A single-atom electron spin qubit in silicon

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강병기

J. J. Pla, et al. Nature 489 541 (2012)

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- Single qubit device
  - Single Electron Transistor(SET)
  - Performance property: ESR Pulsing scheme
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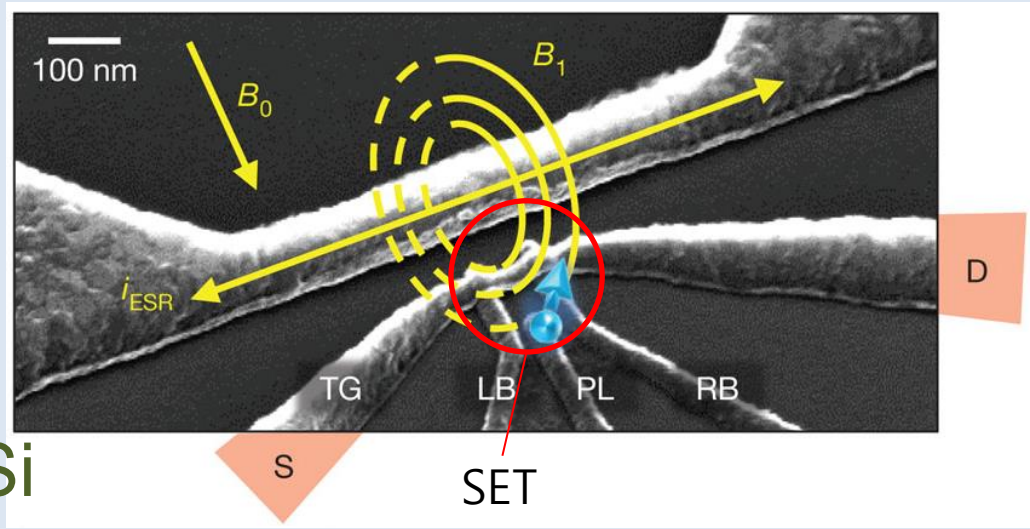
- Coherence time: Measuring T_2
- Summary

Introduction

- Spin ½: Candidate of qubit
- To realize
  - Fabrication
  - Initialization
  - Single qubit operation
  - Reading
  - Coherence
  - Double qubit operation: entanglement

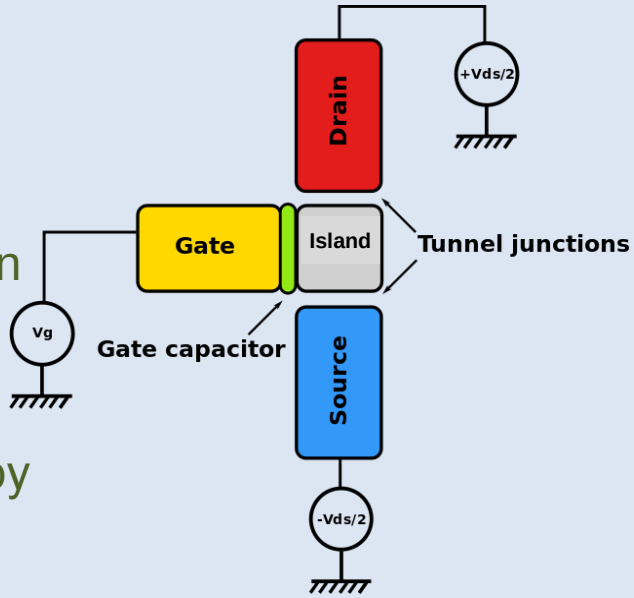
Device

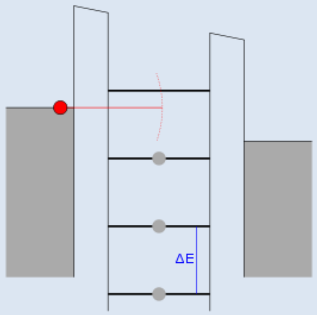
- Si substrate
- Al gate
- P ion implantation
  - It's like H atom in Si
- Single electron transistor(SET)
- Operating environment
  - B_0 ~ 1 T
  - B_1 ~ 30 GHz, ~0.1 mT
  - 300 mK

