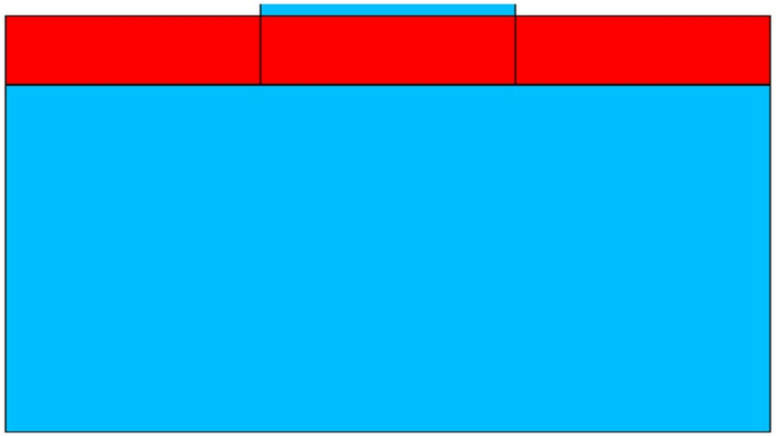


Technology of Next Level
driven through innovation

Monte Carlo Particle Device Simulator

DEVICE MODELING

Approximate ↑ … ↓ *Exact*　　　　*Easy, fast* ↑ … ↓ *Difficult*

	Model	Improvements
Semi-classical approaches	Compact models	Appropriate for Circuit Design
Semi-classical approaches	Drift-Diffusion equations	Good for devices down to 0.5 μm, Include $\mu(E)$
Semi-classical approaches	Hydrodynamic Equations	Velocity overshoot effect can be treated properly
Semi-classical approaches	Boltzmann Transport Equation Monte Carlo/CA methods	Accurate up to the classical limits
Quantum approaches	Quantum Hydrodynamics	Keep all classical hydrodynamic features + quantum corrections
Quantum approaches	Quantum Monte Carlo/CA methods	Keep all classical features + quantum corrections
Quantum approaches	Quantum-Kinetic Equation (Liouville, Wigner-Boltzmann)	Accurate up to single particle description
Quantum approaches	Green's Functions method	Includes correlations in both space and time domain
Quantum approaches	Direct solution of the *n*-body Schrödinger equation	Can be solved only for small number of particles

TNL

PARTICLE DEVICE SIMULATOR

- Particle device simulator takes into account the transport of Monte Carlo particles (Super particles).
- Under influence of applied field, determined self-consistently through the solution of decoupled Poisson's and BTE equation over a suitably small time-step.
- The time step is taken typically less than the inverse plasma frequency obtained with the highest carrier density in the device.

PARTICLE DEVICE SIMULATOR

Technologies implemented in Monte Carlo Particle Device Simulator:

- **MOSFET**
- **FDSOI**
- **Tunneling FET**
- **MESFET**
- **HEMT**

PARTICLE DEVICE SIMULATOR

- Poisson’s solution generated over the node points of the mesh,
- Carrier transport solution is obtained using Ensemble Monte Carlo (EMC) on the full range of space coordinates in accordance with the particle distribution itself.
- Particle-mesh (PM) coupling scheme is used for assignment of carrier charge on different nodes and for calculation force on each charges.

SOLUTION

- The classification of Particle-mesh (PM) coupling scheme is included as;
  - Carrier charge assign at mesh nodes Charge in Cloud (CIC) scheme,
  - Solution of Poisson's equation on node points through Successive over Relaxation (SOR) method,
  - Calculation of the mesh defined electric field components,
  - Interpolation of forces at the particle positions.

BOUNDARY CONDITIONS

- Particle Device Simulator (PDS) contains consistent boundary conditions with those imposed on the potential on the field.
- The particle boundary conditions contain Neumann (zero electric field in the direction normal to the surface) and Dirichlet (contacts) conditions.
- At Neumann boundary the reflecting boundaries has been taken.

