Carrier Transport in Heavily-doped Nanoscale SOI Fillm

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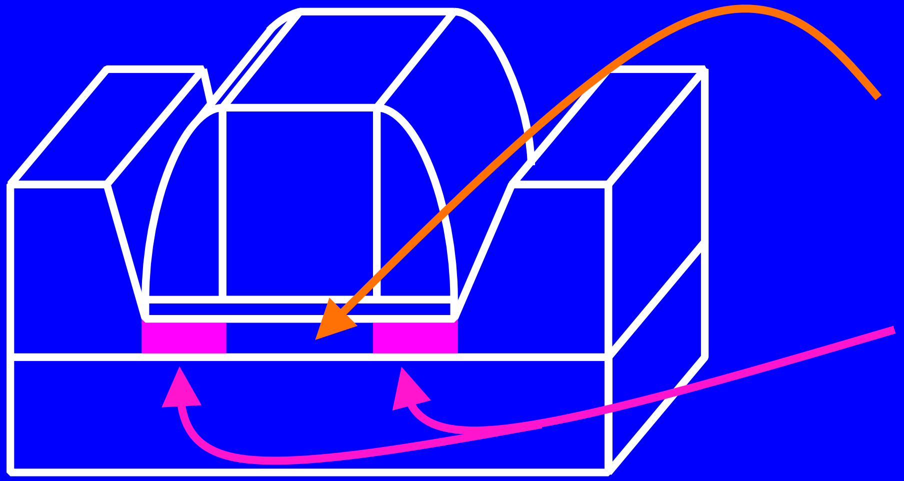
G-COE PICE, IS-AHND 2011

Background

ETSOI MOSFETs have attracted growing interests.



Carrier Transport in

ETSOI Channel

- K.Uchida,*et al*.,IEDM,p47,2002
- D.Esseni,*et.al*.,TED,**48,**p.2842,2001

Diffusion Layer (DL)

No Report

Objective

- To study carrier transport in ETSOI DL.
  - T_{SOI} dependence
  - N_D dependence

Outline

- Background & Objective
- Fabrication of ETSOI Diffusion Layer
- Device Structure & Experimental Method
- Electrical Characteristics
  - μ_e in ETSOI Diffusion Layer (5nm<T_{SOI}<10nm)
    - Simulation of Potential Distribution
    - Universality in $\Delta\mu_e$ Ratio
  - μ_e in ETSOI Diffusion Layer (T_{SOI}=2nm)
    - T_{SOI} Fluctuation and Impurity Distribution Fluctuation
- Conclusion

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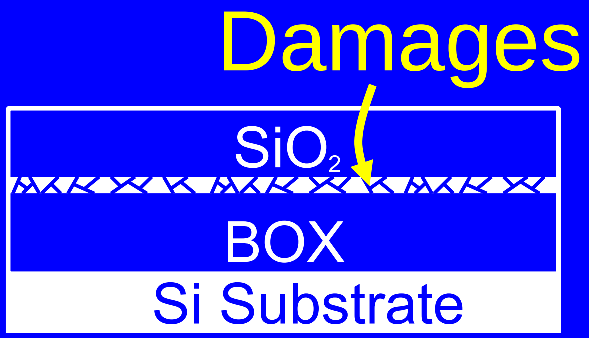
Fabrication of ETSOI Diffusion Layer

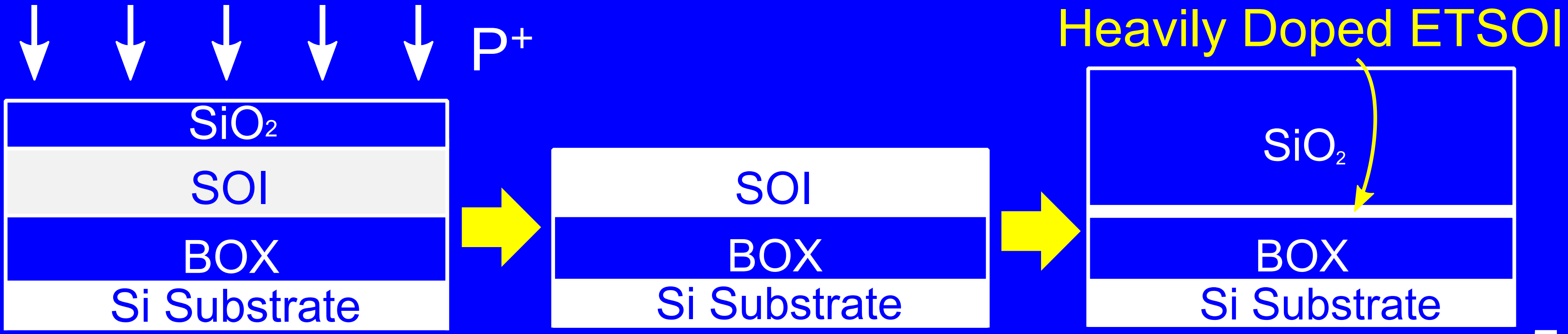
Issue

Damages in *ETSOI* induced by Ion Implantation cannot be recovered.



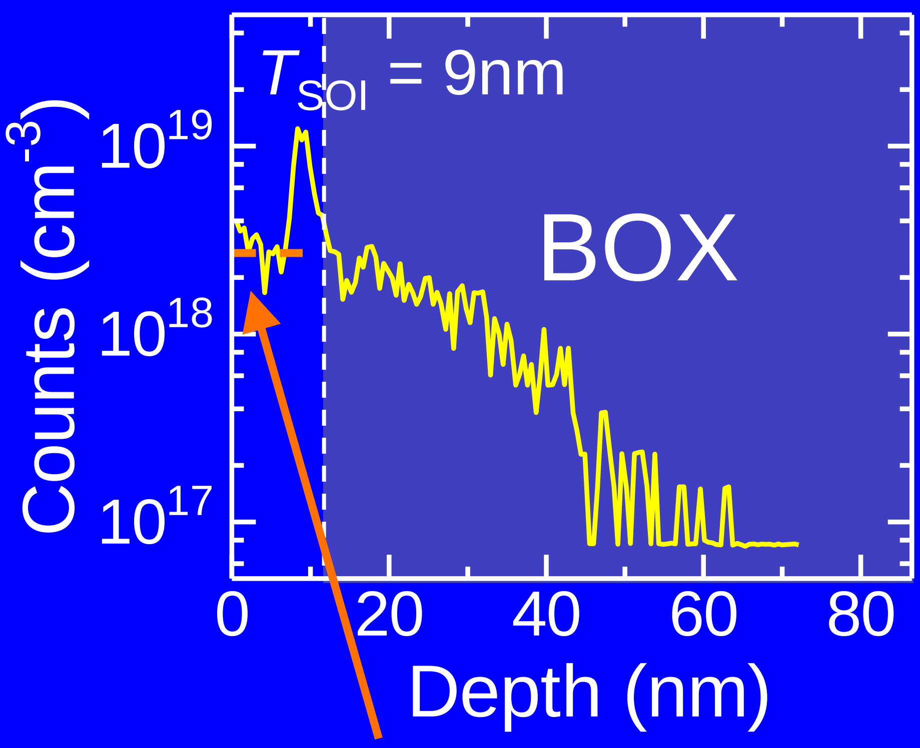
Key Process

- Ion Implantation(I/I) to Thick SOI (T_{SOI}>50nm)
- SOI Thinning after I/I (Oxidation and HF Solution)



