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Analysis of Strained-Si Device including Quantum Effect

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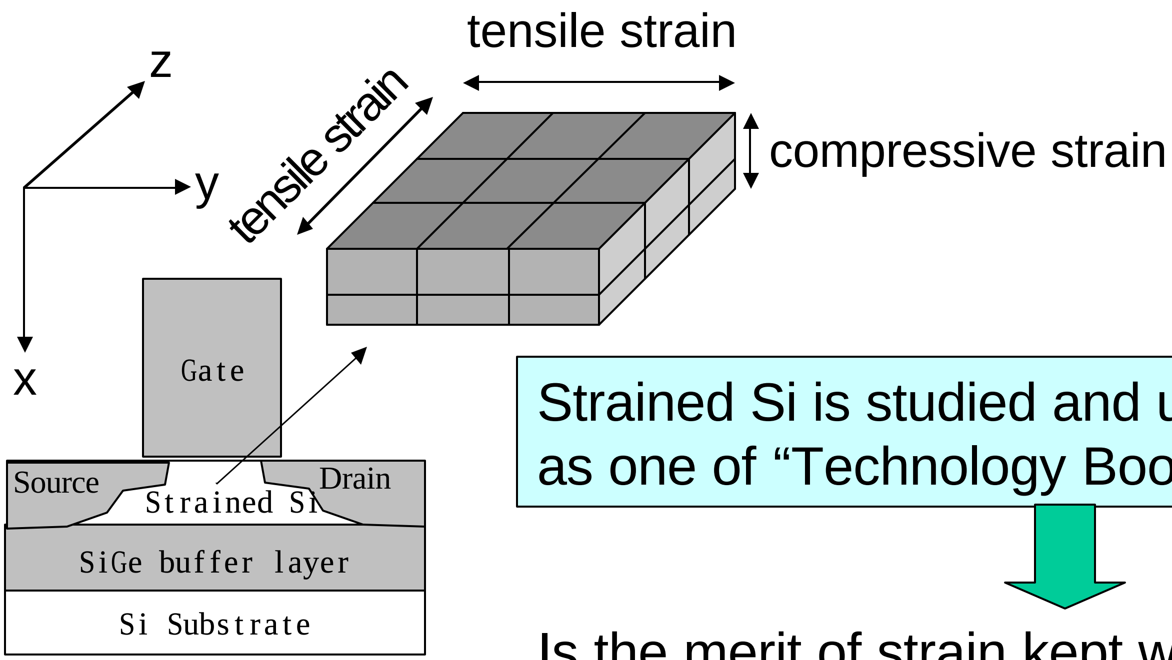
Background



Strained Si is studied and used aggressively as one of “Technology Booster”

Is the merit of strain kept with scaling ?

- Quantum Effect
- Ballistic Transport

The necessity of Strained-Si Monte Carlo simulation including quantum effect.

The Implementation of Strained Band

Full band Monte Carlo simulator :FALCON

The first principle band calculation program :PHASE

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Full band structure of Strained Si

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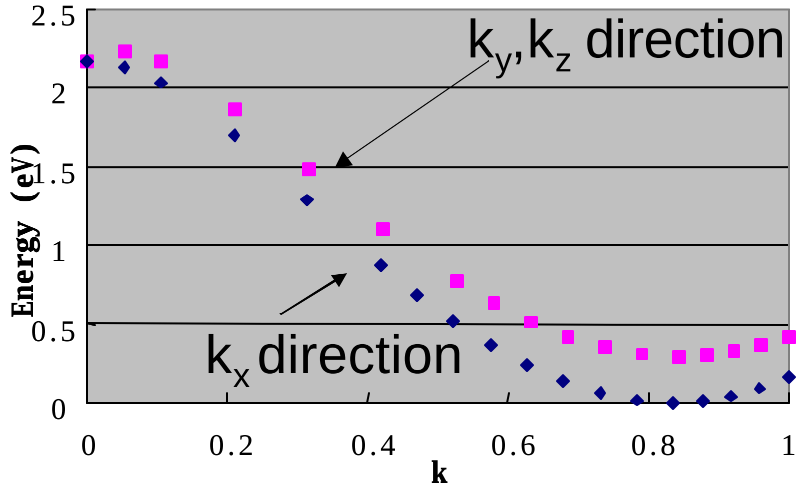
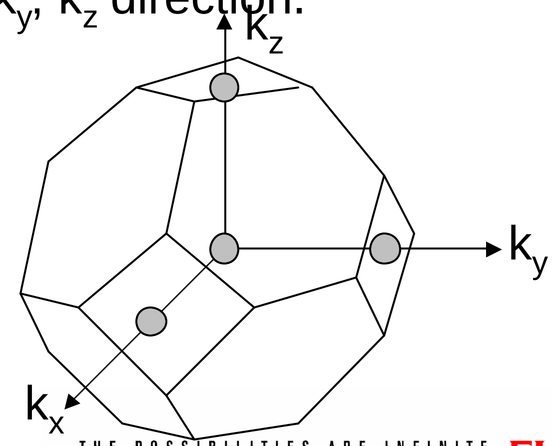
Monte Carlo Analysis

We linked the first principle band calculation program to the FUJITSU ensemble full band Monte Carlo simulator FALCON directly



