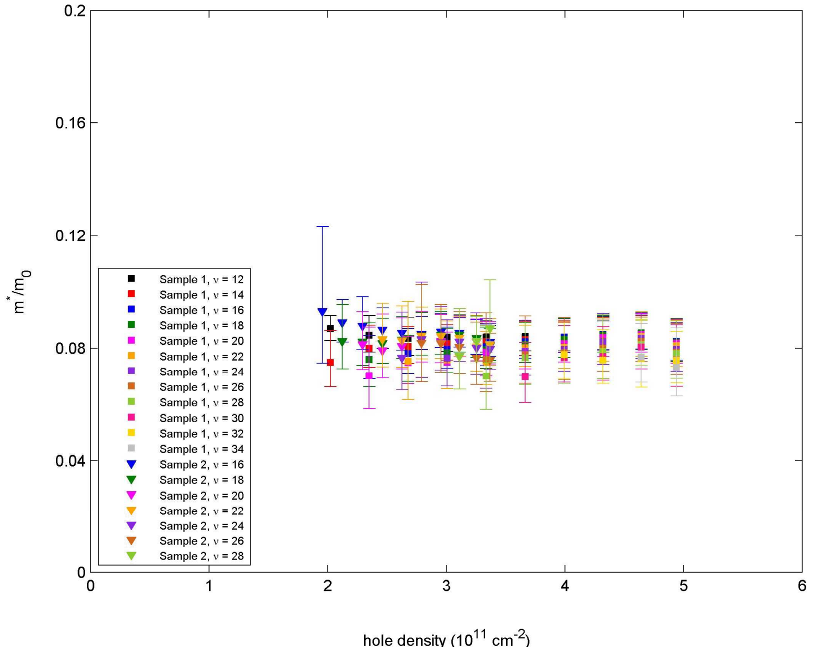
C_{AGU}=53.3 aF
C_{RPU}=10.3 aF
C_{CPU}=5.09 aF
C_{LPU}=4.53 aF
C_{RISO}=8.51 aF
C_{LISO}=1.27 aF
C_{AGL}=9.39 aF
C_{CPL}=1.35 aF
C_{LPL}=0.88 aF
C_{RPL}=1.75 aF

C_{tot}=96.4 aF



x 10^-10
3.5
3
2.5
2
1.5
1
0.5
0
1.5
1
0.5
0
-0.5
-1
-1.5
SDU (mV)
0.48
0.5
0.52
0.54
0.56
0.58
0.6
RPU (V)

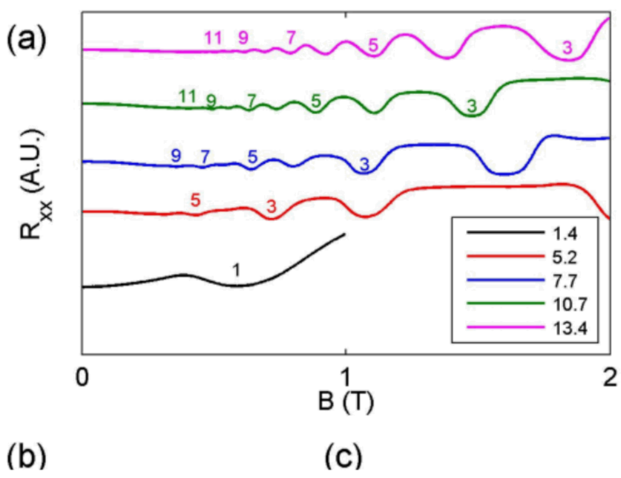
Effective Mass

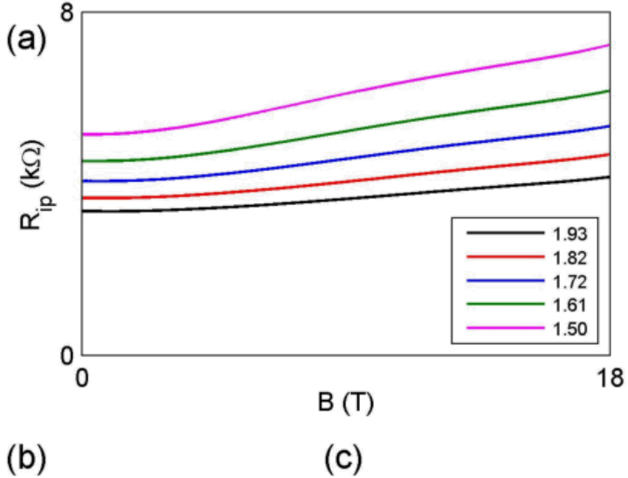


Effective mass extracted from Quantum Hall Effect data.

$m^*=0.08\ m_e$ (independent of density)

g-factor





Lu et al., Appl. Phys. Lett. 111, 102108 (2017)