QUANTUM CONFINEMENT EFFECT

- Density-gradient model: implemented dependent on non-local quantities.
- Density gradient model is first-order quantum-correction model describe carrier confinement by locally modifying the electrostatic potential through a correction potential γ.
- The Boltzmann-Wigner transport equation can be derived as

$$\frac{\partial f}{\partial t} + v.\nabla_r f - \frac{q}{\hbar}\sum_{\alpha=0}^{\infty}\frac{(-1)^{2\alpha}}{4^{\alpha}(2n+1)!}\nabla_k^{2n+1}V(r).\nabla_k^{2n+1}f = \left(\frac{\partial f}{\partial t}\right)_{coll}$$

QUANTUM CONFINEMENT EFFECT

- The corrected quantum effect is included as

$$\frac{\partial f}{\partial t} + \frac{\hbar . k}{m^*} \nabla_{\mathrm{r}} \mathrm{f} - \frac{1}{\hbar} \nabla_{\mathrm{r}} \left(V(\boldsymbol{r}) - \nabla_{\mathrm{r}}^{2} \emptyset \right) \nabla_{\mathbf{k}} f = \left(\frac{\partial f}{\partial t} \right)_{coll}$$

The correction potential term in multidimensional space is

$$\gamma(r,t) = \frac{\hbar^2}{12\lambda k_b T m^*} \left(\nabla_{\mathrm{r}}^{2} \emptyset(\mathrm{r,t}) - \frac{1}{2k_b T} \left(\nabla_{\mathrm{r}} \emptyset(\mathrm{r,t}) \right)^2 \right)$$

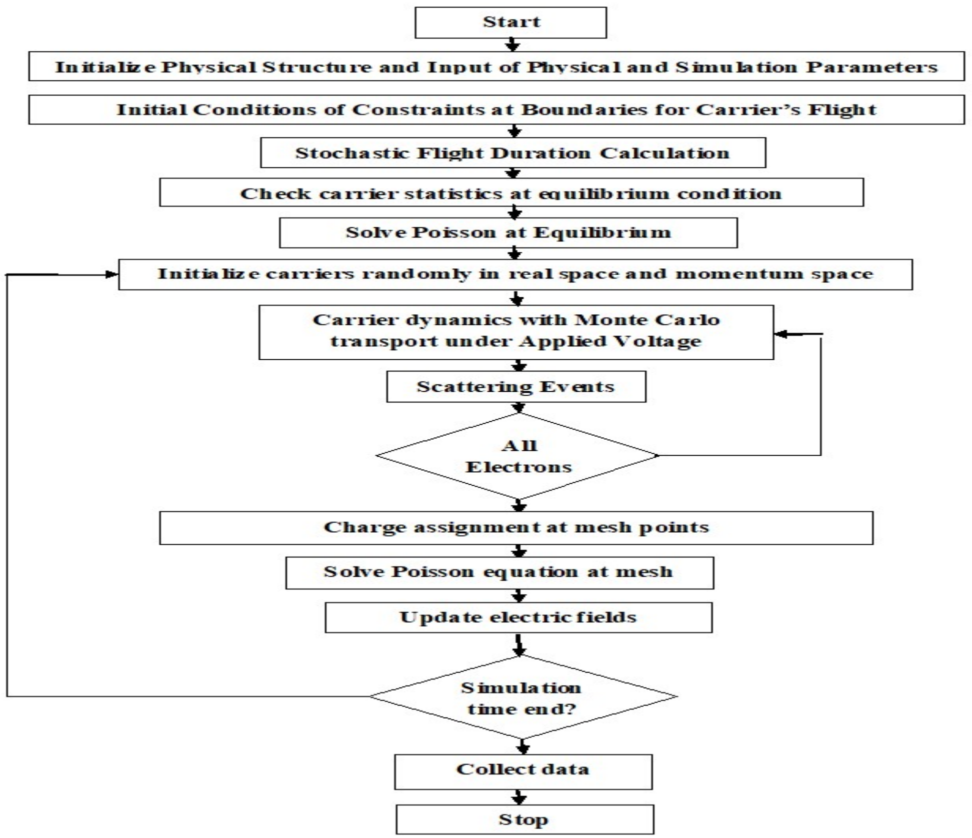
The fitting parameter λ is determined by comparing the carrier density in a device structure to the carrier density obtained by the solution of Poisson Equation.