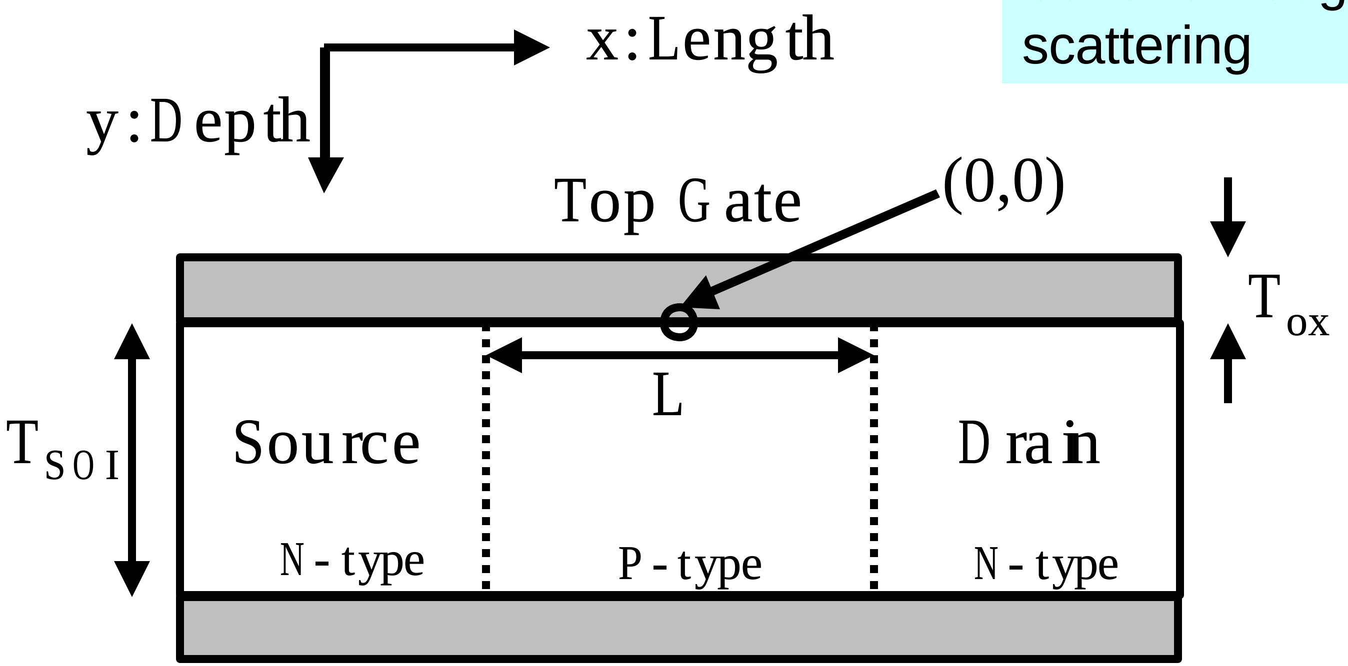
Band structure of conduction band near X point with 50% expansion of k_y, k_z direction.



Evaluated Structure

- We calculated below Lg=50nm.
- We used Double Gate structure.

