# Long Spin Relaxation and Coherence Times of Electrons in Gated Si/SiGe Quantum Dots

Jianhua He, A.M. Tyryshkin and S.A. Lyon, *Princeton University*

C.-H. Lee, S.-H. Huang and C. W. Liu, *National Taiwan University*

- Introduction
- Setup and Device Fabrication
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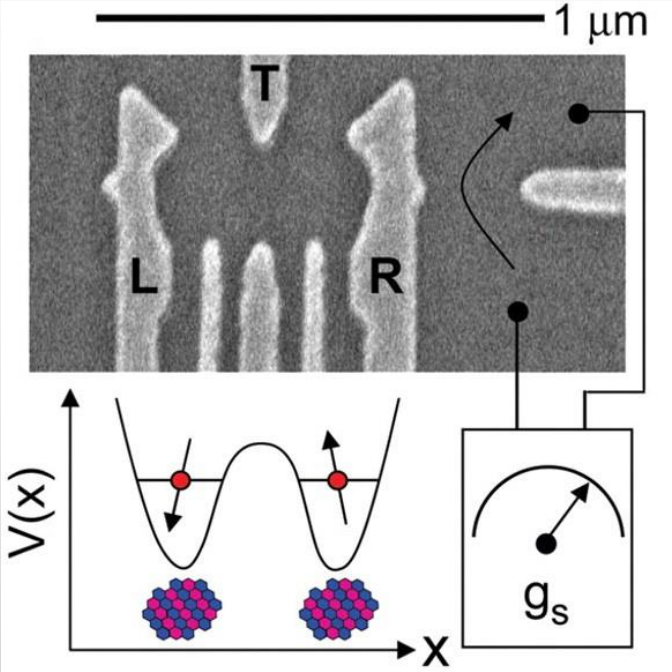
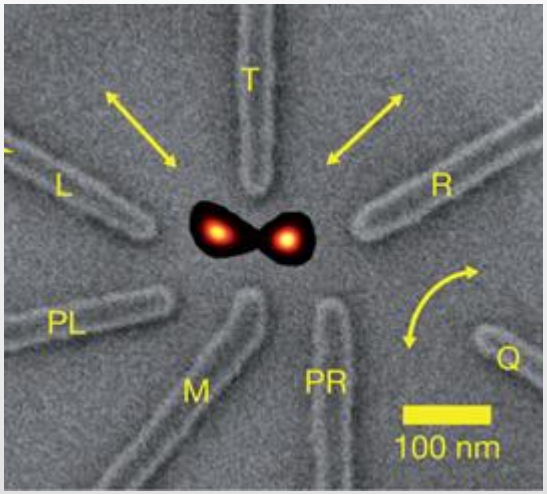
# Spin qubit in Quantum Dot