PARTICLE MESH COUPLING

- The particle-mesh method is a widespread model for space charge calculations.
- Particle dynamics under applied electric field requires accurate solution of Poisson’s equation.
- The particle simulation means the assignation of the particle’s charge to the rectangular mesh.
- Two types of the most famous schemes:
  - Nearest Grid Point (NGP)
  - Cloud In Cell (CIC)

FLOW CHART

Flow Chart for program implementation



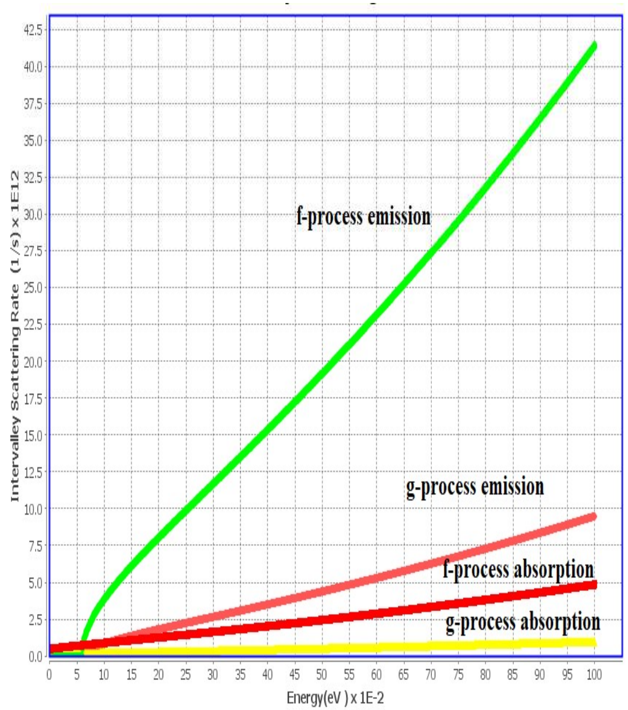
FLOW CHART

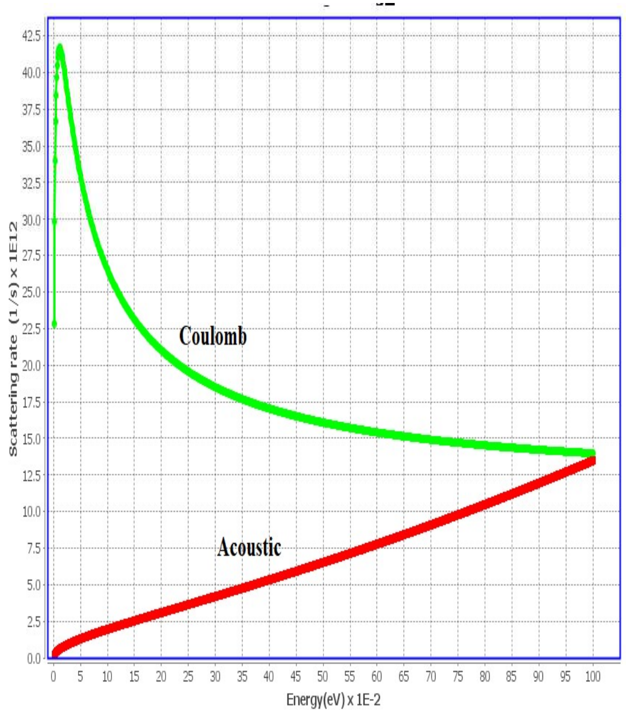
	Nodes (nm)	14nm	10nm	7nm	14nm	10nm	7nm
Structure Parameters		Single Gate			Double Gate		
	L_{eff} (nm)	22	14	10	22	14	10
	W_{eff} (nm)	10		8	10		8
	T_{ox} (nm)	1	0.85	0.75	0.75	0.85	0.75
	Doping ($/cm^3$)	1×10^{24}	5×10^{24}	2×10^{25}	2×10^{25}	5×10^{24}	2×10^{25}
	T_{SOI} (nm)	40	30	20	20	30	20
Device Parameters	Vth (mV)	0.3	0.22	0.2	0.2	0.4	0.5
	SS (/mV/dec)	63.3	67.9	82.9	82.9	87.4	72.2
	gm (mS/µm)	0.252	0.437	0.499	0.499	0.494	0.449