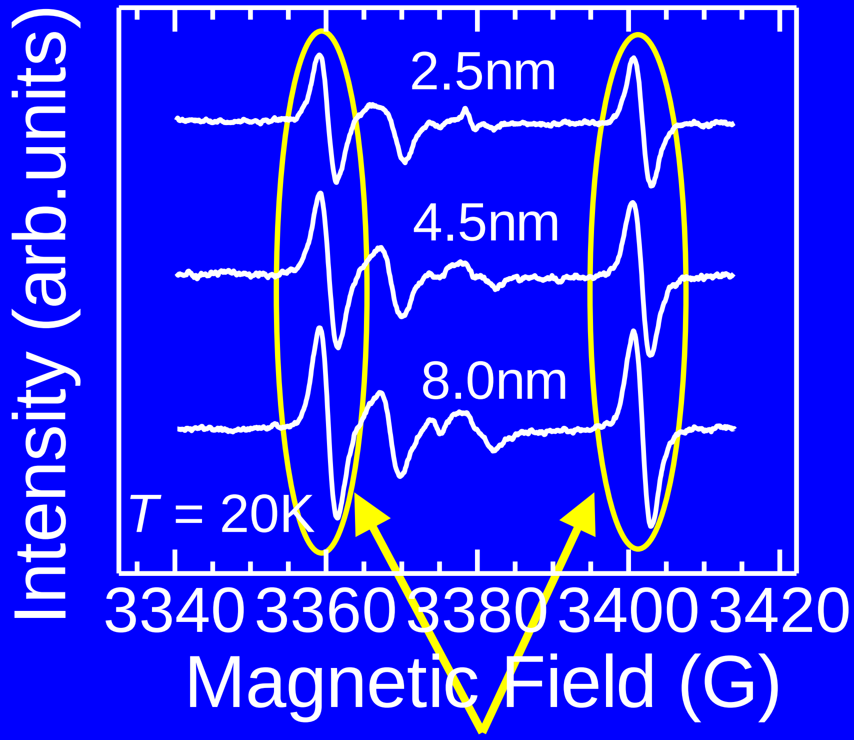
SIMS & ESR of Fabricated ETSOI

SIMS



2.7×10^{18} cm^{-3}

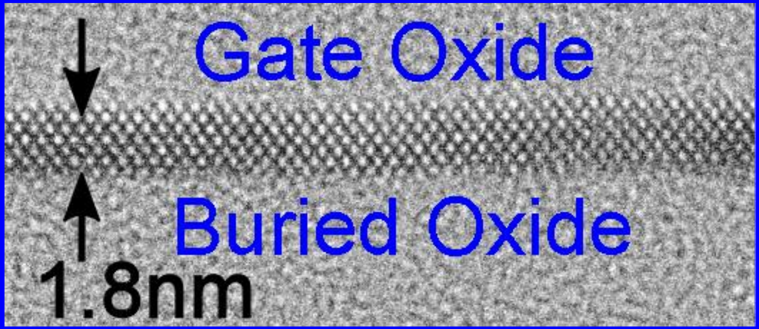
ESR



Hyperfine Structure

High doping concentration and successful activation of dopant are confirmed.

Successful Fabrication of Heavily Doped ETSOI Diffusion Layers



- Extremely Thin SOI Thickness

  $T_{\mathrm{SOI}} = 1.8$ nm
- High Doping Concentration

  $N_D > 1 \times 10^{18}$ cm^{-3}
- Good Crystal Quality

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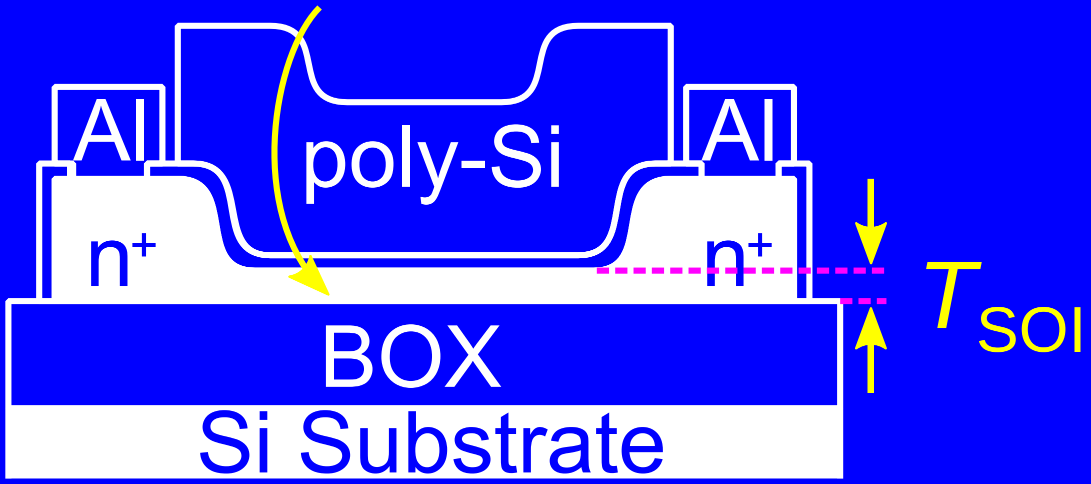
Device Structure