GaAs quantum dot
$T_2$ limited by nuclear spins

Petta, *et al.*, Science 2005
Maune, *et al.*, Nature 2012

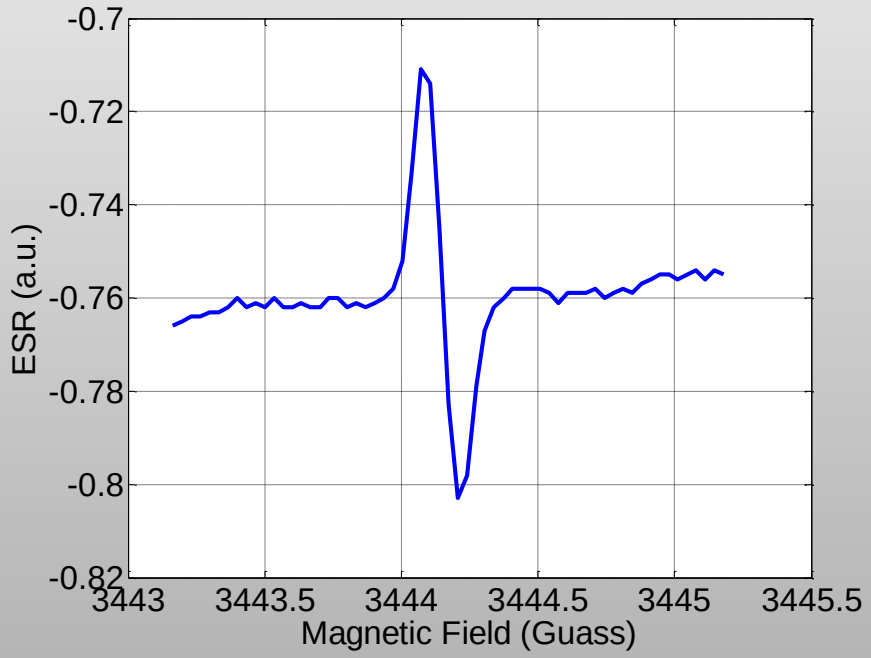


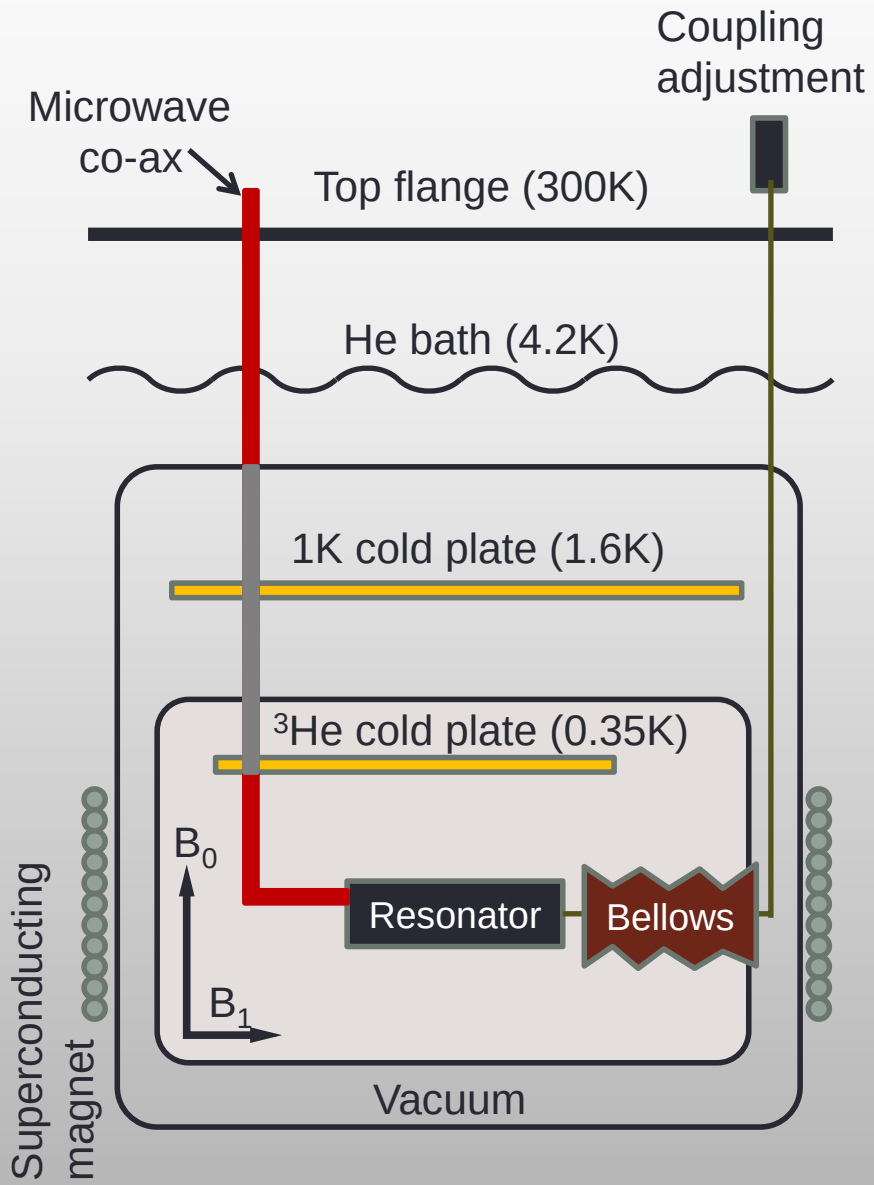

Si quantum dot

- (Expected) long $T_1$ and $T_2$
  a. weak hyperfine
  b. small spin-orbit coupling
- Integration with current microelectronics

# Ensemble ESR in $^3$He system

- Ensemble measurement: $10^8$ unpaired spins
- Zeeman Splitting: 0.35 T ~ 10 GHz ~ 0.46 K
- ESR: g-factor ~ 2
  linewidth ~ 100 mG