FDSOI TECHNOLOGY UP TO 7NM

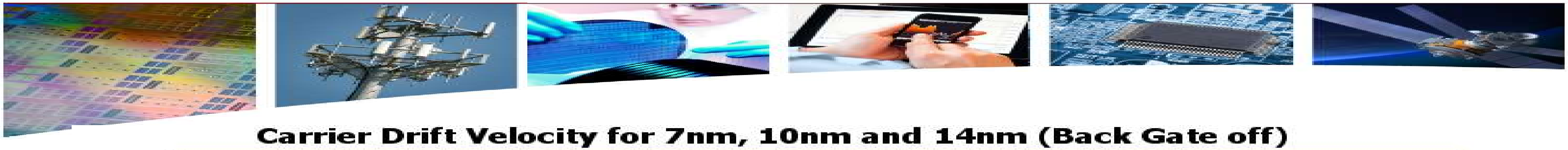
Scattering Rates

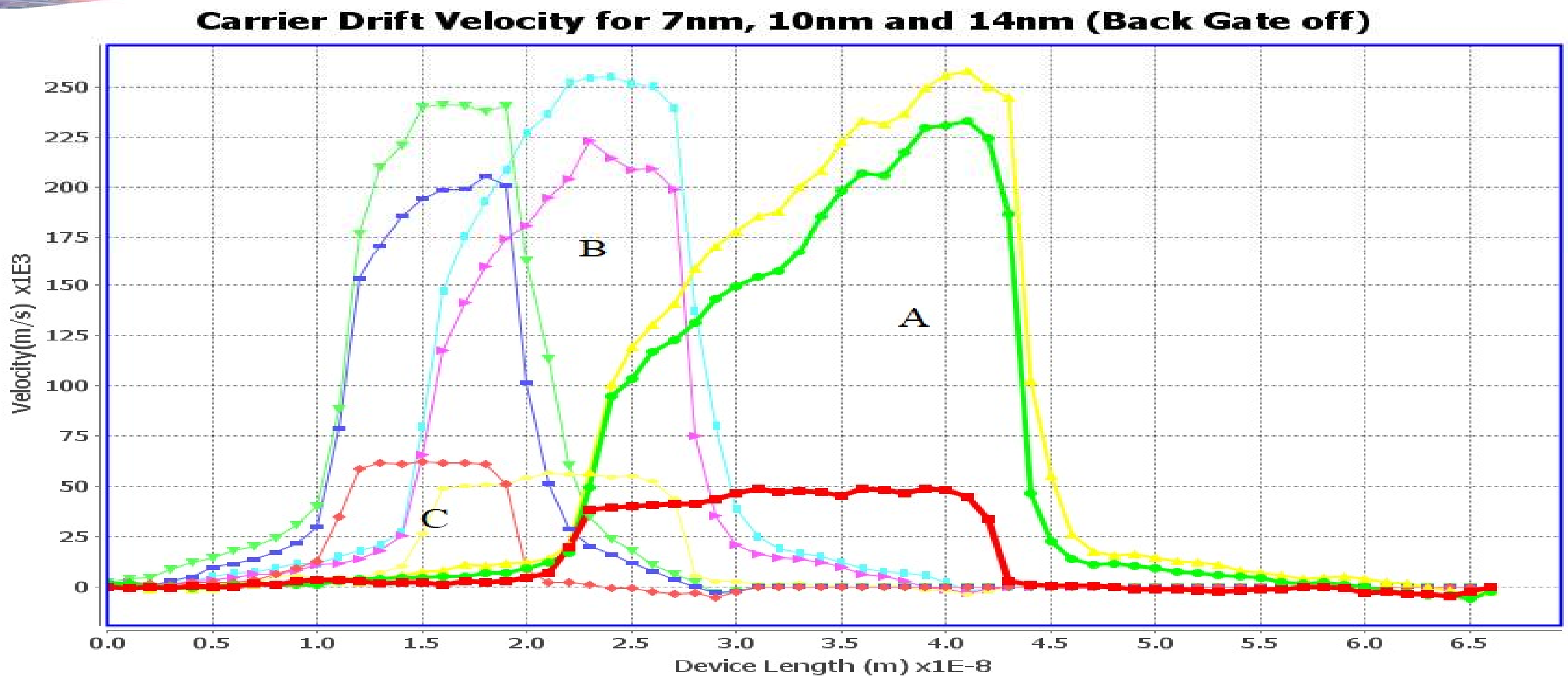
- Intervalley,
- Acoustic and