Heavily n^+ Doped ETSOI



L = 100~400 µm

W = 10~40 µm

T_{SOI} = 2~56 nm

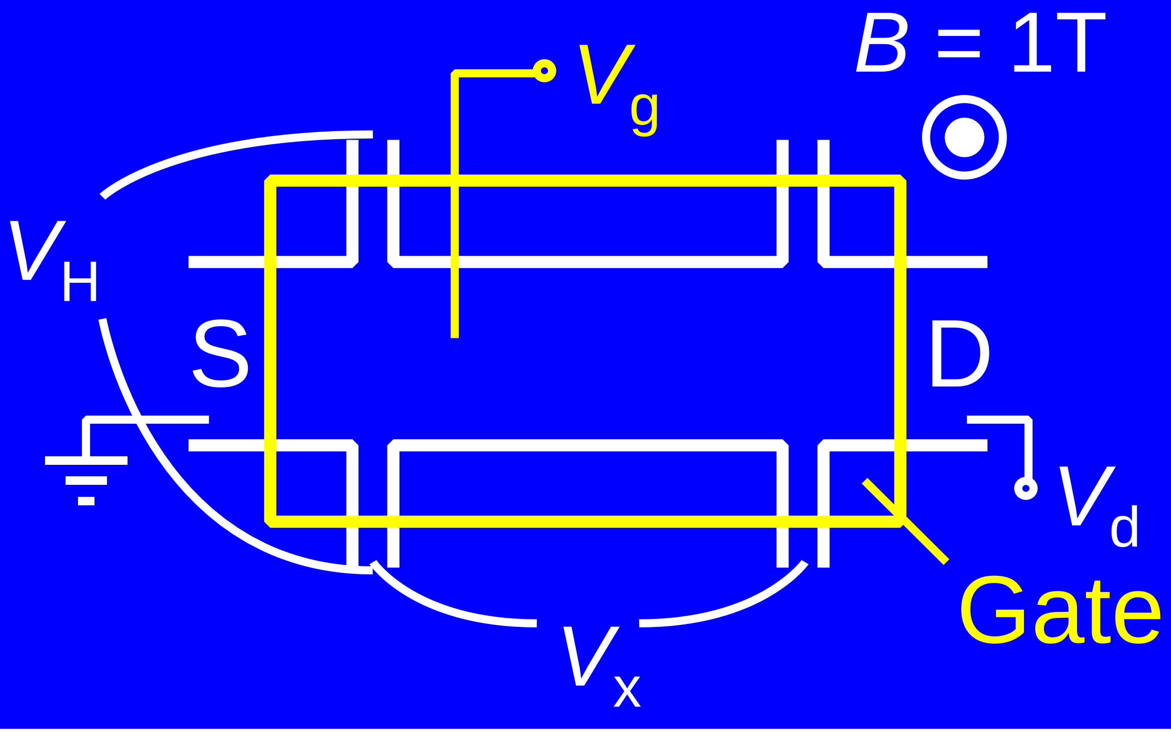
T_{ox} = 10~20 nm

T_{BOX} = 400 nm

$N_D^+ = 1\text{x}10^{17}\sim 1\text{x}10^{19}\ \text{cm}^{-3}$

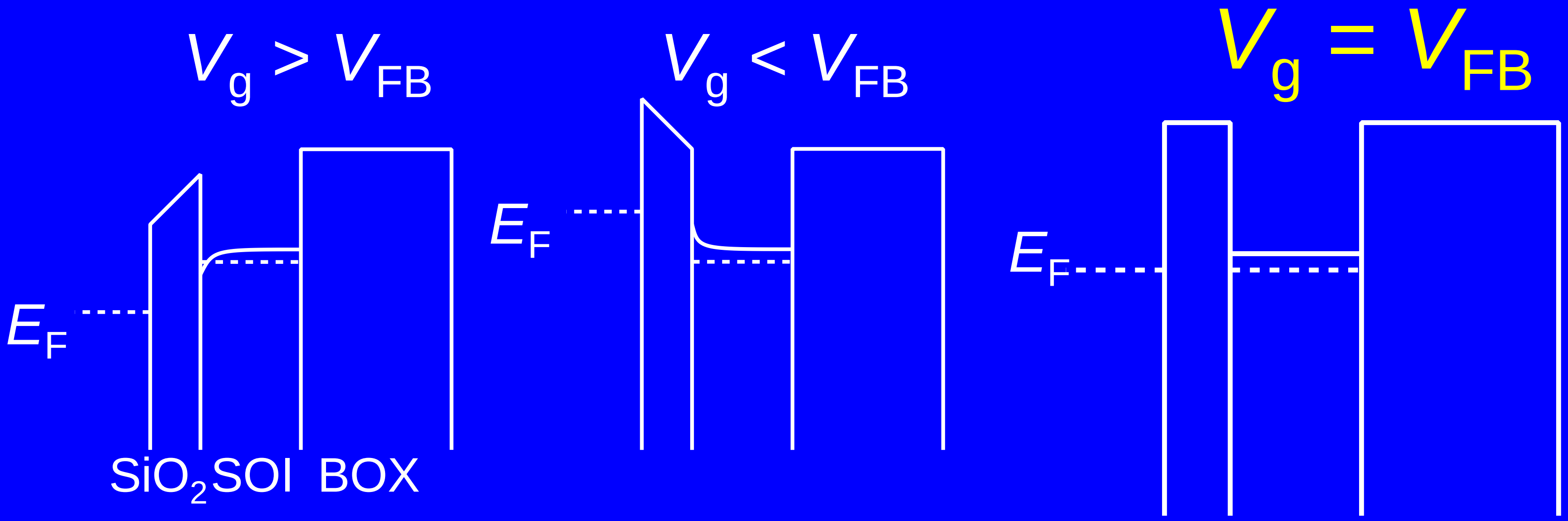
Experimental Method

Hall Effect Measurement



Gate electrode enables us to control channel potential.

Extraction of μ_e & N_D^+



Accumulation

Depletion

Flat Band → Diffusion Layer

When $V_g = V_{FB}$

$$\begin{cases} \mu_e = \mu_H / \gamma \\ N_D^+ = \gamma N_H / T_{SOI} \end{cases}$$