Phonon, Impurity and Surface Roughness scattering

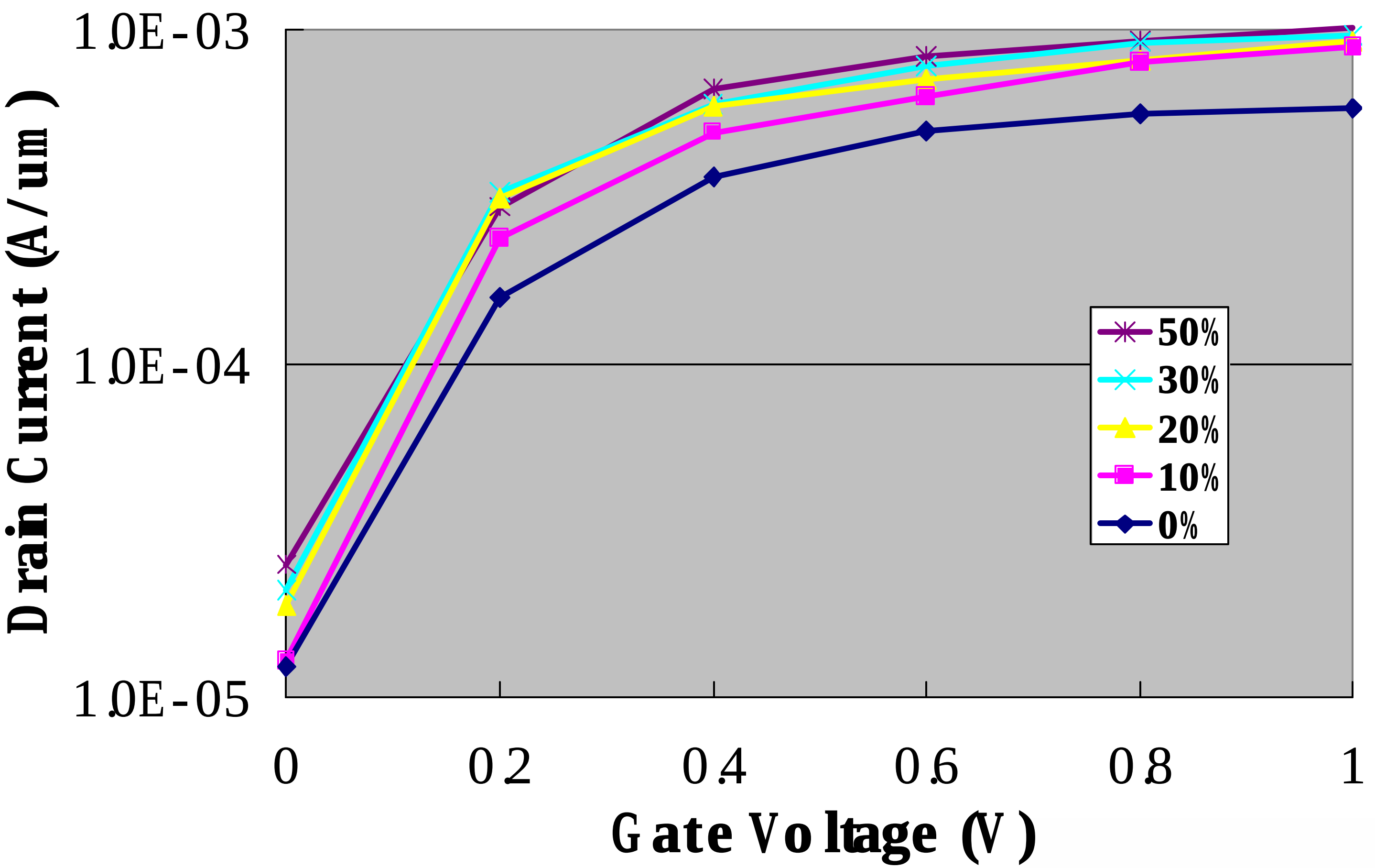


P - type : 1×10^{10} (/ cm ^{3})
N - type : 1×10^{20} (/ cm ^{3})

