“Numerical Modeling of Novel Electron Materials and Devices”

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Fermi Lab Seminar

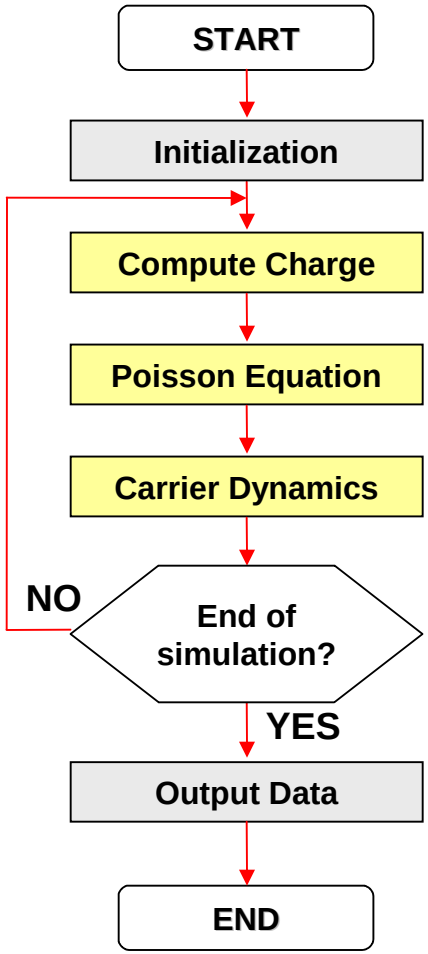
March 21st 2006

Outline

- Introduction
- Full-band particle-based simulations
- Isotropic model of impact ionization
- Germanium-On-Insulator technology
- Conclusion