μ_H : Hall Mobility

N_H : Electron Density Measured with Hall Measurement

γ : Hall Factor

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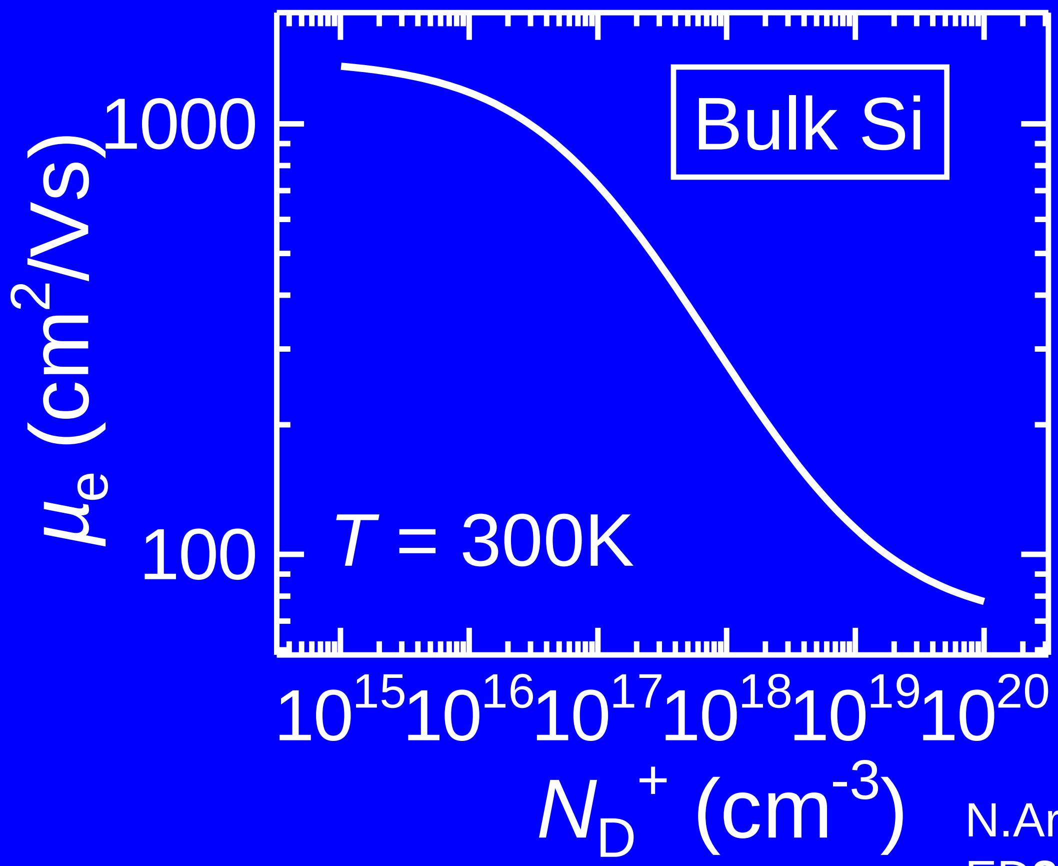
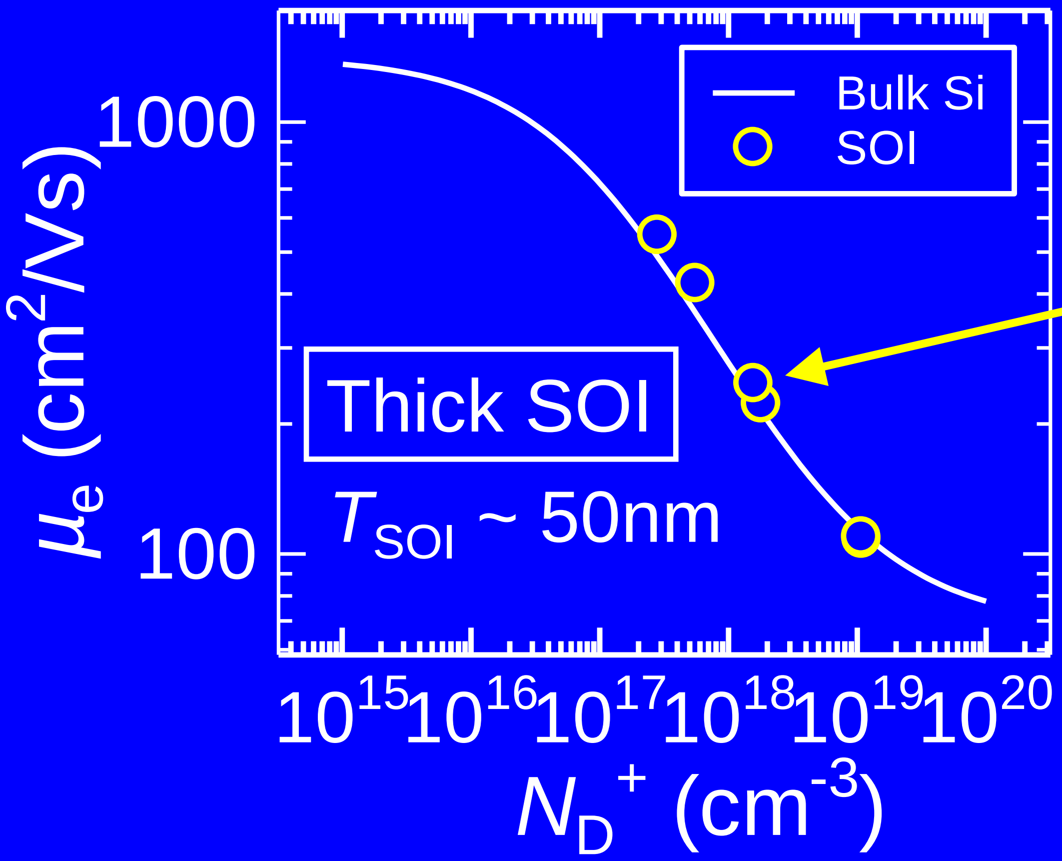
Electron Mobility in Bulk Si



N.Arora *et al*., Trans. Electron Devices, ED**29**,292,1982

μ_e in thick SOI will be measured.

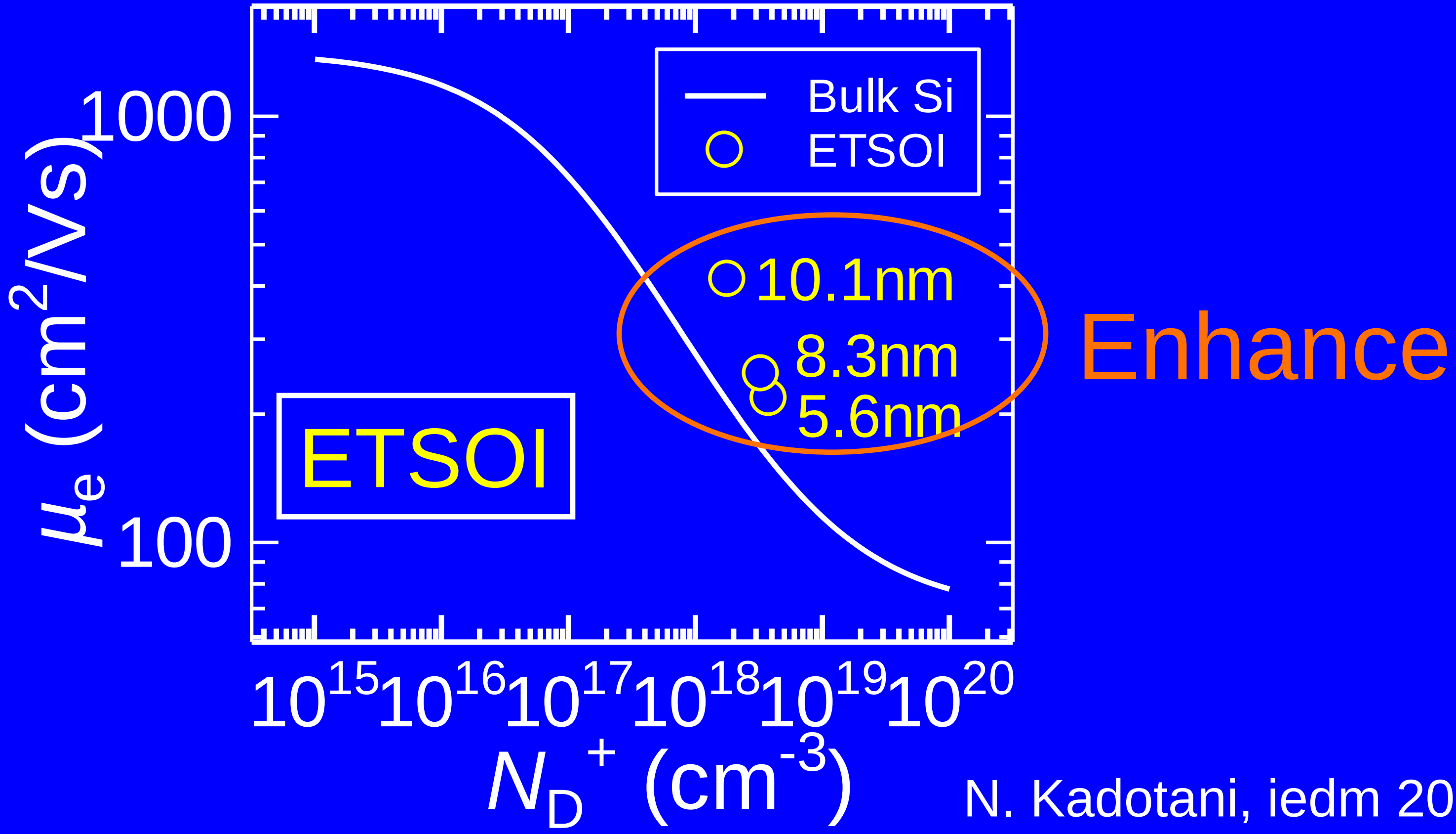
Electron Mobility in Thick SOI



$\mu_e^{\text{Thick}} \sim \mu_e^{\text{Bulk}}$

Validity of experimental method is confirmed.