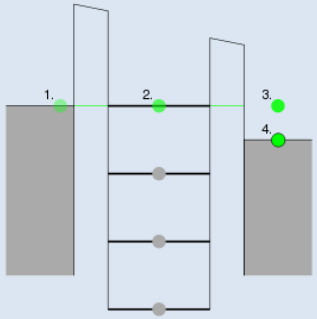


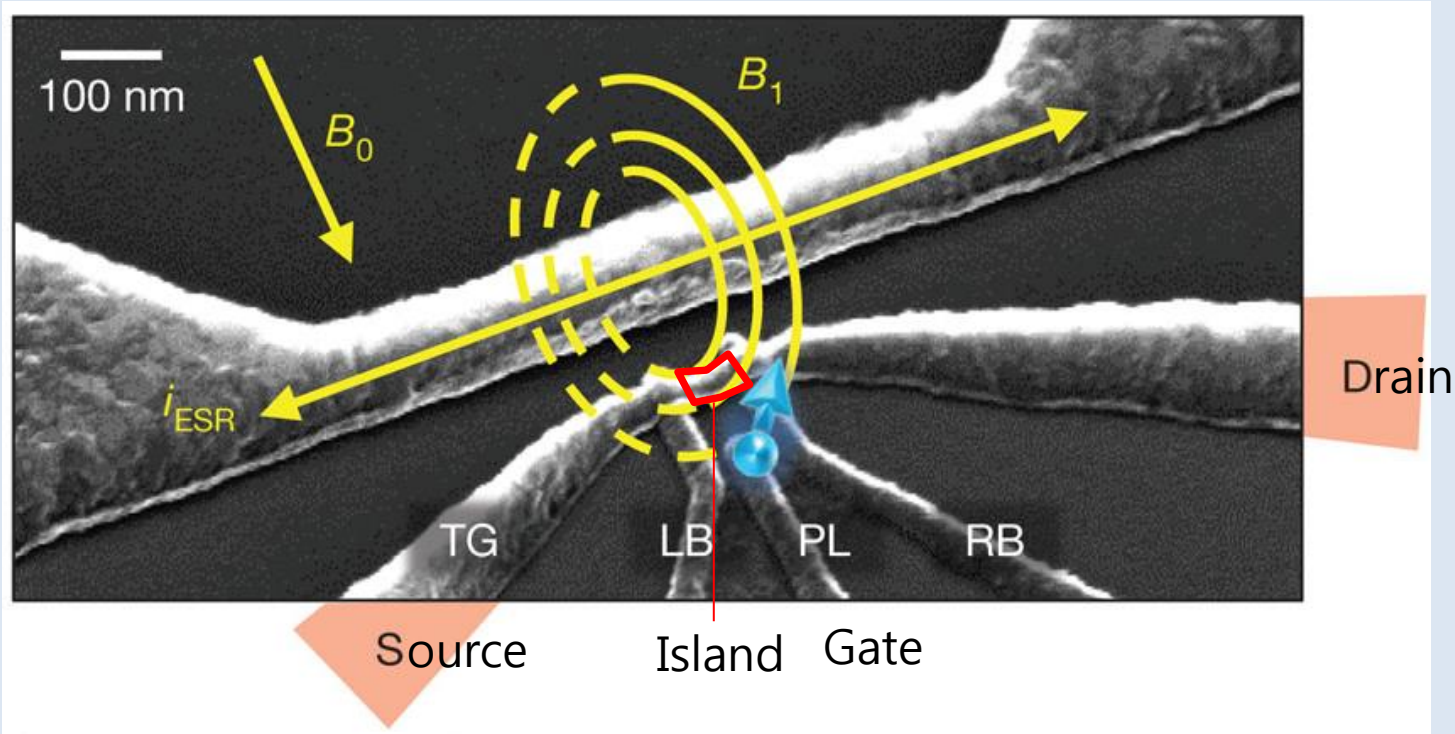
SET

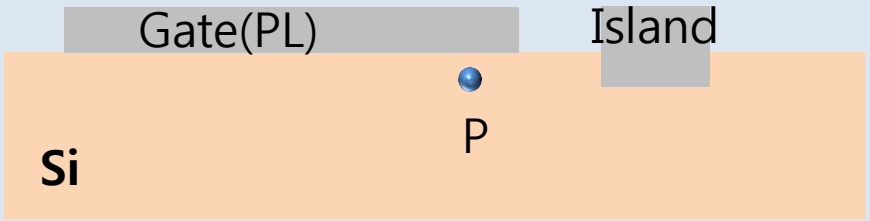
- Property
  - The SET is made by placing 2 tunnel junctions in series
  - The 2 tunnel junction create what is known as a “Coulomb Island” that electrons can only enter by tunneling through one of the insulators.
  - Since tunneling is a discrete process, the electric charge that flows through the tunnel junction flows in multiples of the charge of electrons ***e***.
- Coulomb blockade
  - The effect in which electron can not pass through the island unless the energy in the system is equal to the Coulomb energy e^2/C.
  - Coulomb blockade tries to alleviate any leak by current during the off state of the SET.