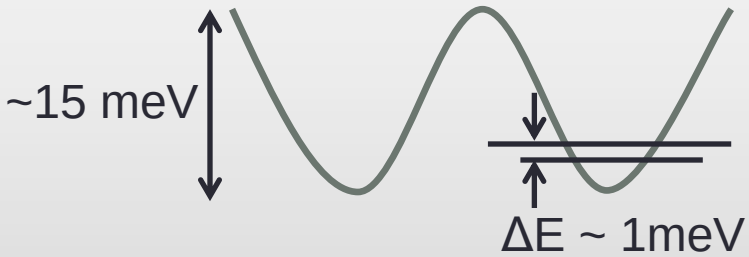



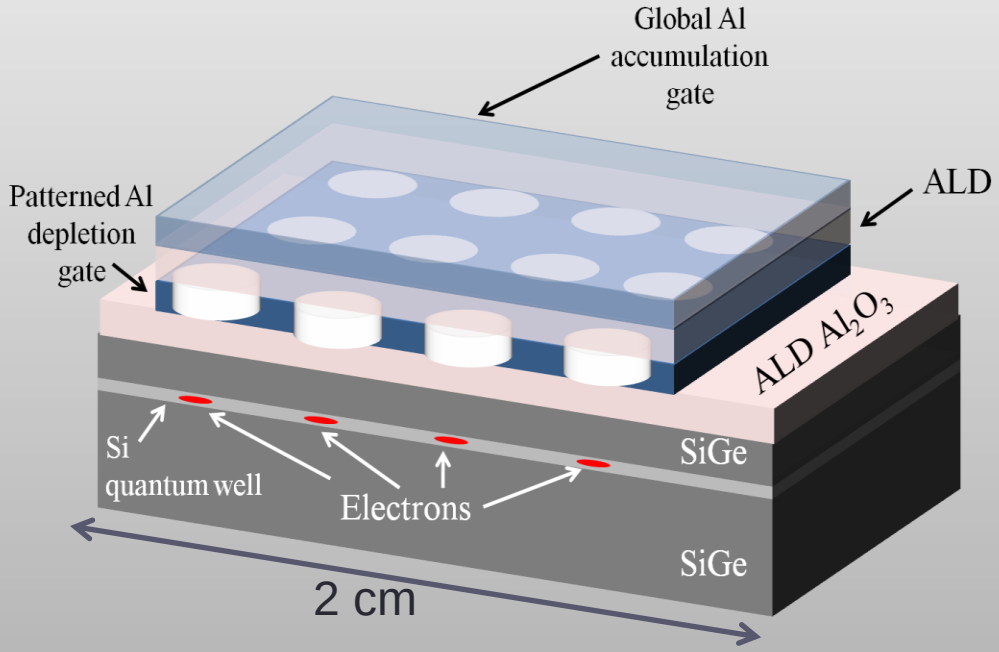
# Device Fabrication

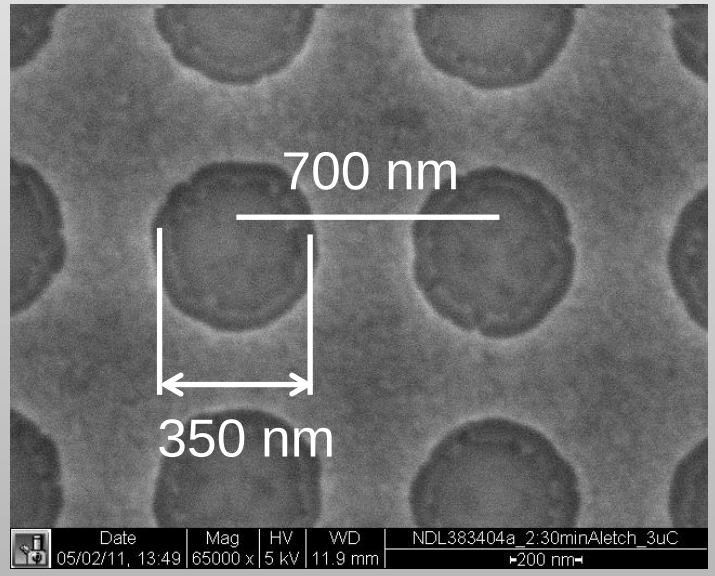
- Undoped natural Si/SiGe:
  $\mu$ > 800,000 cm$^2$/Vsec
  $n_e$ ~ $10^{10}$ /cm$^2$