Electron Mobility in ETSOI



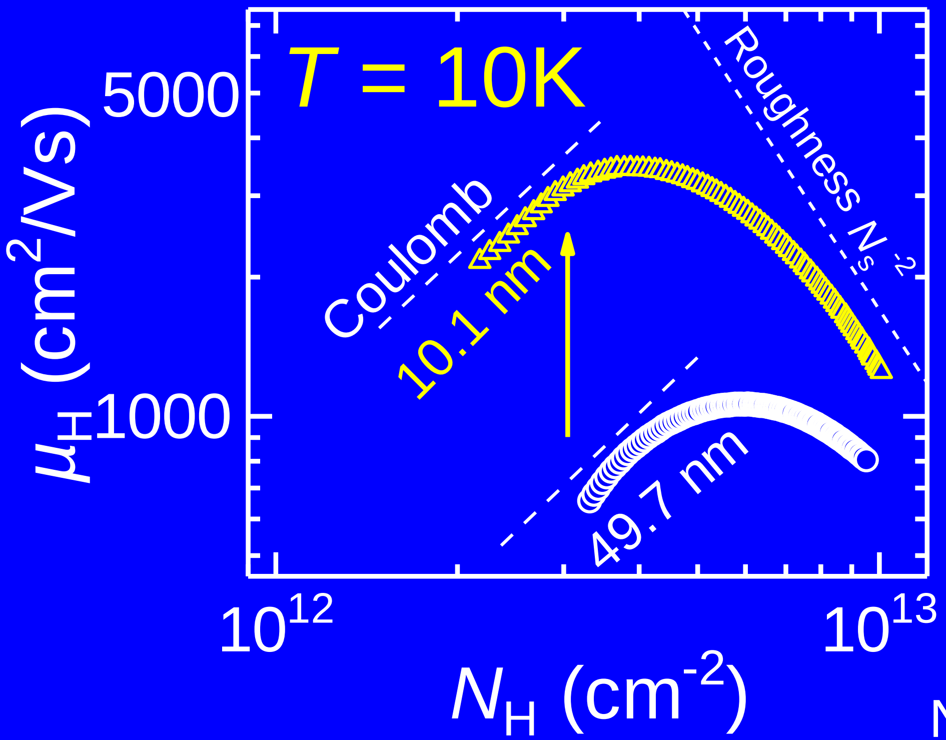
N. Kadotani, iedm 2010.

μ_e^{ETSOI} is much higher than μ_e^{Bulk}.

Hall Mobility vs N_s

-Low Temperature-

$N_D^+ = 1.8 \times 10^{18} \mathrm{cm}^{-3}$ (at 300K)



μ_{Coulomb} is enhanced in ETSOI

N. Kadotani, iedm 2010.

Coulomb scattering is reduced in ETSOI.

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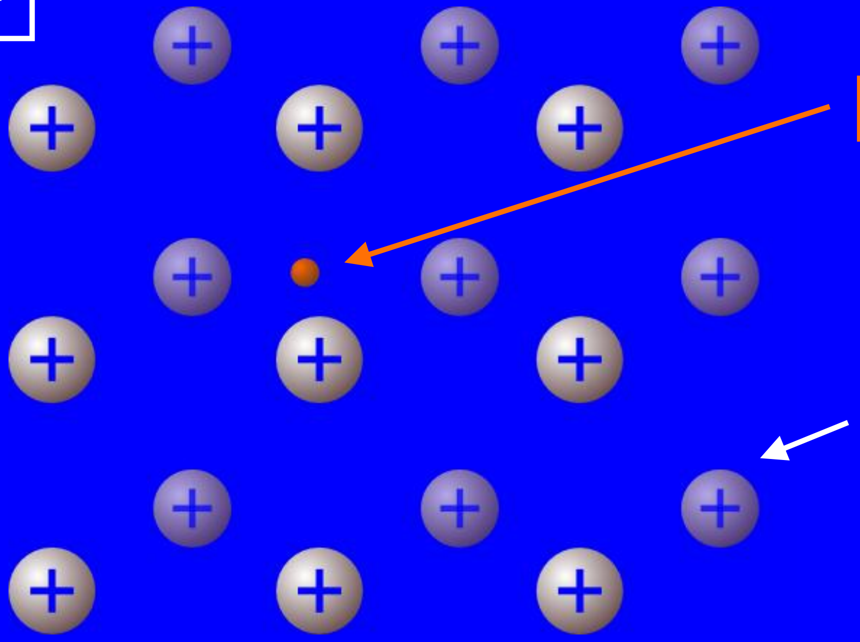
Donor Ions in Bulk Si

Bulk Si


Electron

Donor Ion

In bulk Si, electron is surrounded by donor ions in all direction.