Lg=40nm
T_{soi}=10nm
T_{ox}=1nm

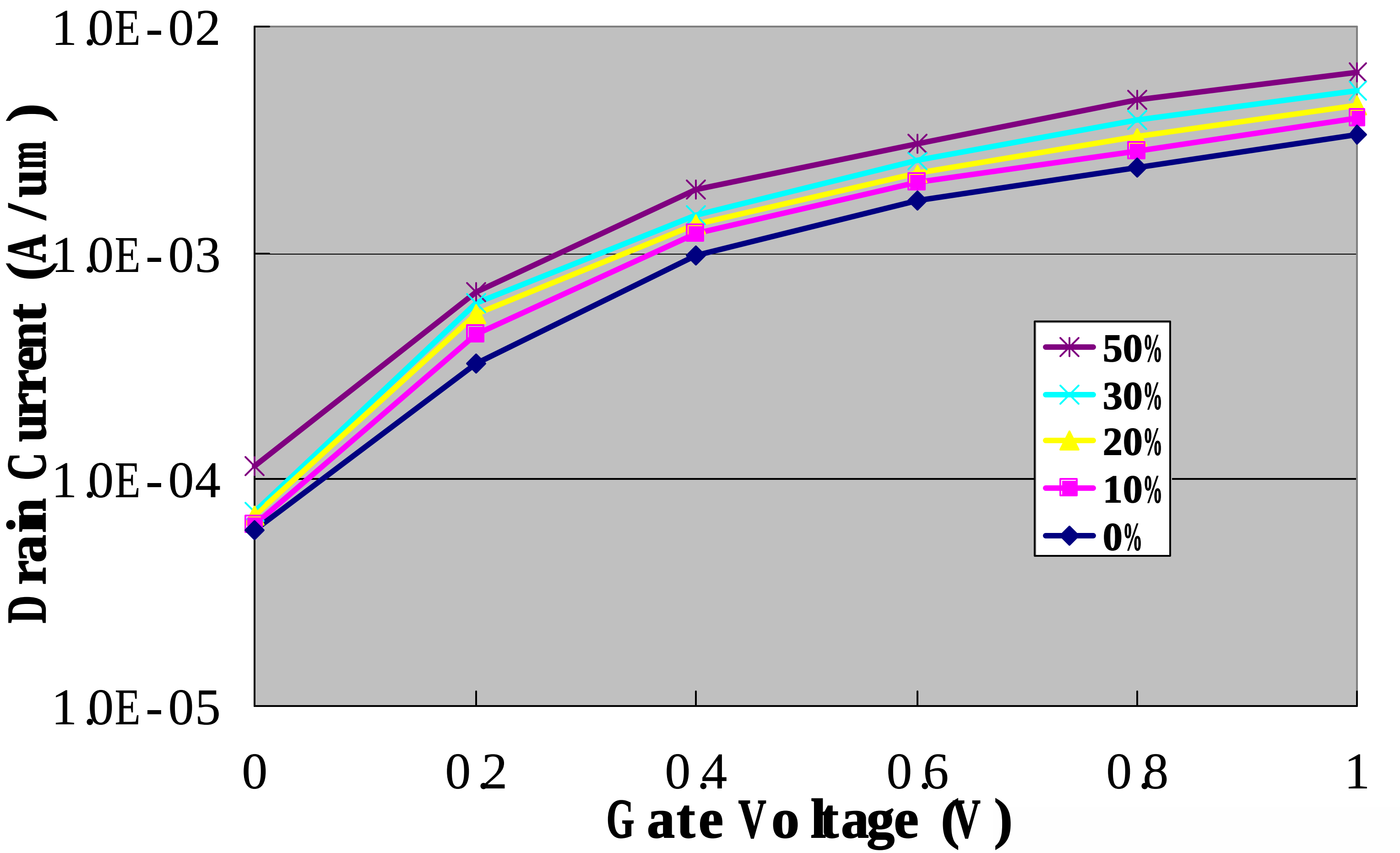
I_d-V_g@V_d=0.05V

- V_d=0.05V
- Drain current is saturated at Ge=20%

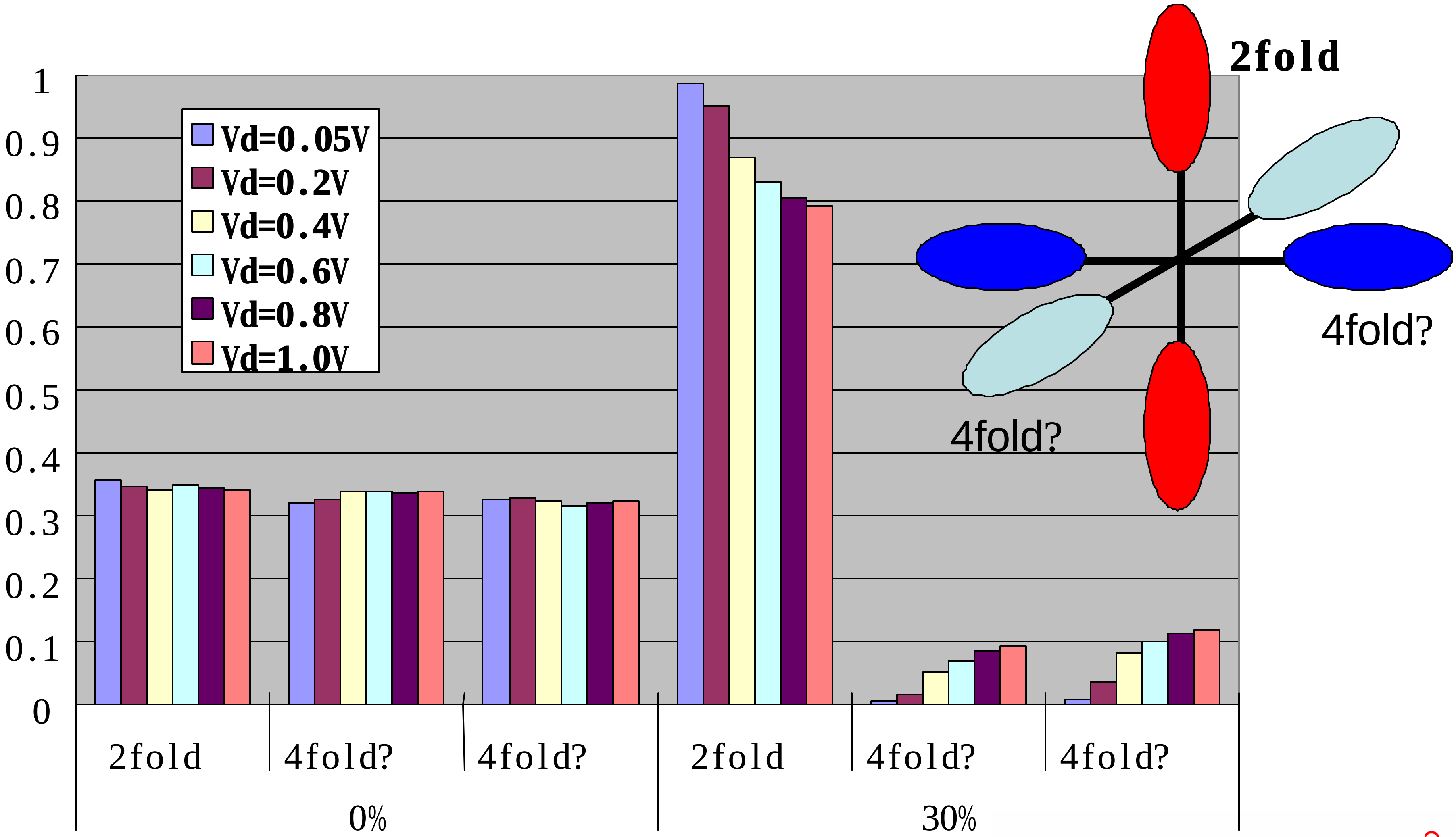


I_d-V_g@V_d=0.8V

- Vd=0.8V
- Drain current is not saturated.