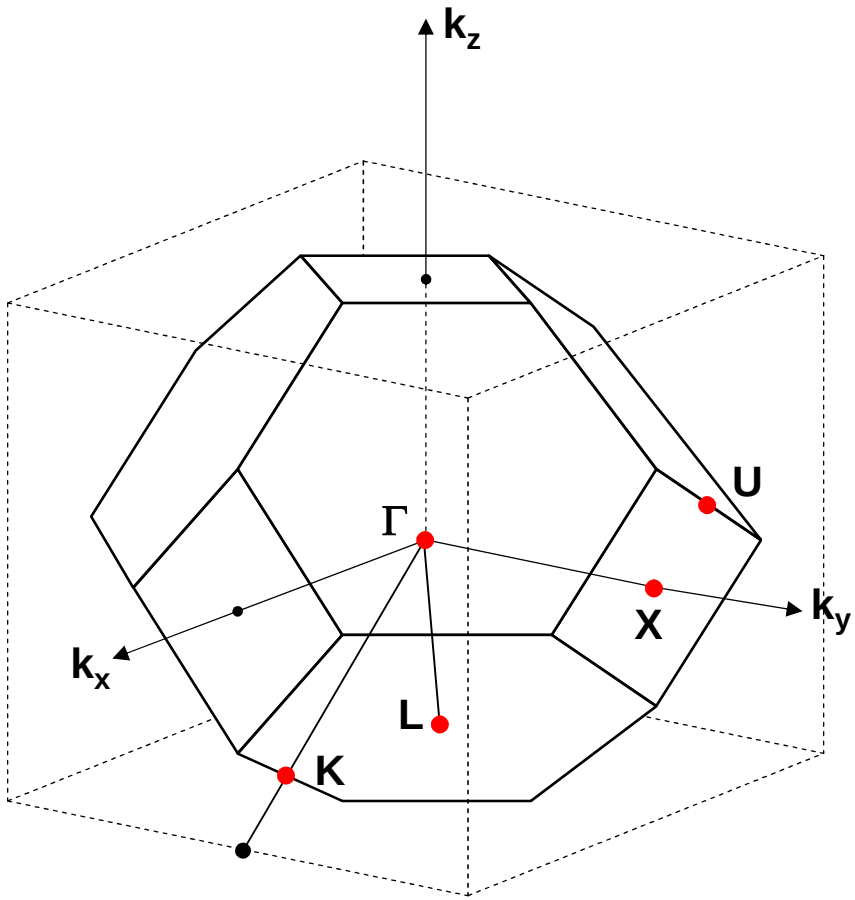
Full-Band Particle-based Simulations

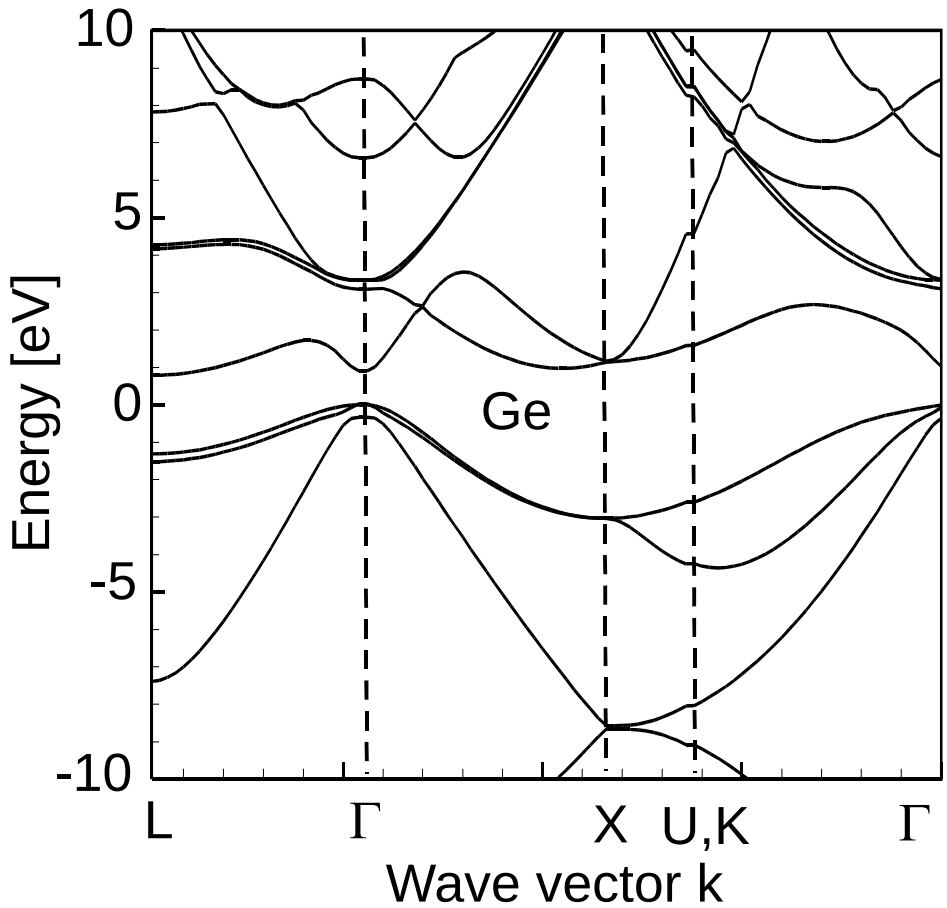
- Typical flowchart of a self-consistent particle-based simulator