- 2x$10^8$ dots/cm$^2$ ~1 cm$^2$ total area
- Al - $Al_2O_3$ (100 nm) - Si/SiGe:
  low gate leakage

Quantum well 200 nm below the surface

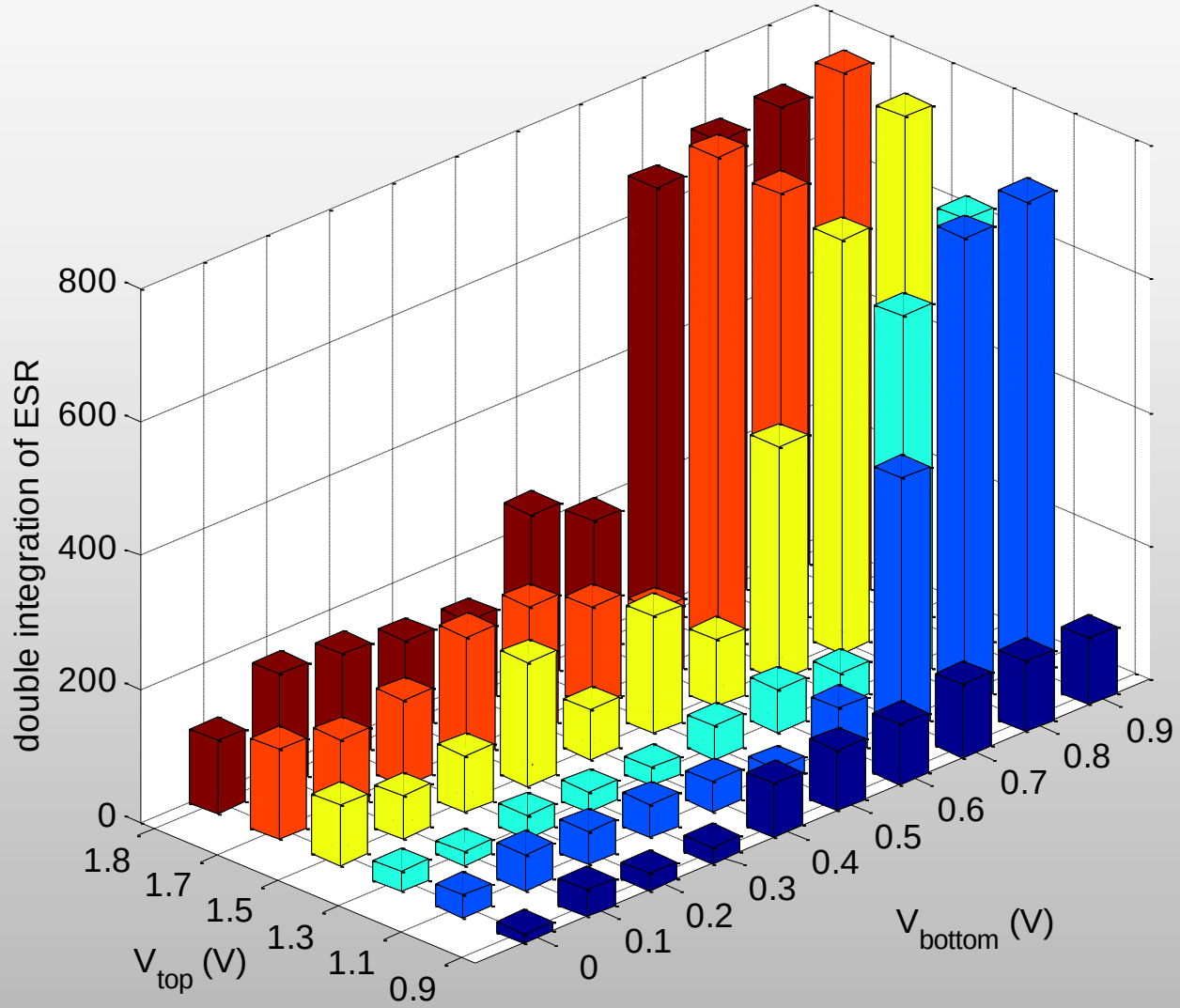
$\Delta Vg = V_{top} - V_{bottom} = 1.5$ V