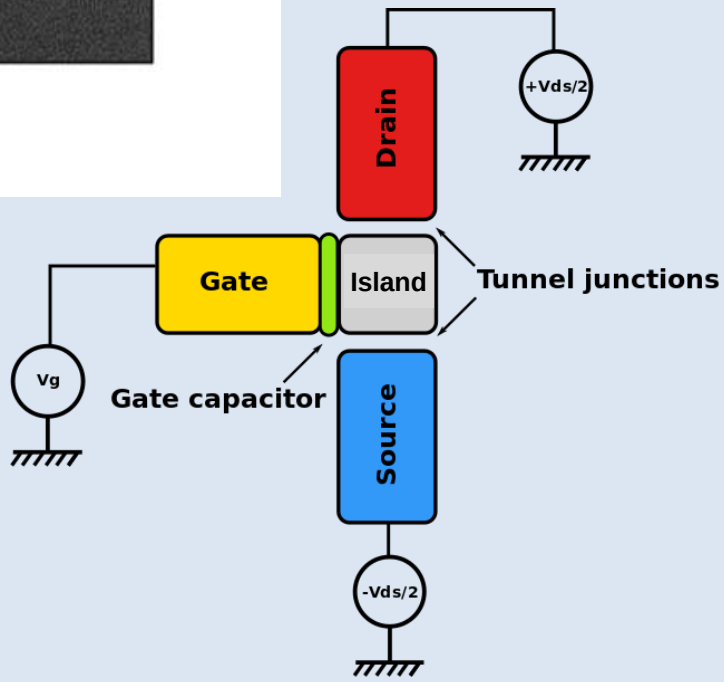






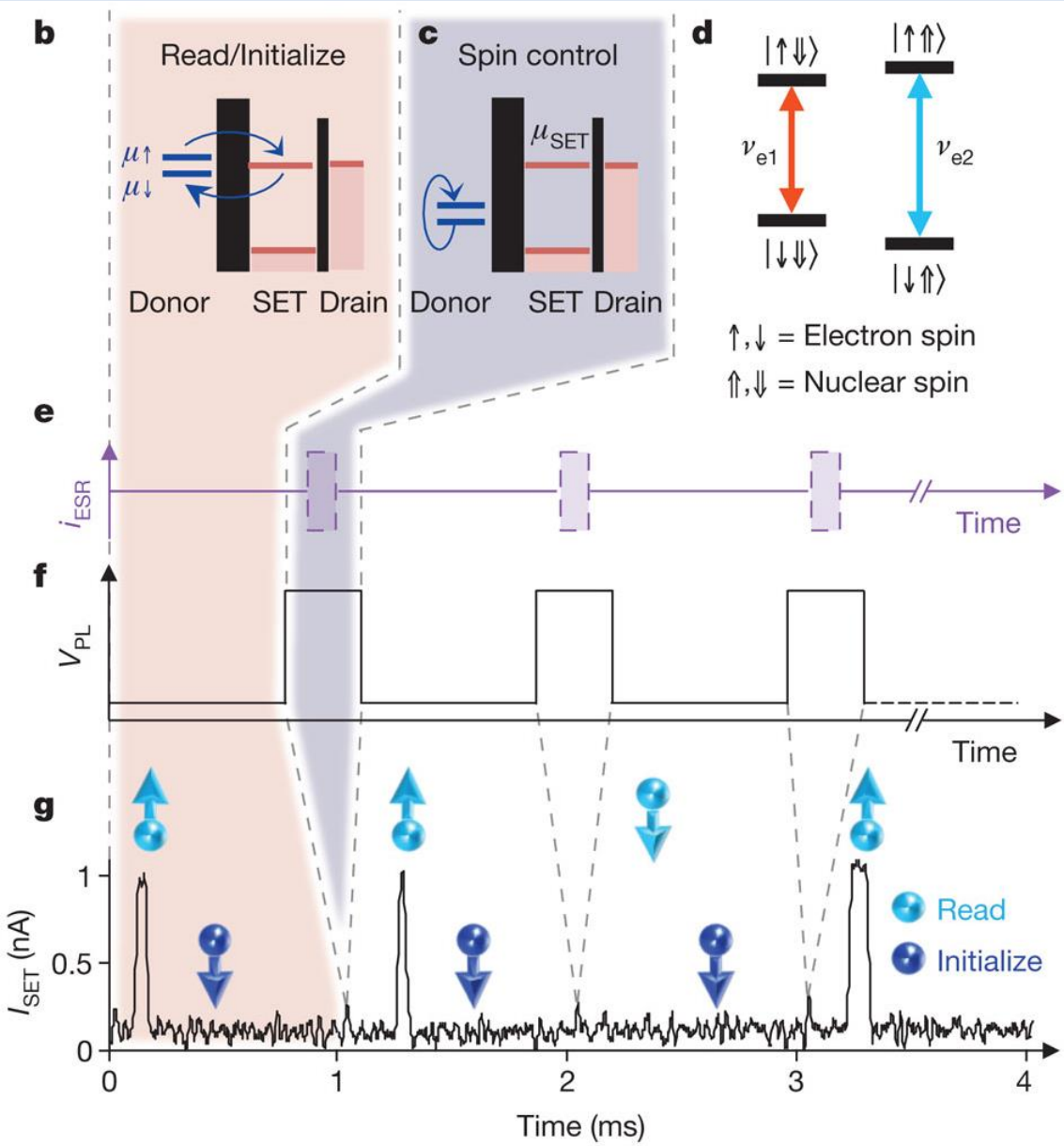

100 nm
B_0
B_1
i_{ESR}
TG
LB
PL
RB
Drain
Source
Island
Gate


Gate(PL)
Island
P
Si


Drain
+Vds/2
Gate
Island
Tunnel junctions