Full-Band Particle-based Simulations

- Full-band representation





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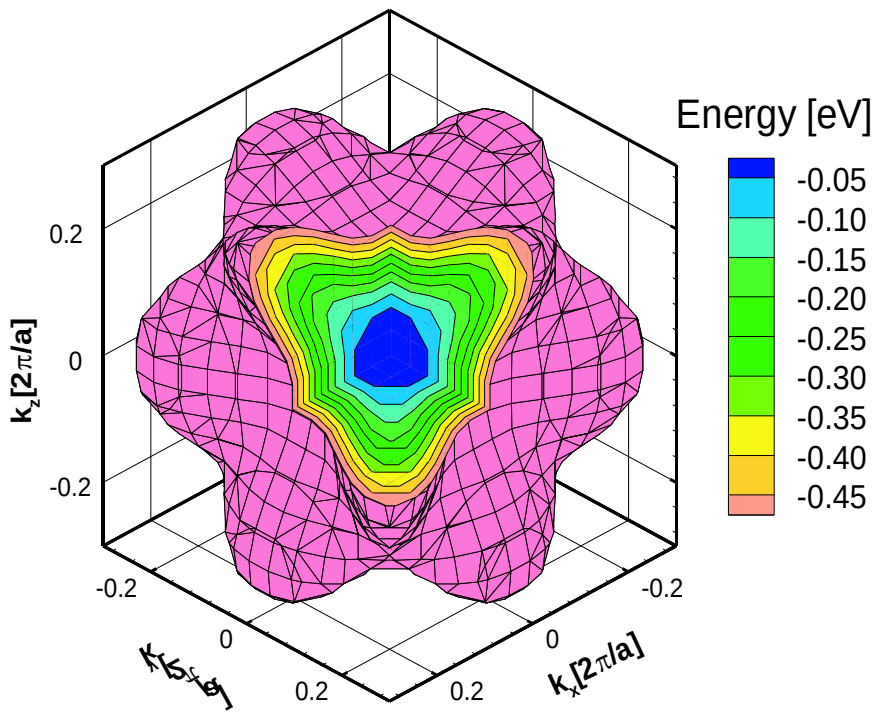
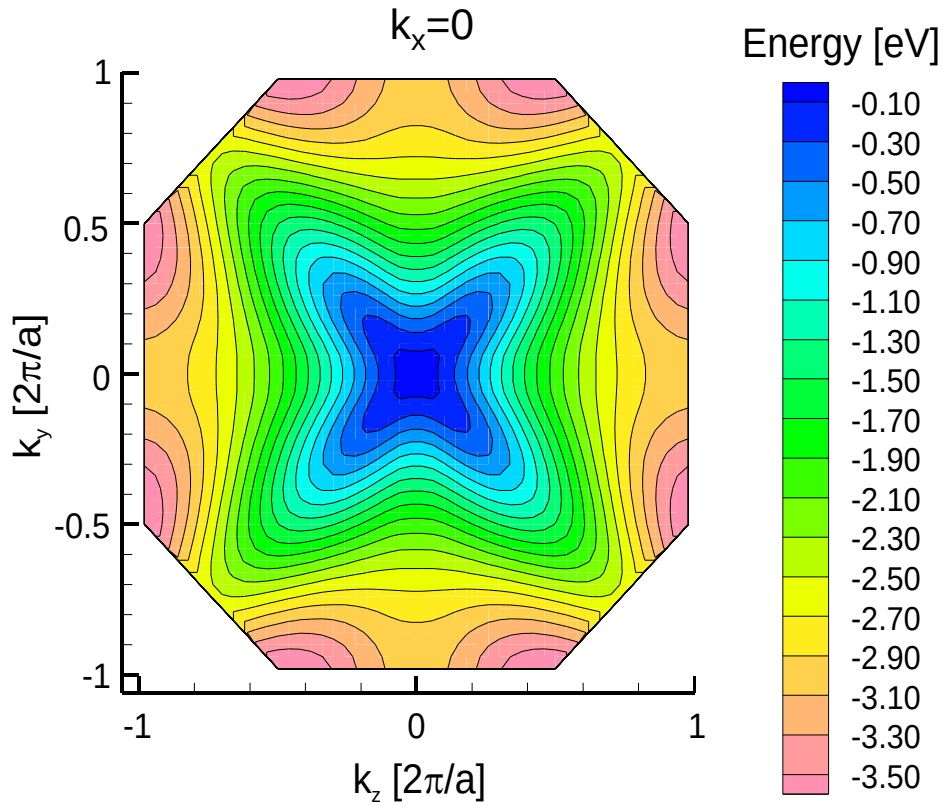
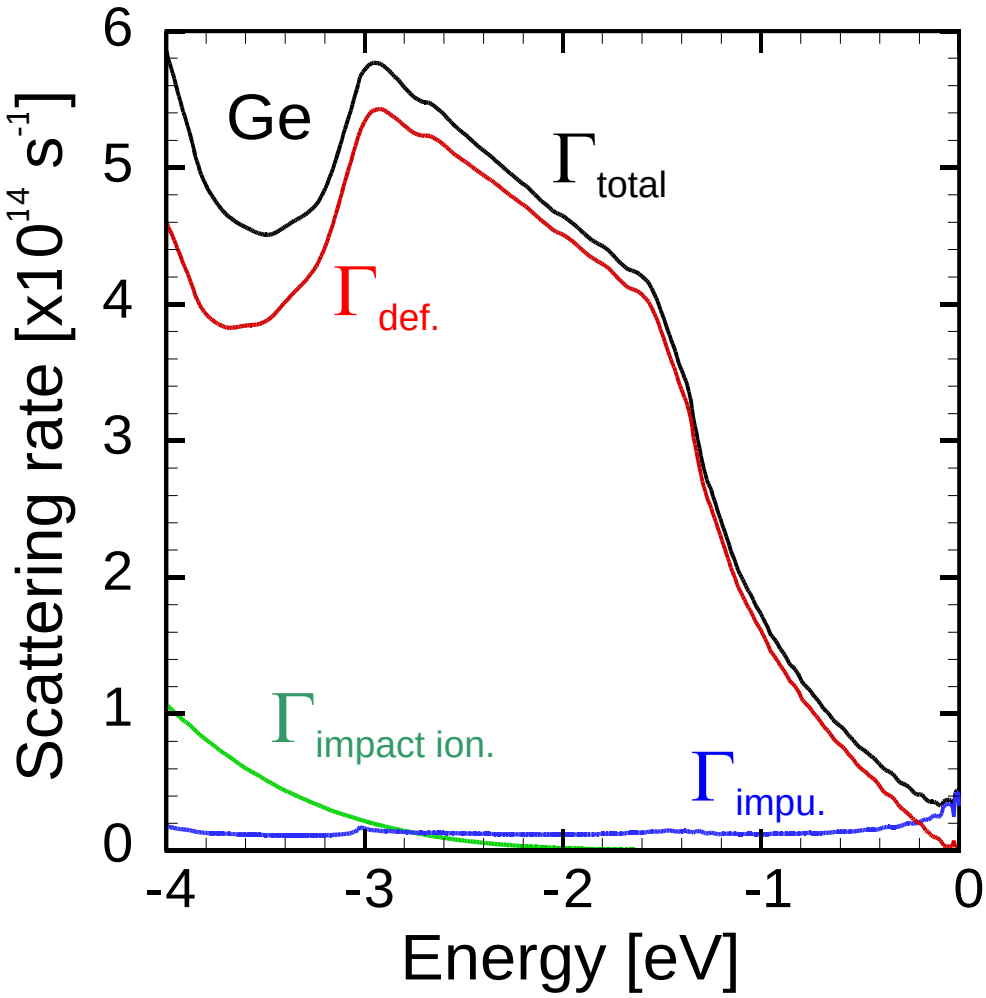