# Confining Electrons




- Both gates can control $n_e$
- 2DEG (2 valleys) ~ $2.4 \times 10^9$ spins
- QD (1 spin/dot) ~ $1.2 \times 10^8$ spins

$$\frac{Sig_{2DEG}}{Sig_{QD}} \sim 20 \pm 7.7$$

- Resolve single electron transitions?

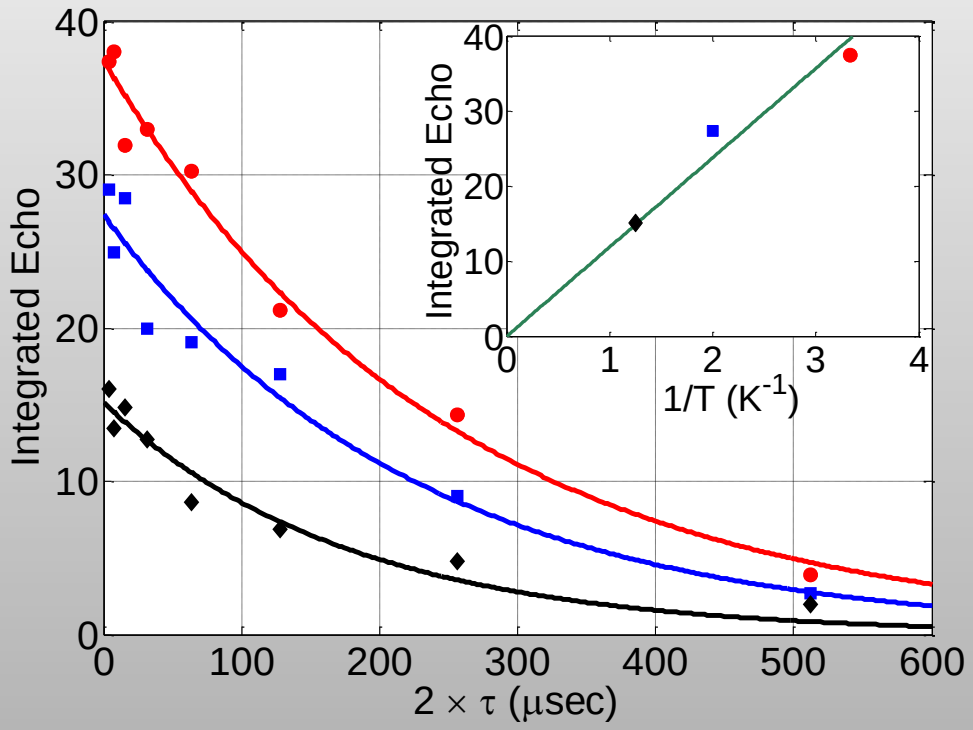
# $T_1$ and $T_2$ of Electrons in QD

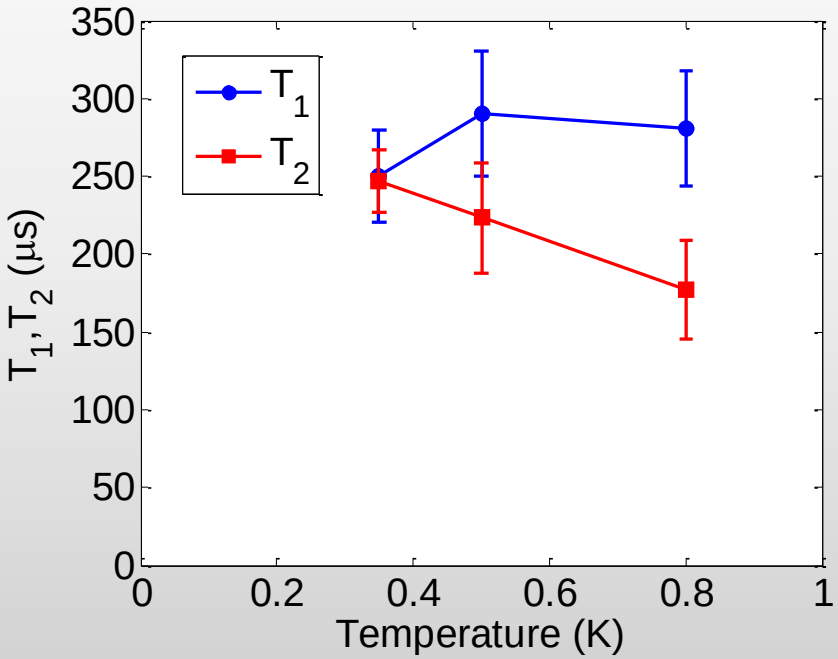
- Echo intensity ratio:

$$\frac{I_{2DEG}}{I_{QD}} \sim 17$$

- Curie dependence

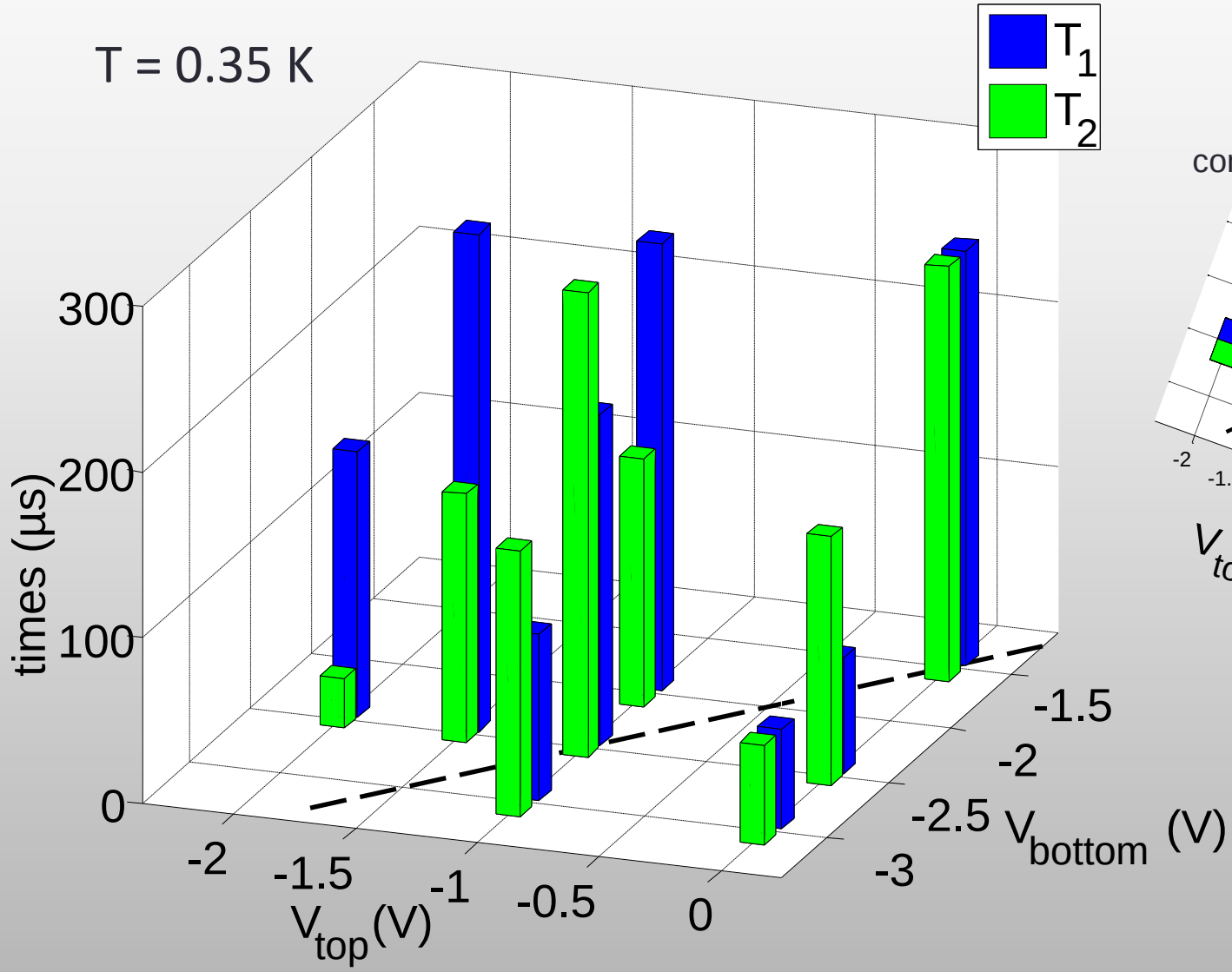
Hahn-echo decays at 0.35 K, 0.5 K, 0.8 K

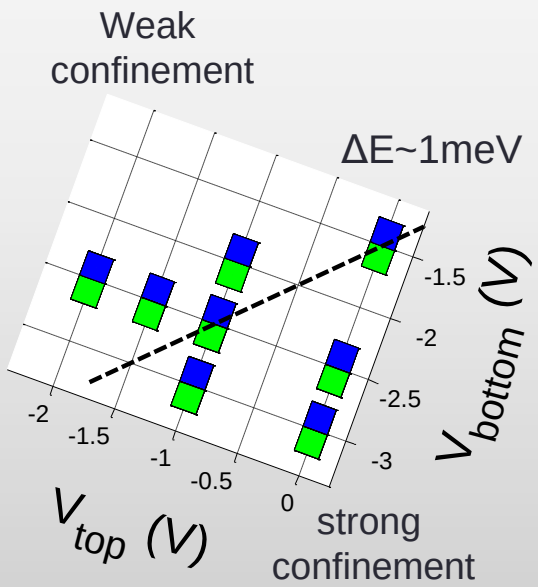


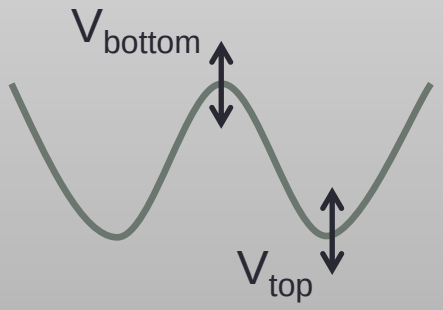




- $T_1 \sim T_2 \sim 250$ us
- $T_2 \downarrow$ as temperature $\uparrow$
  $T_1$ does not