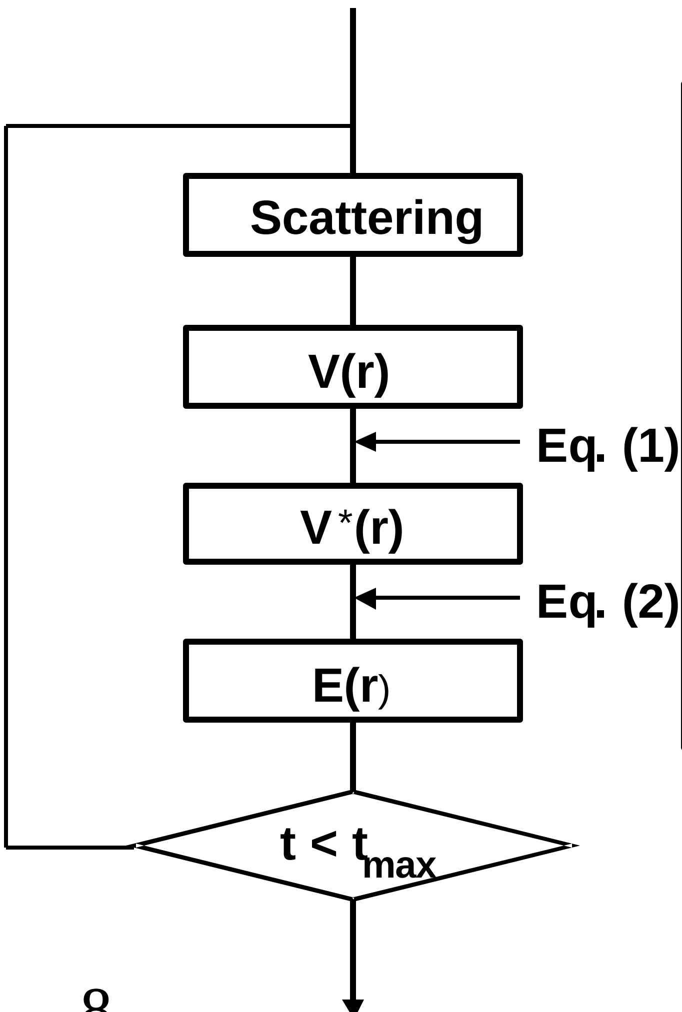


Valley Distribution



The Introduction of Quantum Effect

- We implemented quantum effect by Bohm Potential method



$$V^*(r) = V(r) - \frac{\hbar^2}{2m_{x,y}} \frac{\nabla^2 \sqrt{n}}{\sqrt{n}}$$

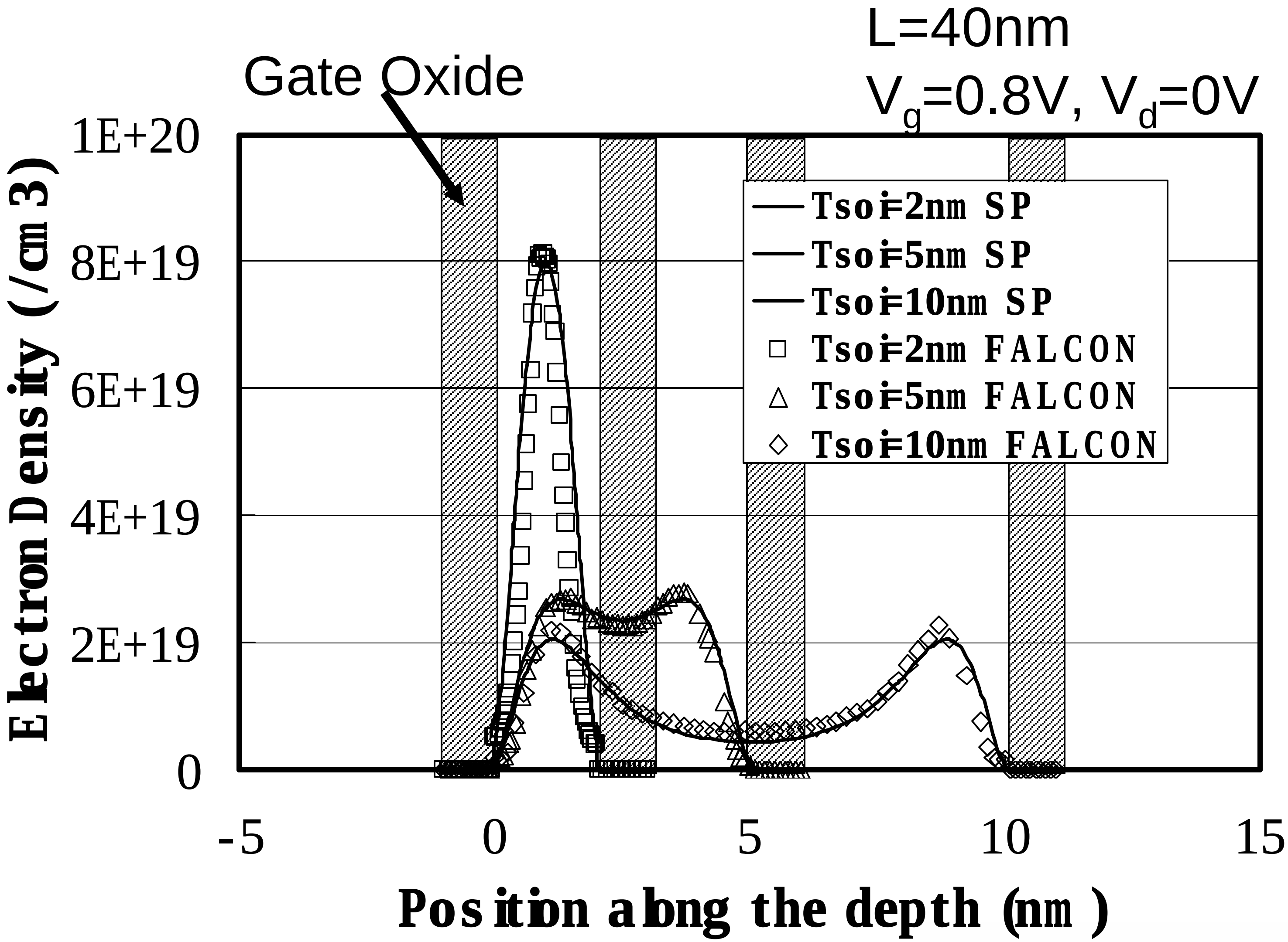
$$n(\vec{r}) \propto \exp\left(-\frac{V^*(\vec{r})}{k_B T} \right)$$

$$V^*(r) = V(r) + \frac{\hbar^2}{4m_{x,y} r k_B T} \left[\nabla^2 V^*(r) - \frac{1}{2} \frac{1}{k_B T} \left(\nabla V^*(r) \right)^2 \right] \quad \cdots \quad (1)$$