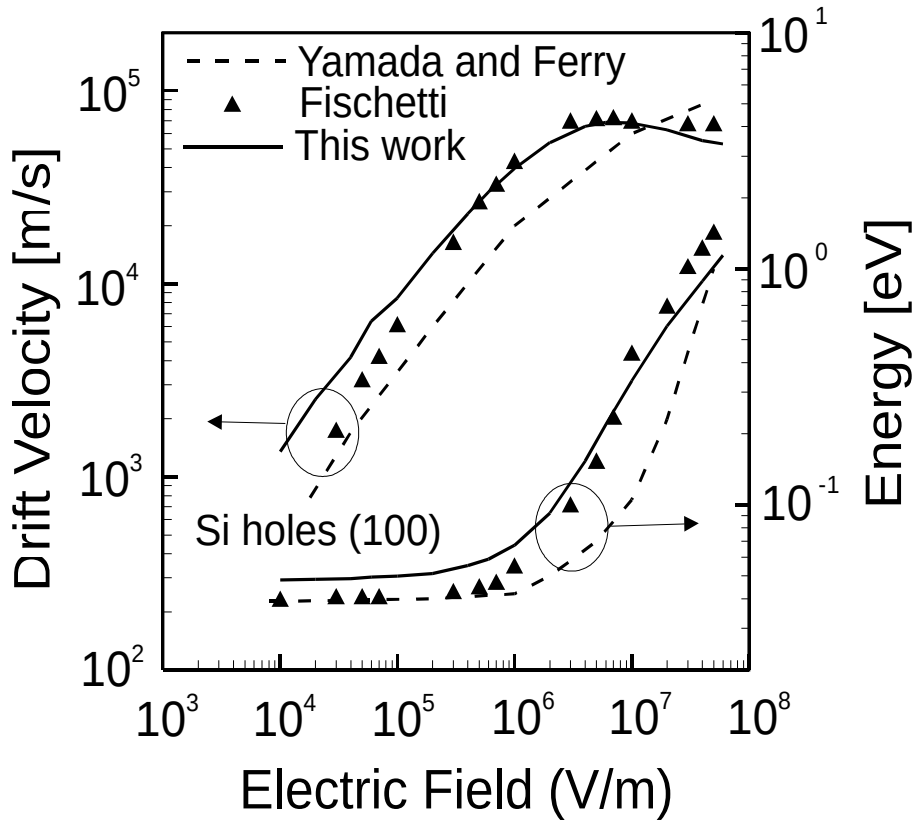
Full-Band Particle-based Simulations

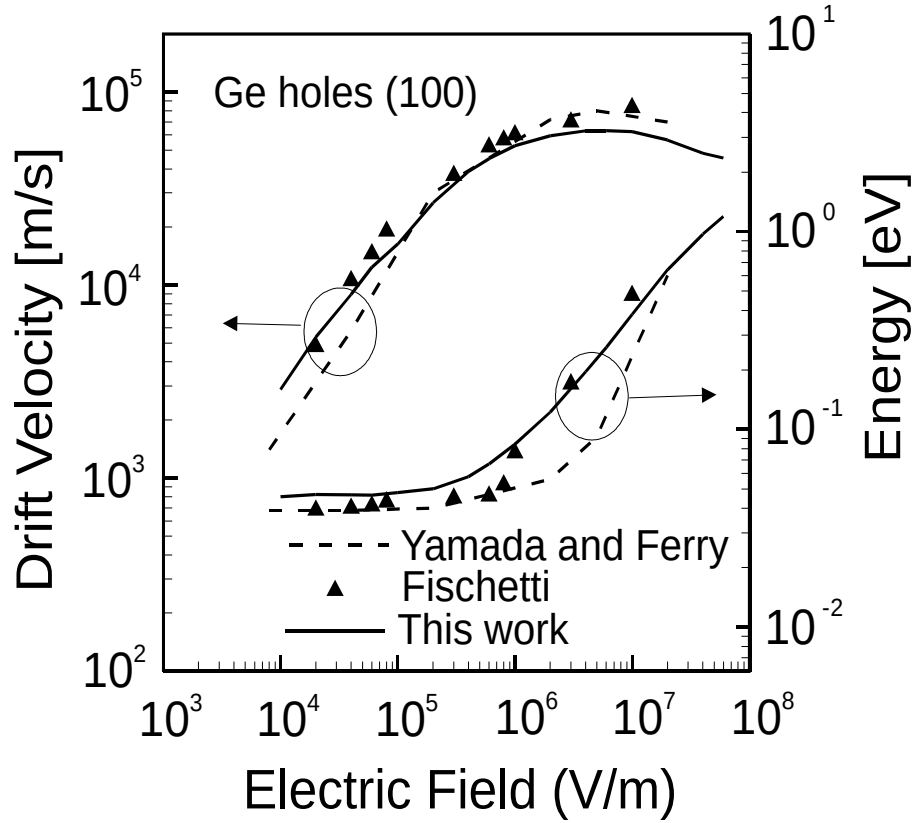