- Coulomb





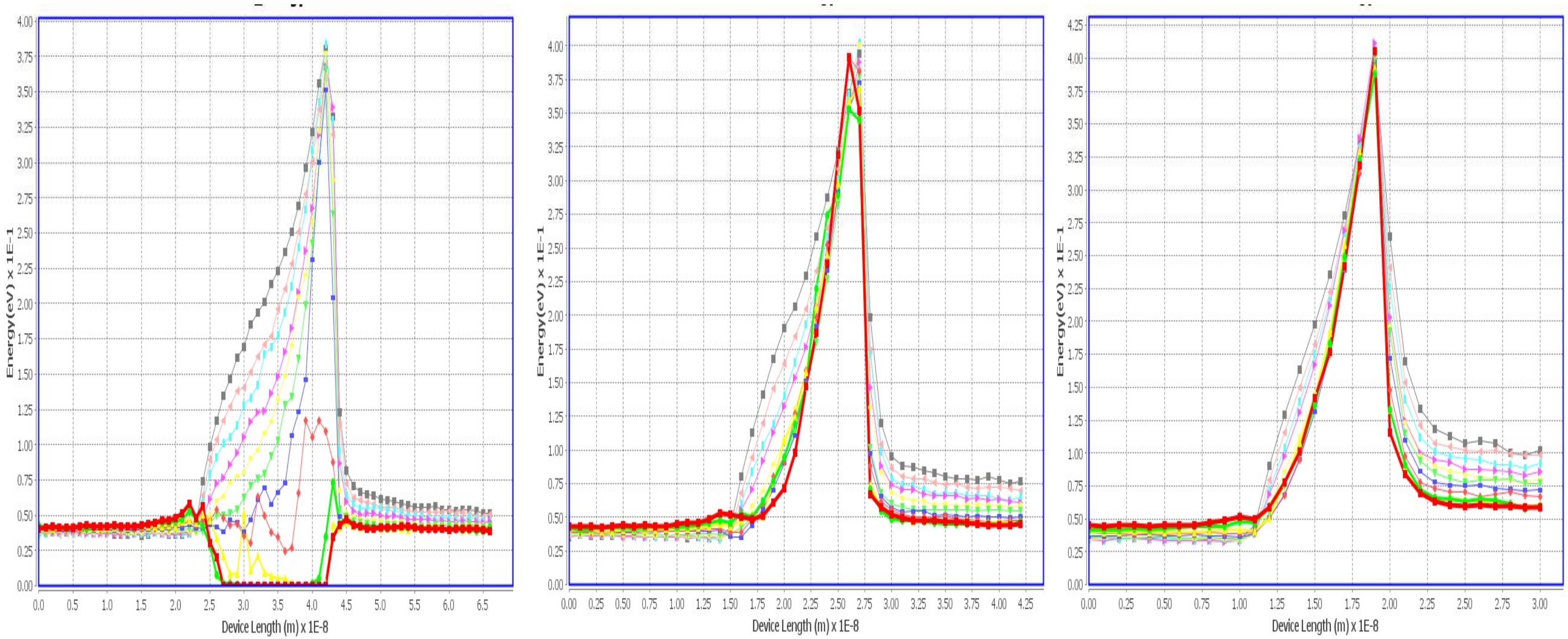
DRIFT VELOCITY





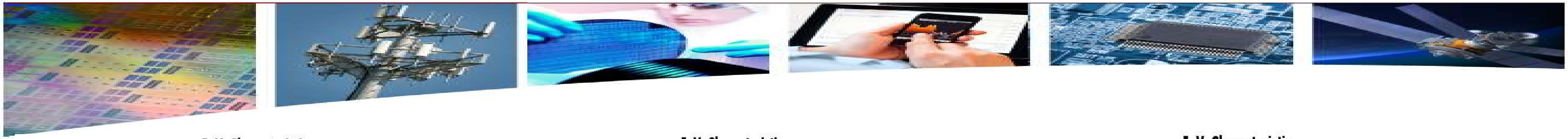
Carrier Drift velocity a) 14nm b) 10nm c) 7nm