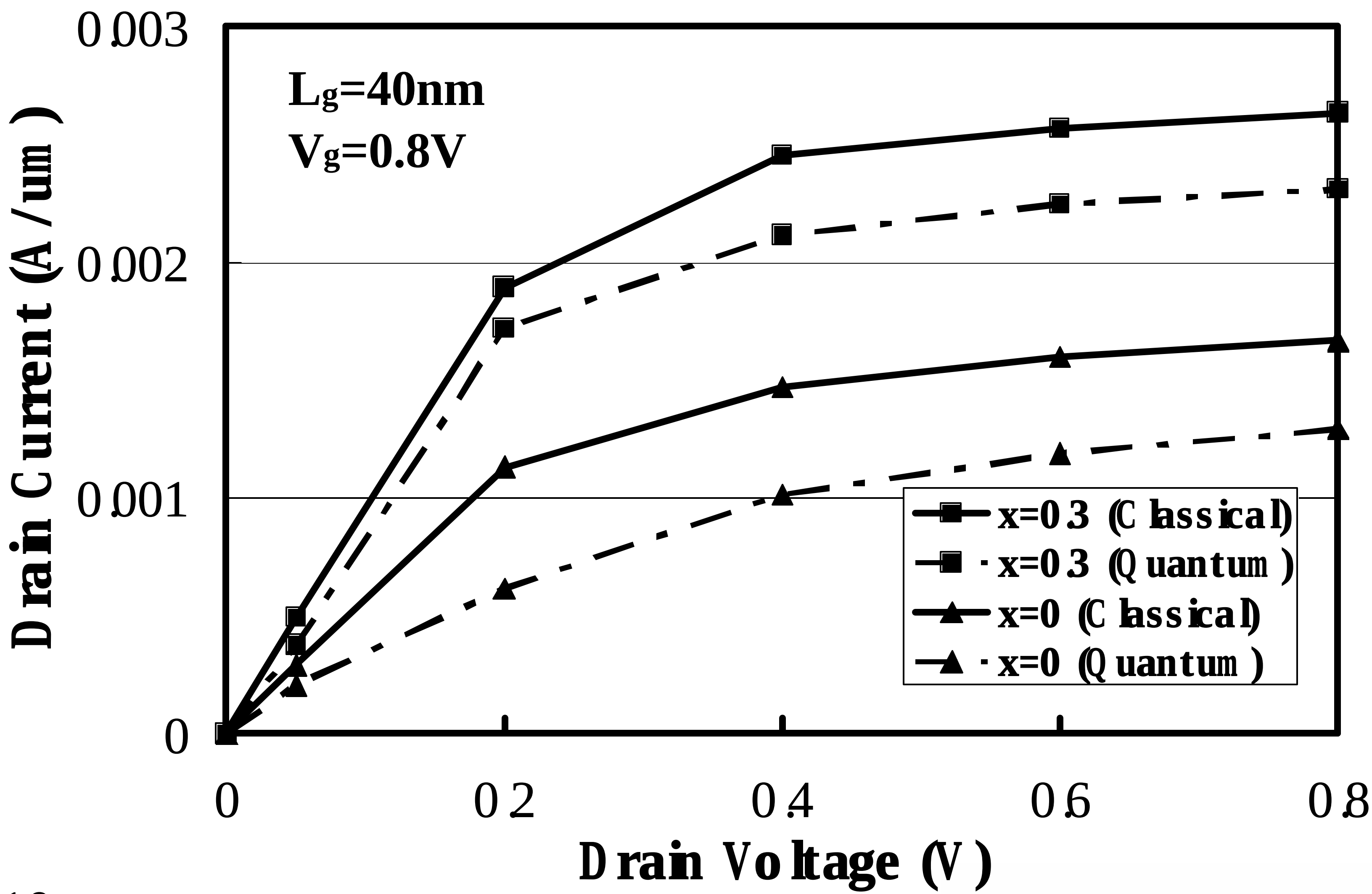
$$\frac{dk}{dt} = -\frac{1}{\hbar} \nabla_r V^*(r) \quad \cdots \quad (2)$$