- Scattering rates



Full-Band Particle-based Simulations

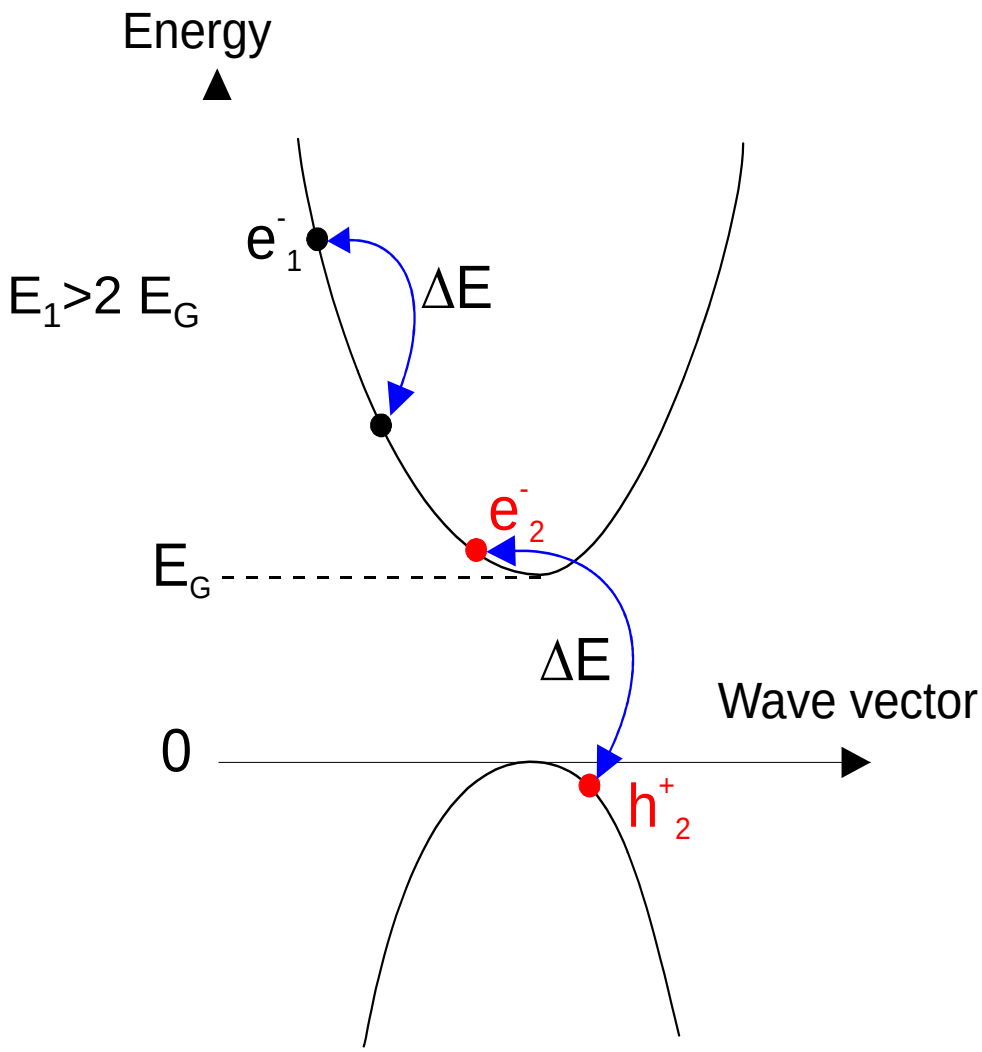
- Bulk simulation results