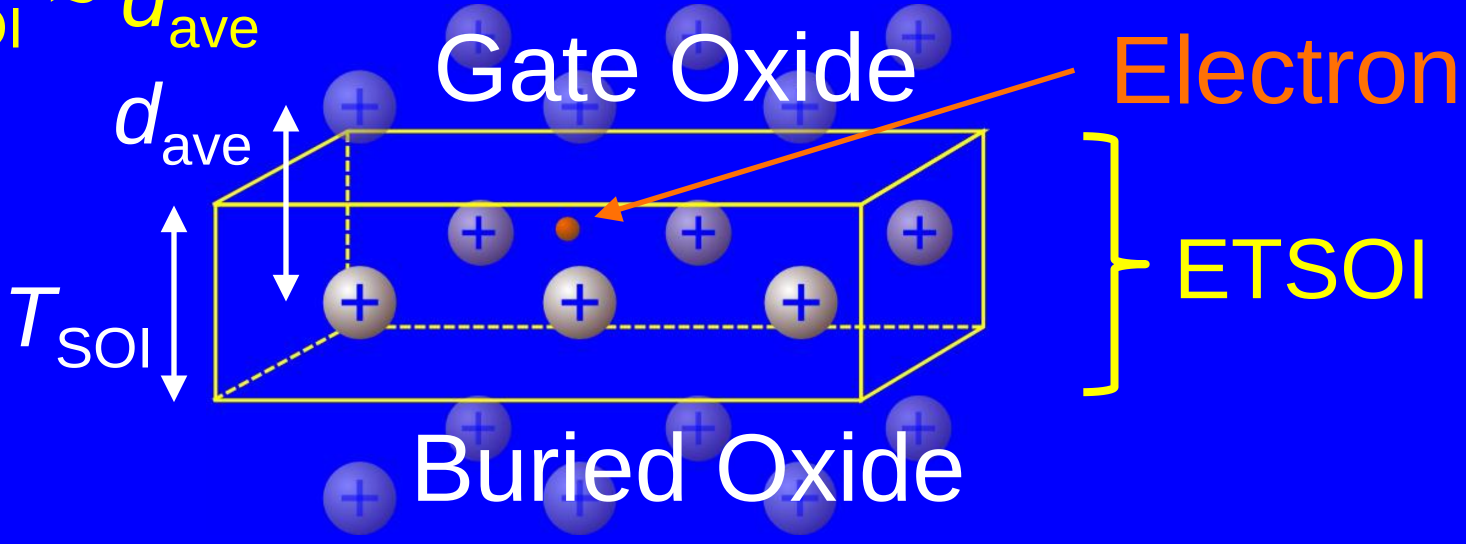
Reduced number of Donor Ions in ETSOI

ETSOI

average distance between donor ions

$$d_{ave} = (N_D^{+})^{-1/3}$$

$T_{SOI} \sim d_{ave}$

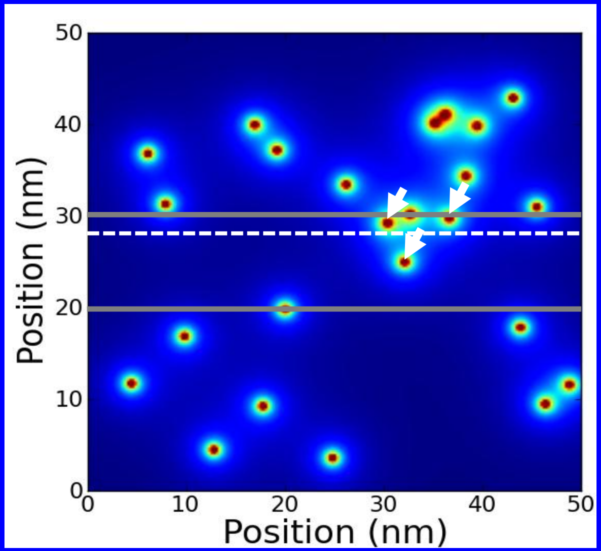


Number of Donor Ions is reduced in ETSOI.

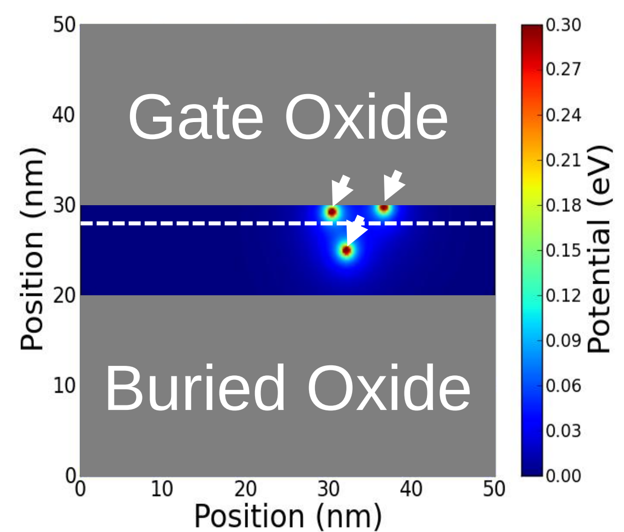
Coulomb Potential Simulation

$N_D^+ = 1\text{x}10^{18}\text{cm}^{-3}$ (d_{ave} = 10nm)

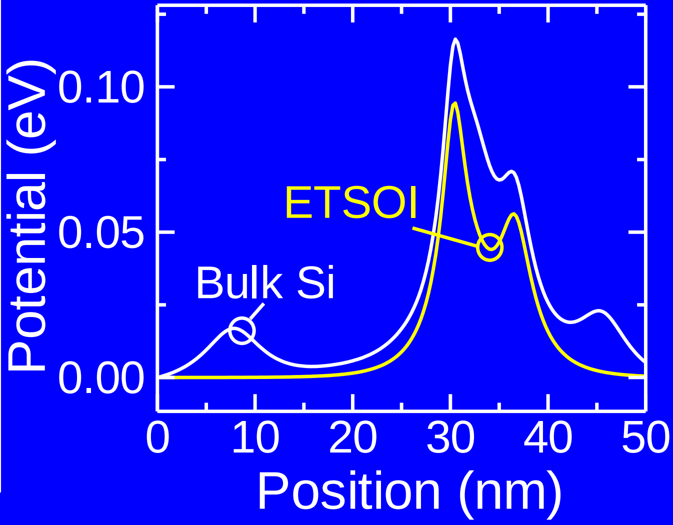
Bulk Si



ETSOI(T_{SOI} = 10nm)



Coulomb Potential along Broken Line



Potential fluctuation is smaller in ETSOI than that in bulk Si.