V(r): Potential
V*(r): Quantum Corrected Potential
E(r): Electric Field

The Comparison with Schrödinger-Poisson



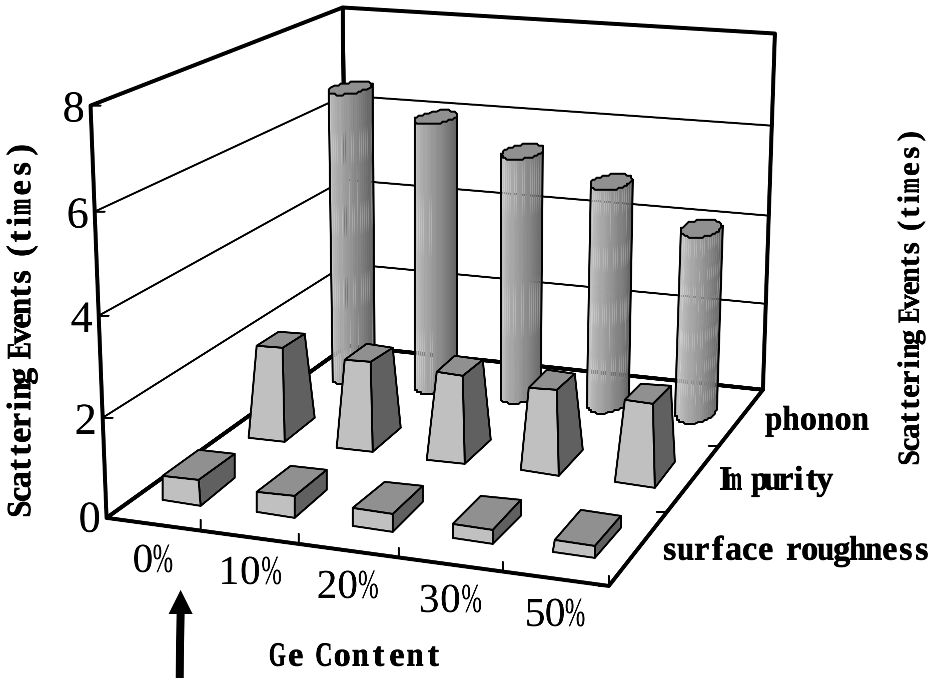
I_d-V_d@V_g=0.8V



Lg=40nm
Vg=0.8V
0.003
0.002
0.001
0
Drain Current (A/um)
0
0.2
0.4
0.6
0.8
Drain Voltage (V)
x=0.3 (Classical)
x=0.3 (Quantum)
x=0 (Classical)
x=0 (Quantum)