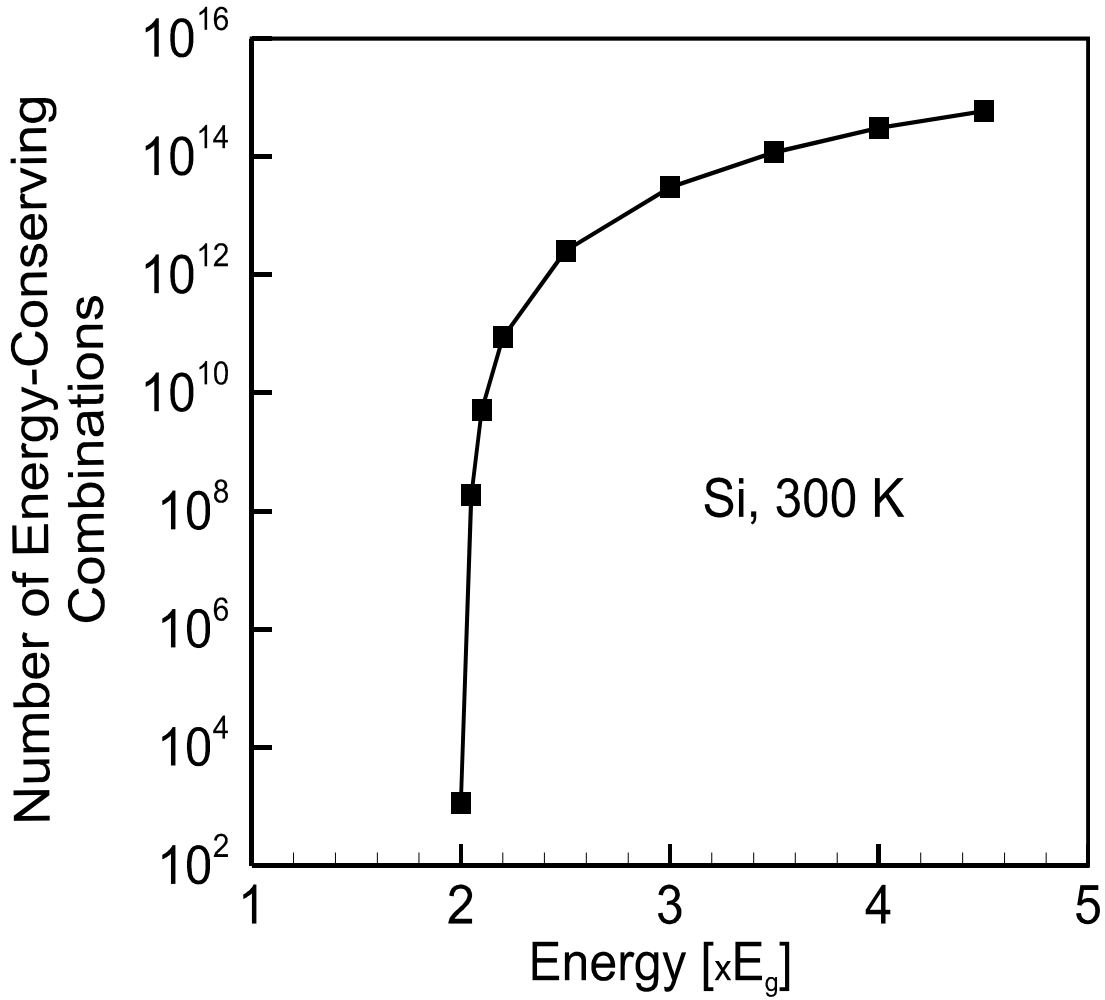
Impact Ionization

- Overview



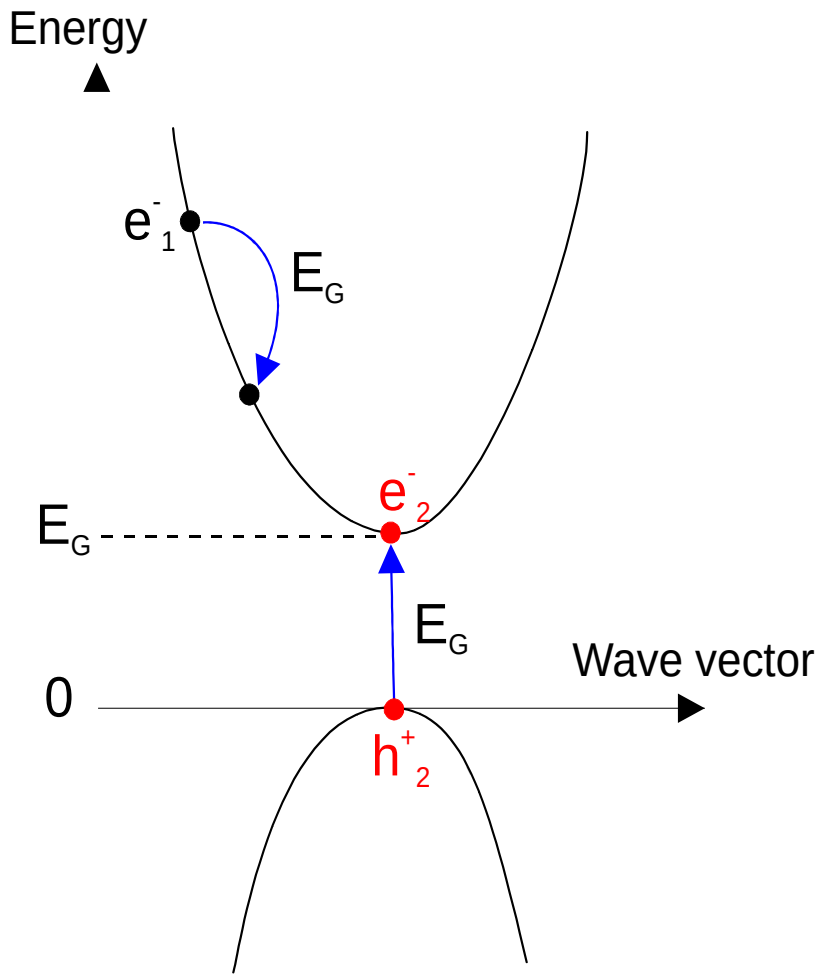