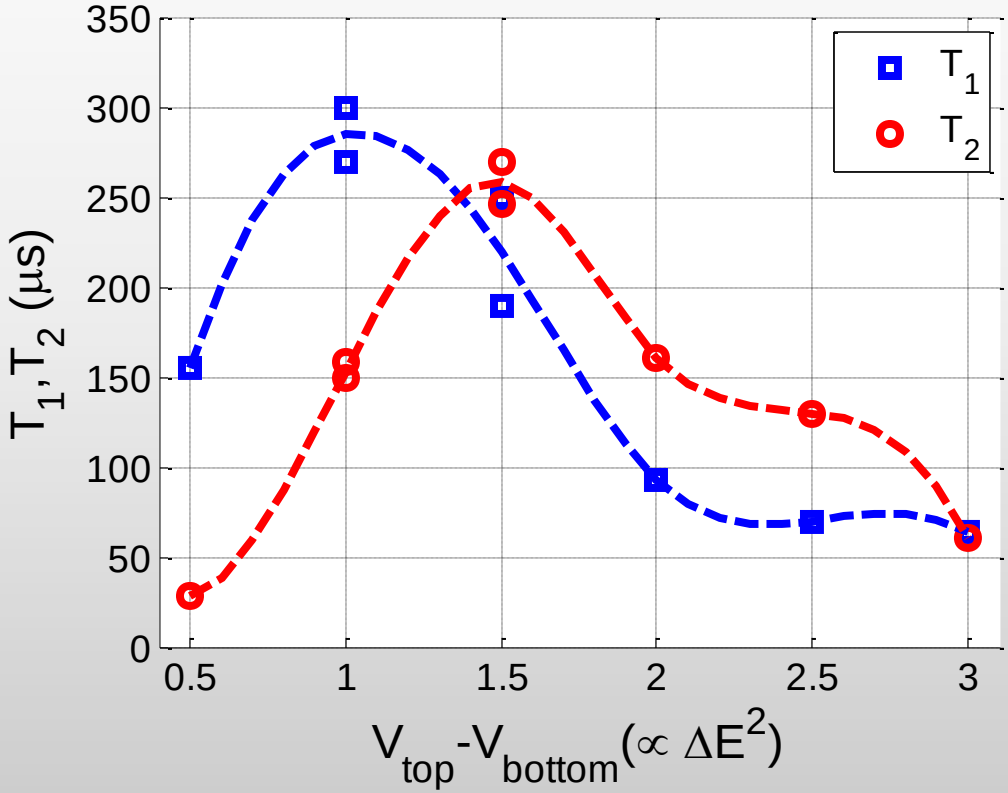
# $T_1$ and $T_2$ vs Gate Voltages



# Spin Relaxation and Decoherence in QD




- Single Phonon: $T_1 \sim {\Delta E^4}/{B^7}$
- $^{29}$Si hyperfine: $T_1 >> T_2$
- Exchange or dipolar interaction

- Valley splitting?
- Many electron dots?
- Stark effect?

# Summary

- Fabricated a large area double gated device on Si/SiGe for ensemble ESR
  i) low gate leakage
  ii) 2DEG and QD
- $T_1$ and $T_2$ of high mobility 2D electrons
  $T_1 \sim 10\ \mu s$, $T_2 \sim 6.5\ \mu s$ at T = 0.35 K
- Single spin qubits in QD
  $T_1 \sim 250 \mu s$, $T_2 \sim 250\ \mu s$
  weak dependence on temperature
  strong dependence on confinement energy
- Relaxation and decoherence not yet understood