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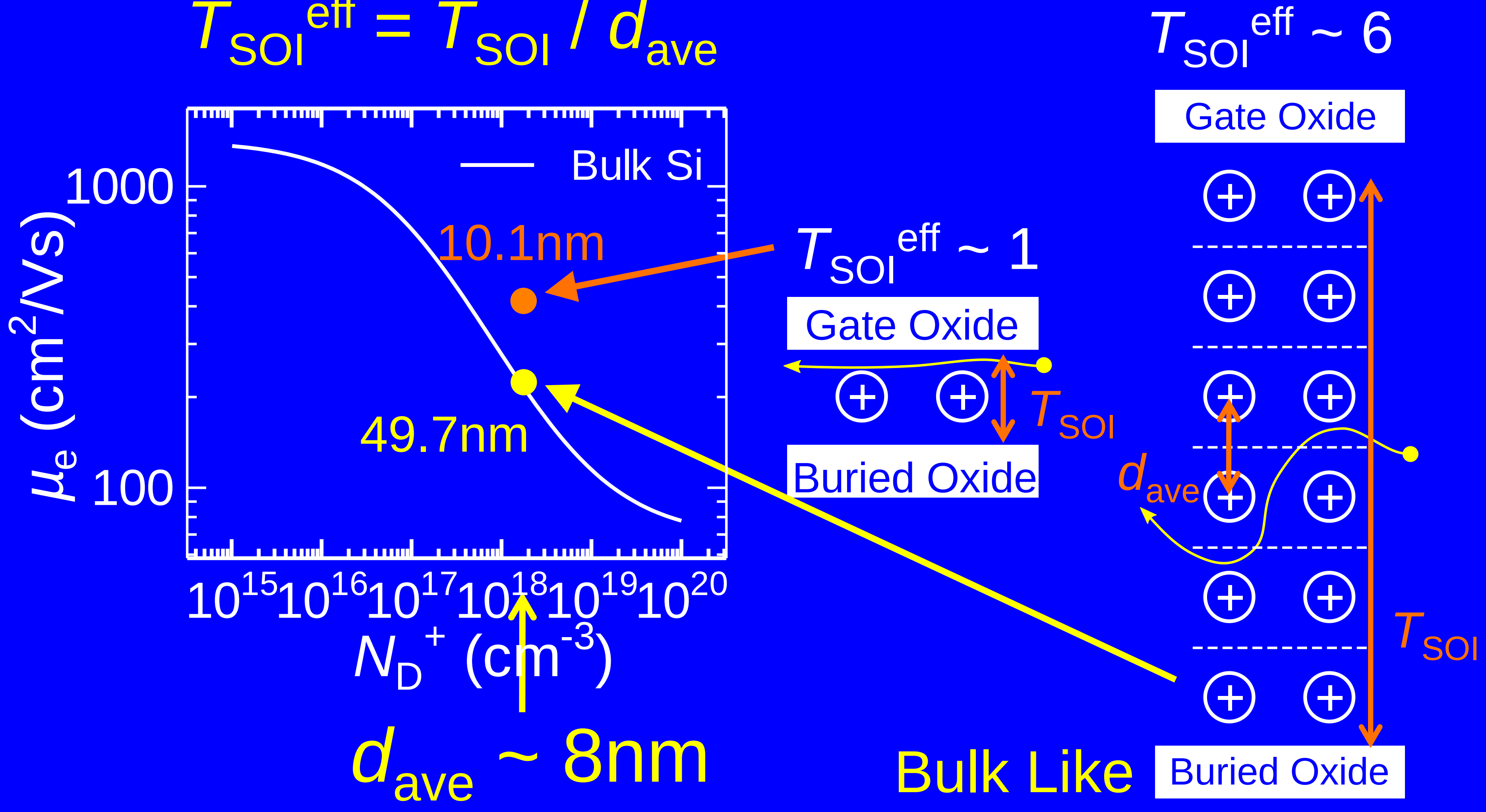
Effective T_{SOI}

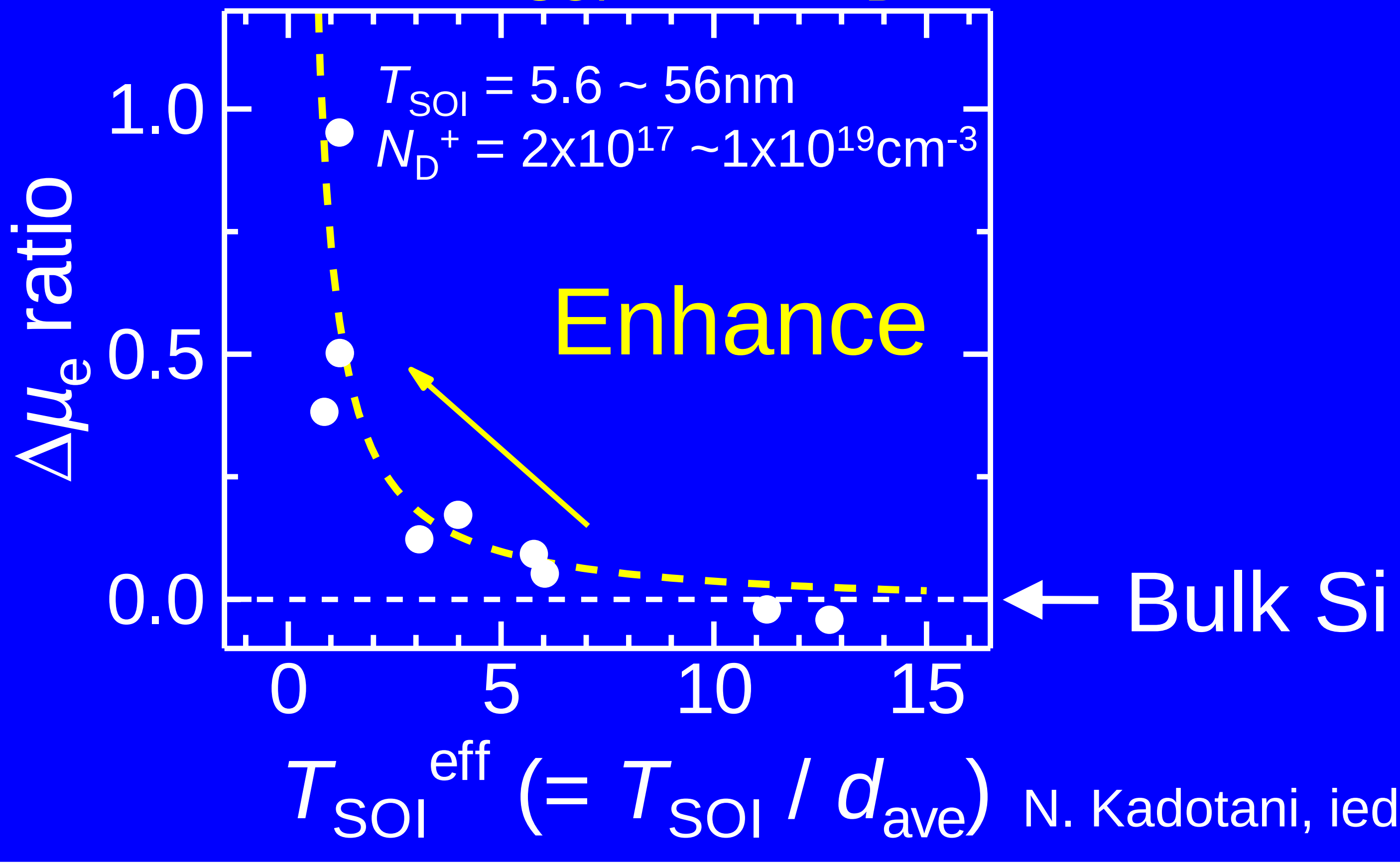
$T_{SOI}^{eff} = T_{SOI} / d_{ave}$



μ_e increases as T_{SOI}^{eff} decreases.

μ_e Enhancement Universality

Various T_{SOI}s and N_D^+s



N. Kadotani, iedm 2010.

μ_e enhancement ratio is universally described as a function of T_{SOI}^{eff}.