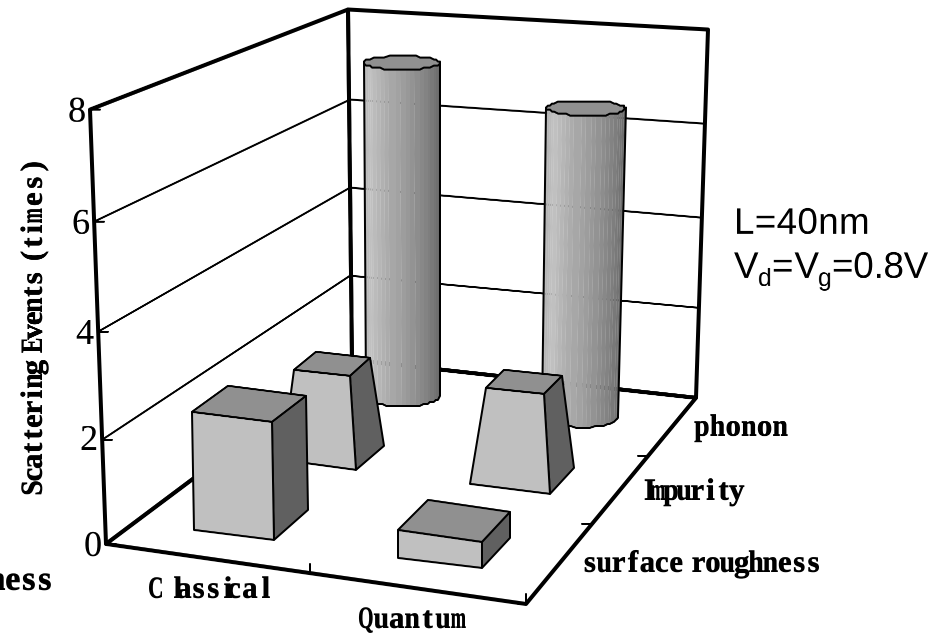
The Comparison of Scattering

Strain Effect

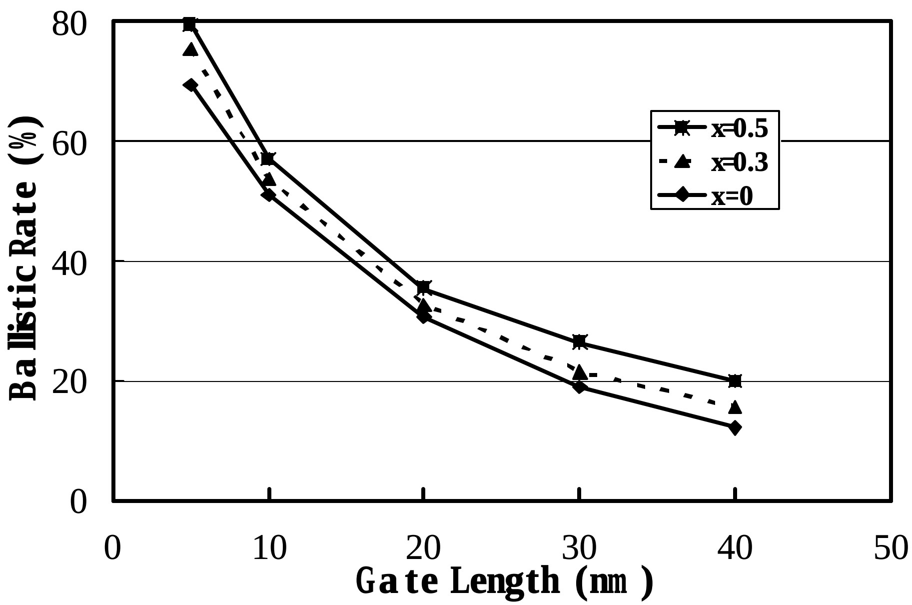


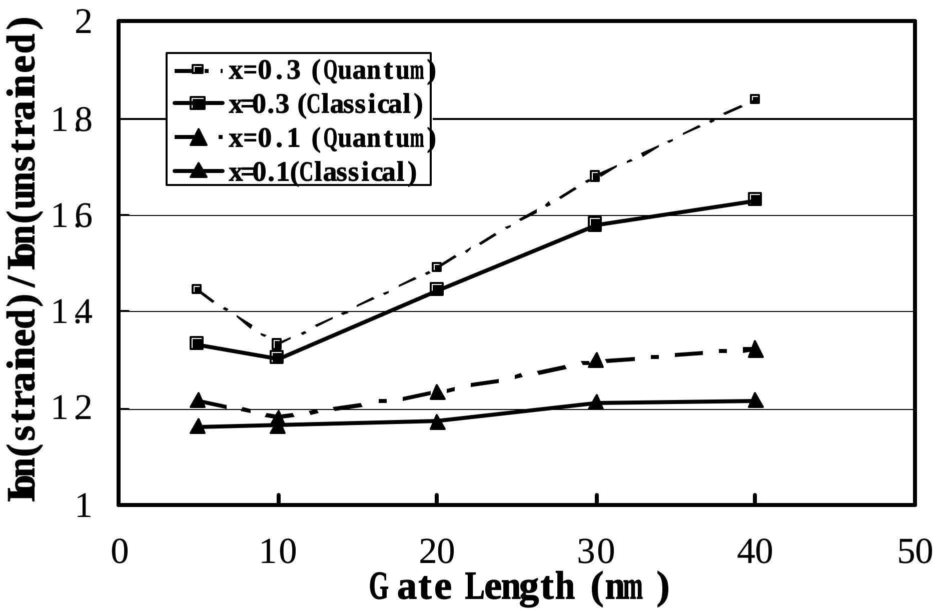
Including quantum effect

Quantum Effect



Ballistic Rate and I_{on} Improvement

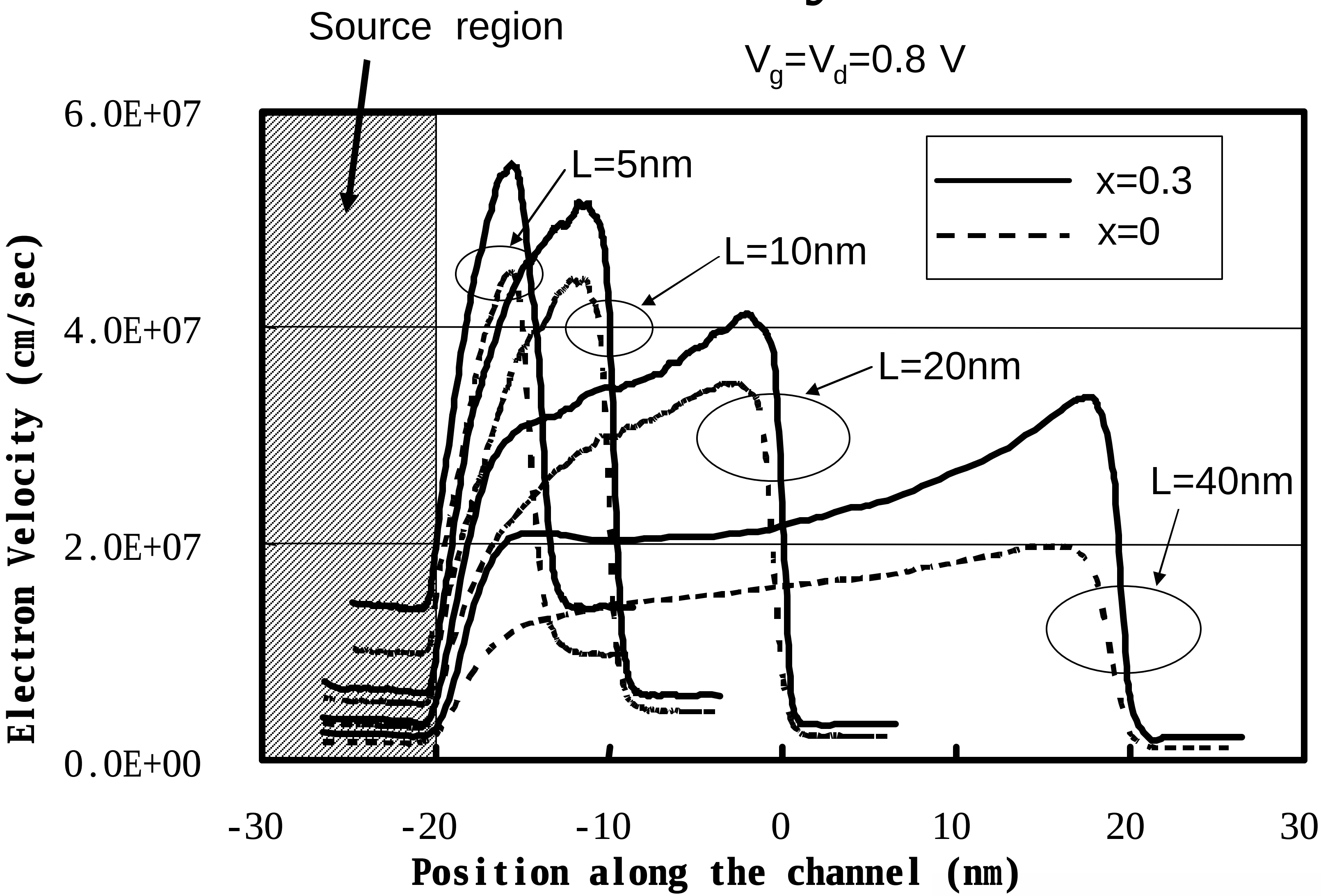




· Ballistic particles exceed 50% at L=10nm.

· Both ballistic rate and I_{on} improvement with quantum effect are larger than with classical.

The Comparison of Electron Velocity



Summary

•We linked the first principle band calculation program to full-band MC simulator directly.

•We implemented Bohm Potential Quantum correction model and analyzed Strained-Si device including quantum effect.

•As gate length is scaled down, I_{on} improvement by strain effect will decrease, but In the regime that ballistic transport is dominant (about below 10nm), strain effect will increase again due to increasing injection velocity from source region.