Vg
Gate capacitor
Source
-Vds/2

ESR Pulse scheme

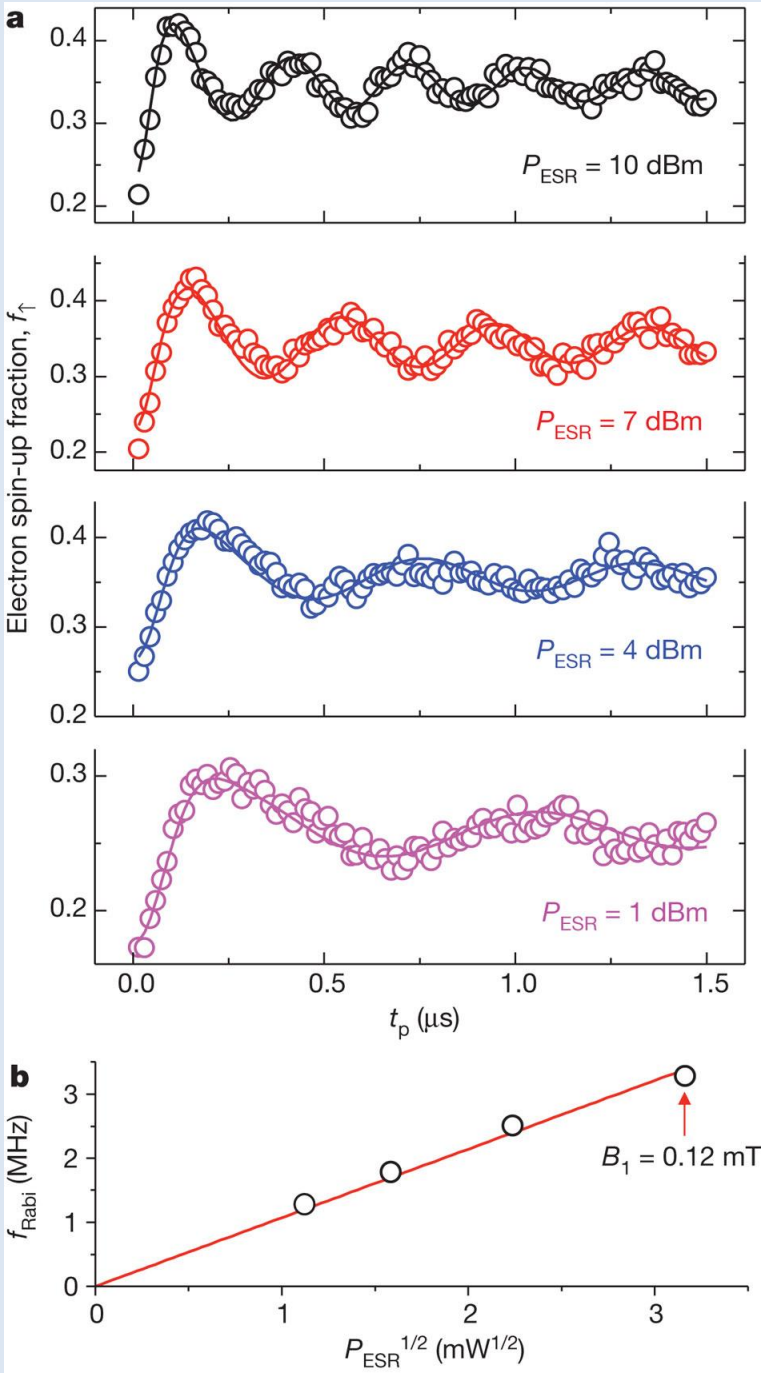
- Donor P in Si
  - $H = \gamma_e B_0 S_z - \gamma_n B_0 I_z + AS \cdot I$
  - $\nu_{e1} \approx \gamma_e B_0 - A/2$
  - $\nu_{e2} \approx \gamma_e B_0 + A/2$
- V_{PL}: donor level control
  - Mode change
- i_{ESR}: B_1 ESR pulse
  - Qubit control
  - Freq.: ν_{e1}, ν_{e2}
- I_{SET}: drain current
  - Reading qubit state