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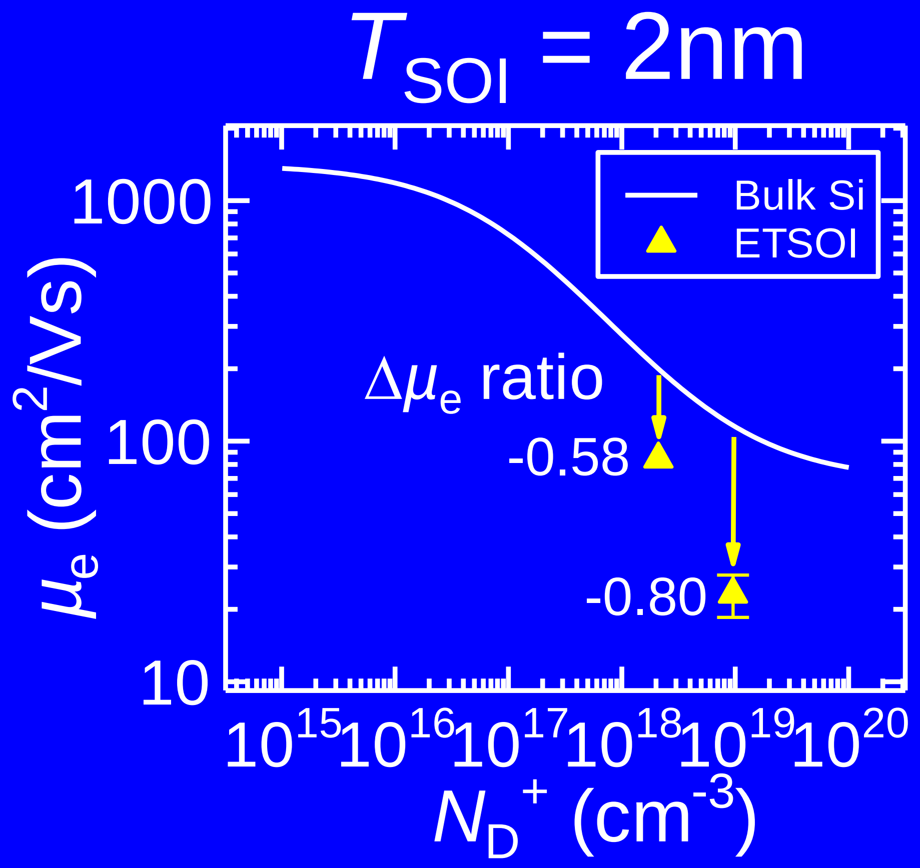
μ_e in ETSOI with T_{SOI} = 2nm



μ_e is degraded when T_{SOI} = 2nm

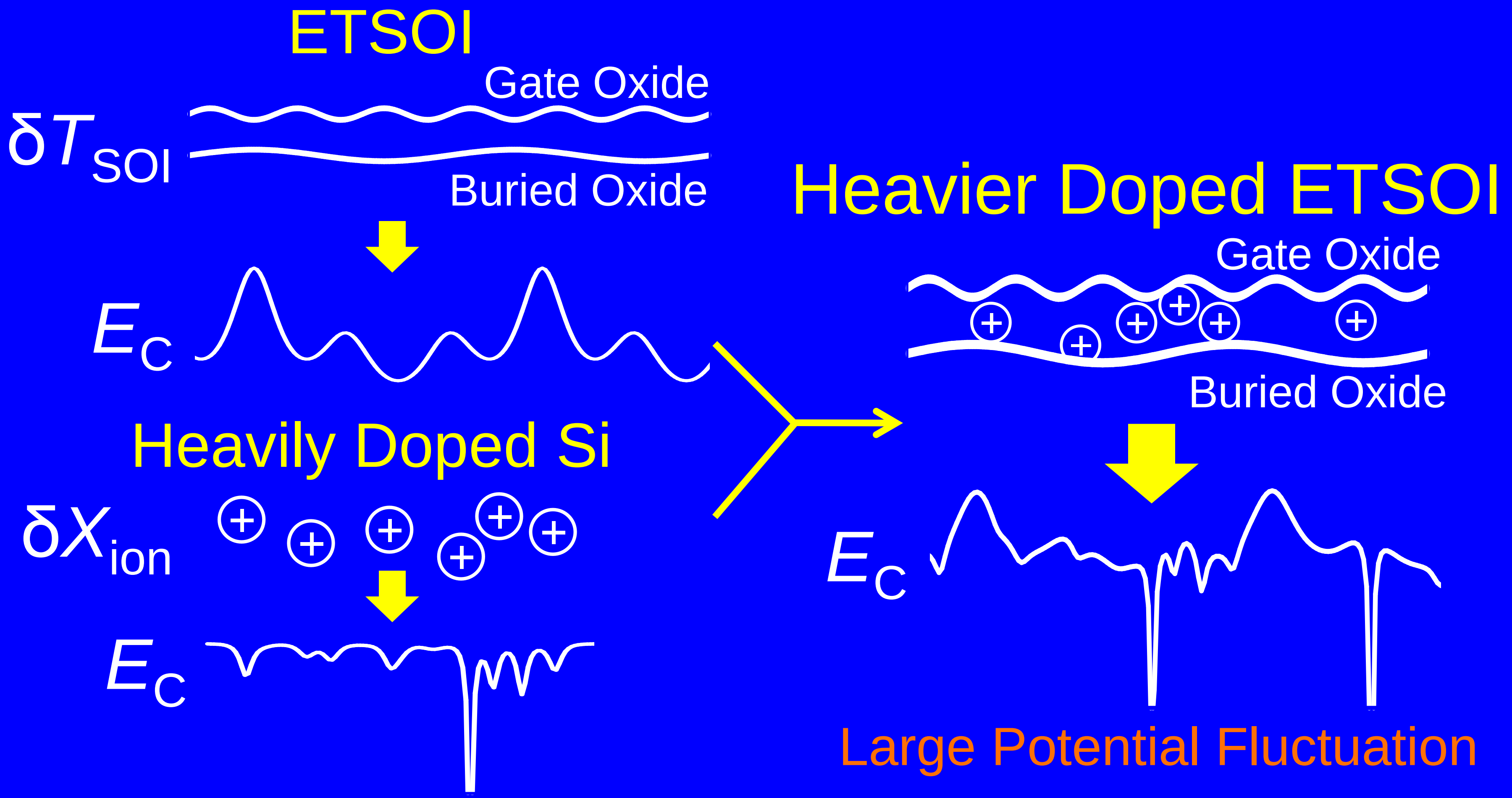
⬇

δT_{SOI} induced scattering

N. Kadotani, iedm 2010.

μ_e degradation is more drastic in heavier doped ETSOI.

Conduction Band Profiles



ETSOI

Gate Oxide

δT_{SOI}

Buried Oxide

E_{C}

Heavily Doped Si

δX_{ion}

E_{C}

Heavier Doped ETSOI

Gate Oxide

Buried Oxide

E_{C}

Large Potential Fluctuation

Combination of δT_{SOI} and δX_{ion} results in large potential fluctuation.

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Conclusion

- ✓ Heavily doped ETSOI DL is successfully fabricated.
- ✓ μ_e increases when $T_{\mathrm{SOI}}^{\mathrm{eff}}$ decreases due to reduced Coulomb scattering.
- ✓ μ_e decreases when T_{SOI}=2nm due to potential fluctuation induced by δT_{SOI} and δX_{ion}.
- ✓ In order to enhance μ_e in ETSOI DL, $T_{\mathrm{SOI}}^{\mathrm{eff}}$ should be less than 3 while T_{SOI} should be thicker than 4nm.