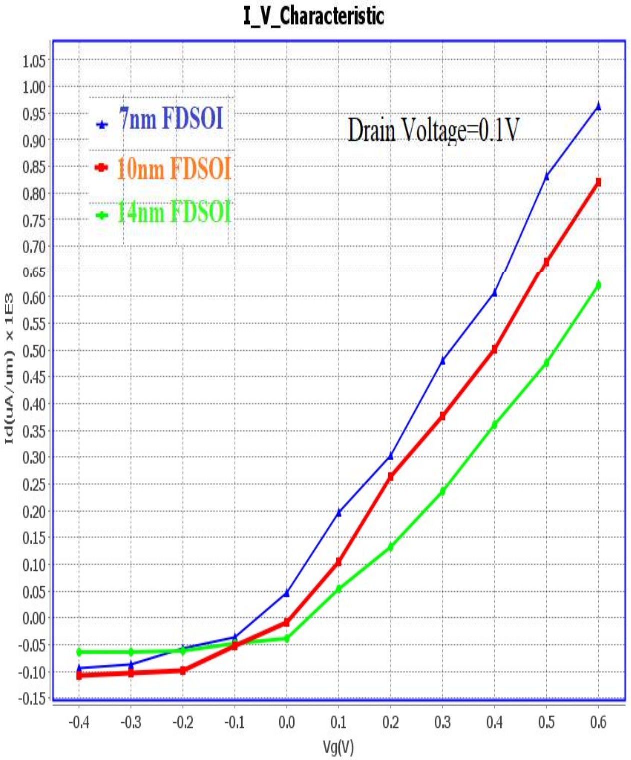
CARRIER AVERAGE ENERGY

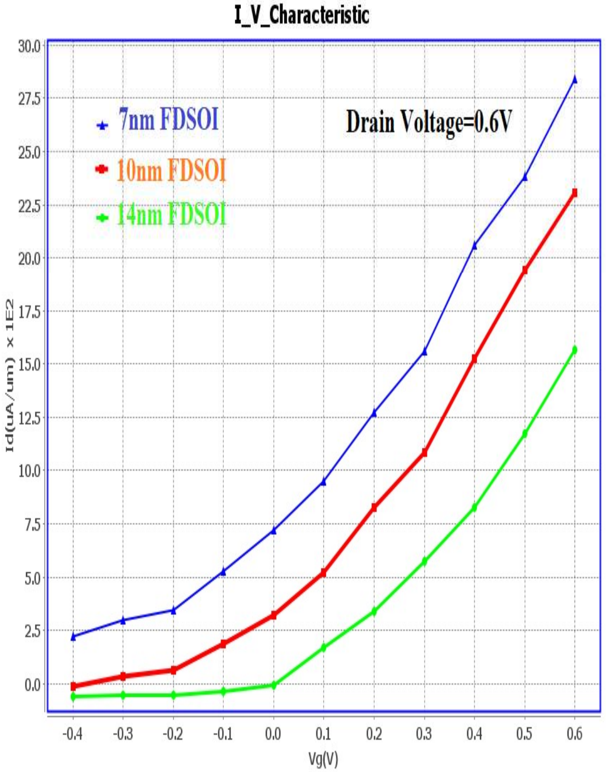


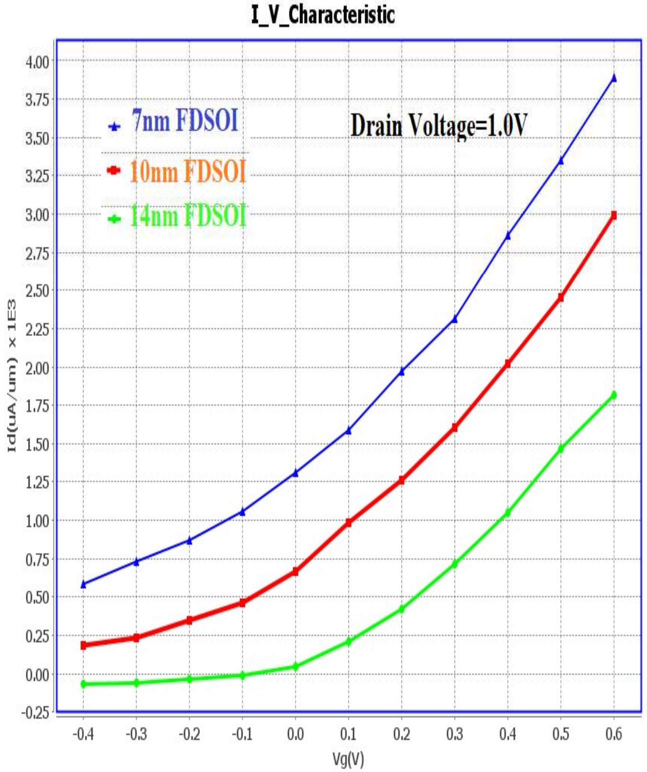
a) 14nm FDSOI MOSFET b) 10nm FDSOI MOSFET c) 7nm FDSOI MOSFET