Video clip

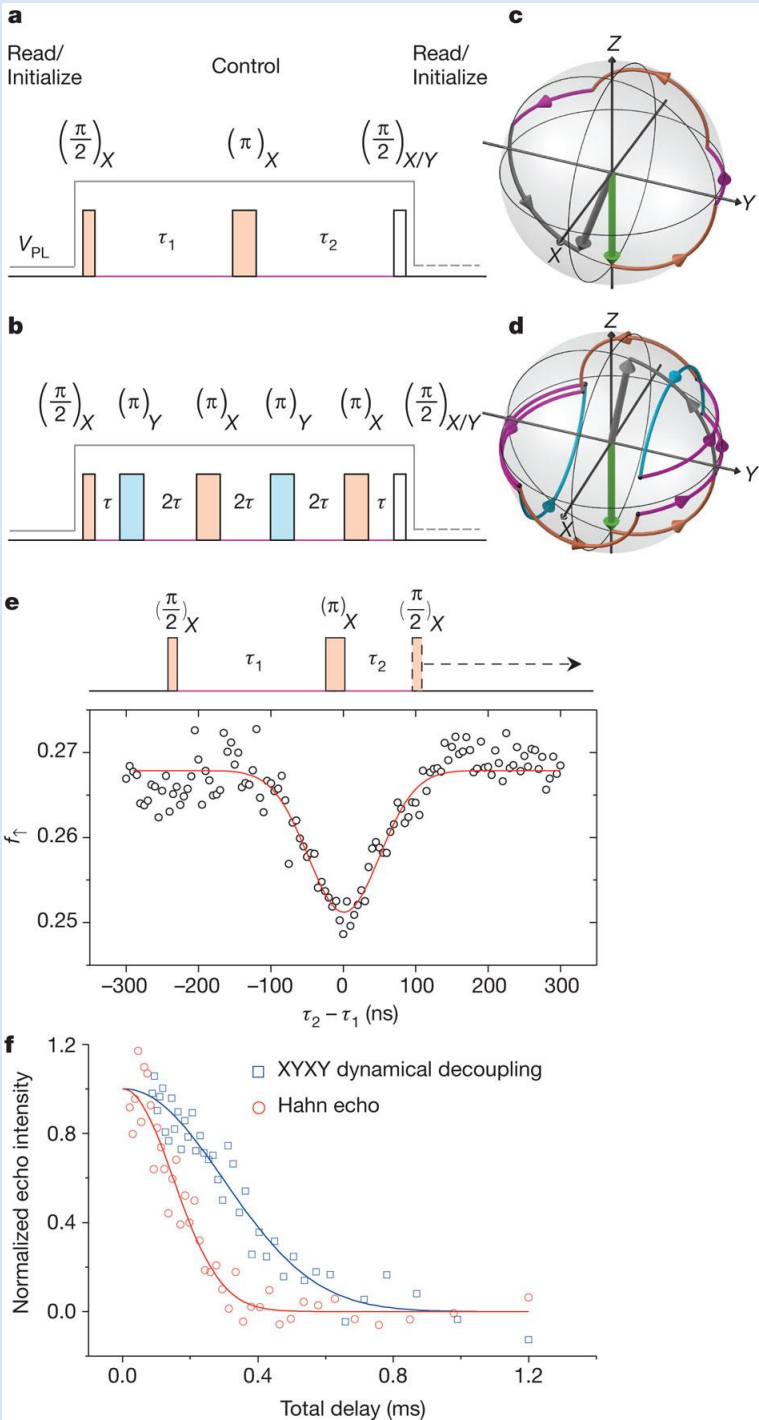
Rabi oscillation

- t_P: B_1 ESR pulse duration
- $f_\uparrow$: electron spin-up fraction
- P_{ESR}: power of ESR pulse
  - $P_{ESR}^{1/2} \propto \gamma_e B_1$
- f_{Rabi}: Rabi frequency $1/t_P$
  - $B_1 \cdot t_P$ = constant(angle)



Coherence time

- T_2 measuring
- Decoherence source
  - Diffusion of ^{29}Si
  - Noise in external field
  - Paramagnetic defects
  - Charge traps at interface
- Spin echo technique: **e**
  - $T_2^* \sim 55ns$
- Hahn echo : **a, c**
  - $T_2 = 206 \pm 12\ \mu s$
- XYXY dynamic decoupling: **b, d**
  - $T_2 = 410 \pm 20\ \mu s$



Summary

- Single-qubit realization with single atom electron with P ion in Si
  - Fabrication of SET
  - Operation with pulse-ESR
- Rabi oscillation: demonstration of coherence control
- Measuring T_2: coherence time
  - Hahn echo
  - XYXY dynamic decoupling