Transfer I_d - V_g Characteristics

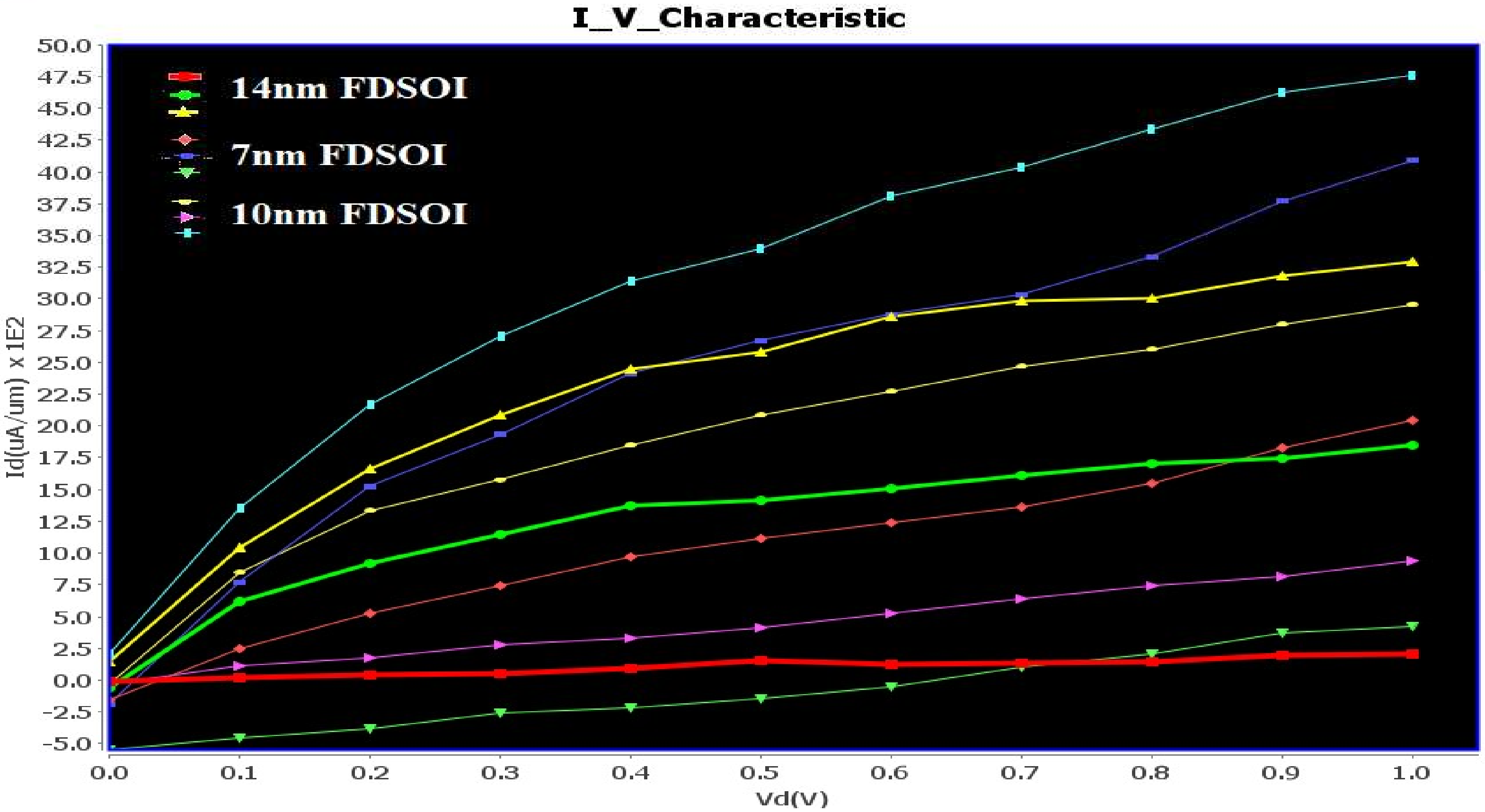




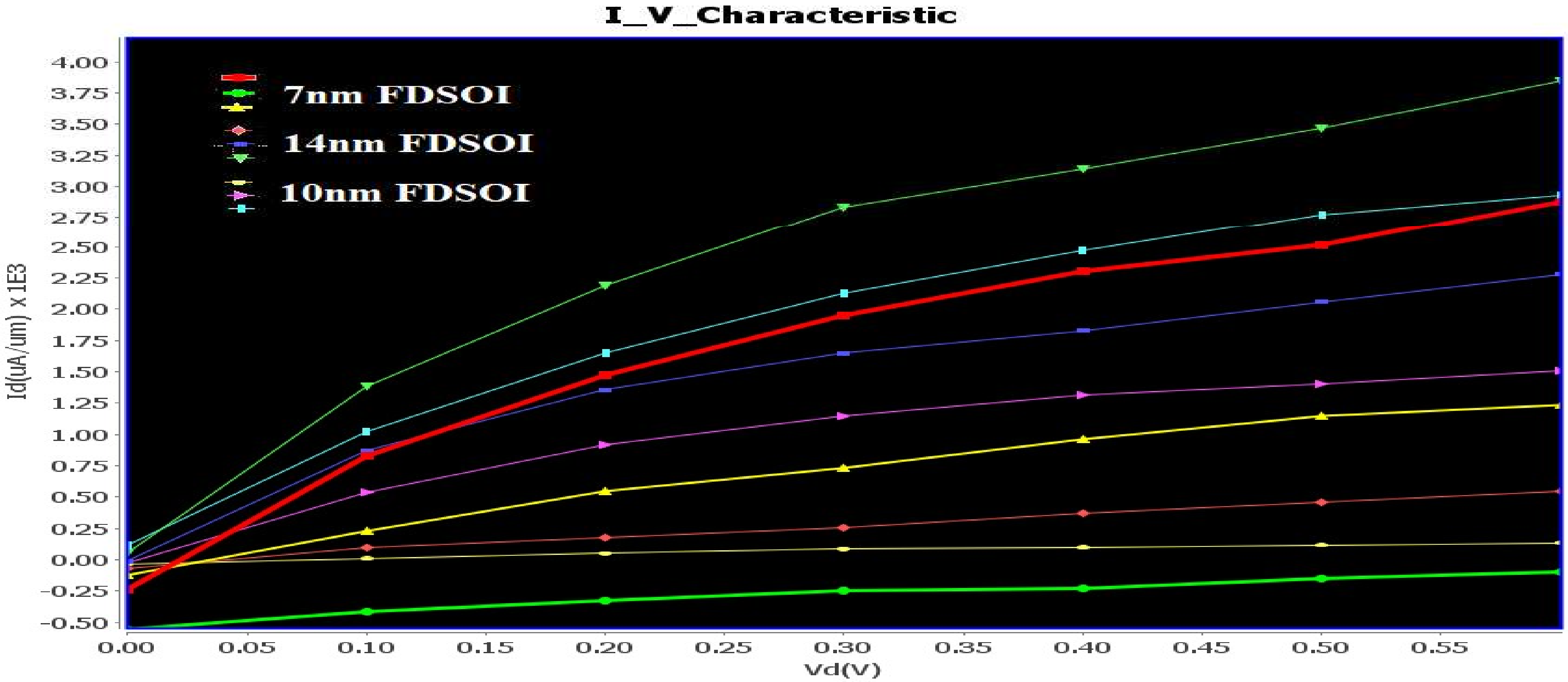




Single Gate I_d - V_d Characteristics



Dual Gate I_d - V_d Characteristics



Thank You

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