Impact Ionization

- Complexity



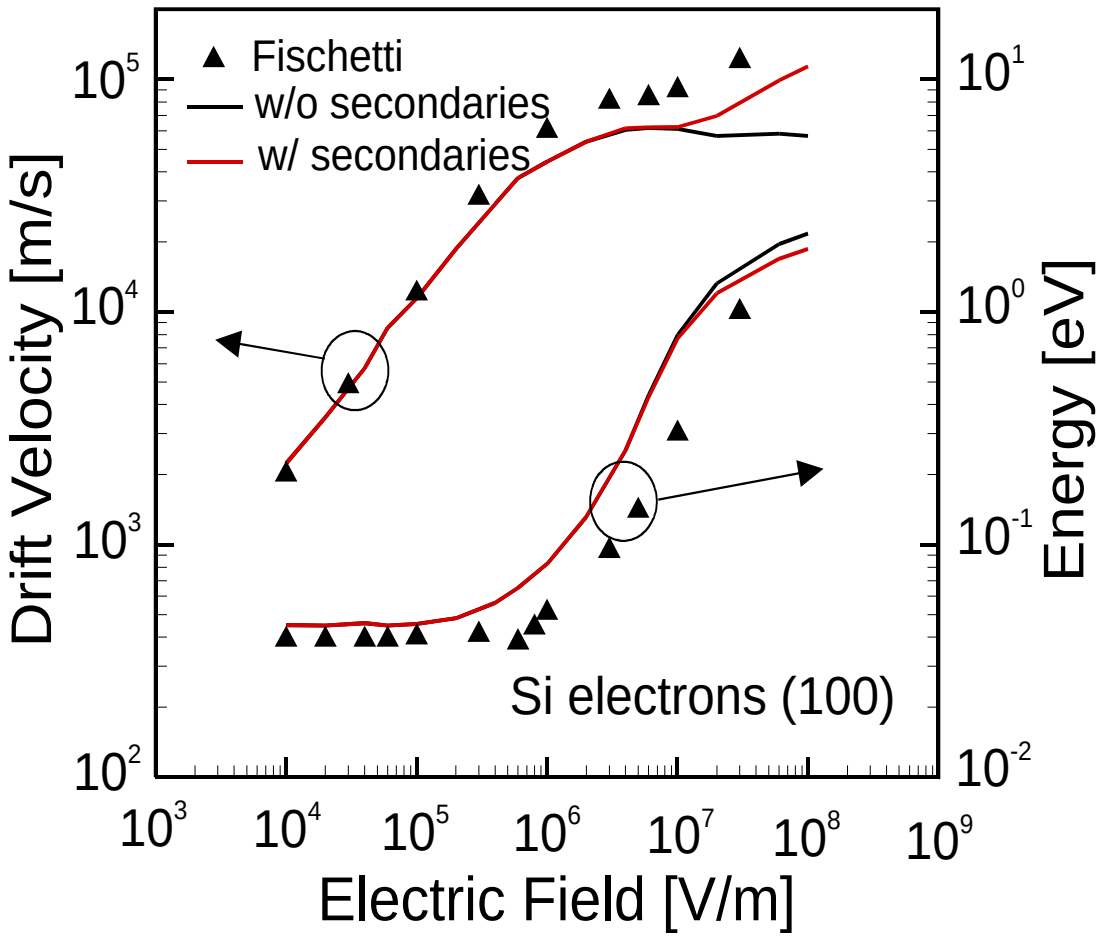
Impact Ionization

- Simplified model



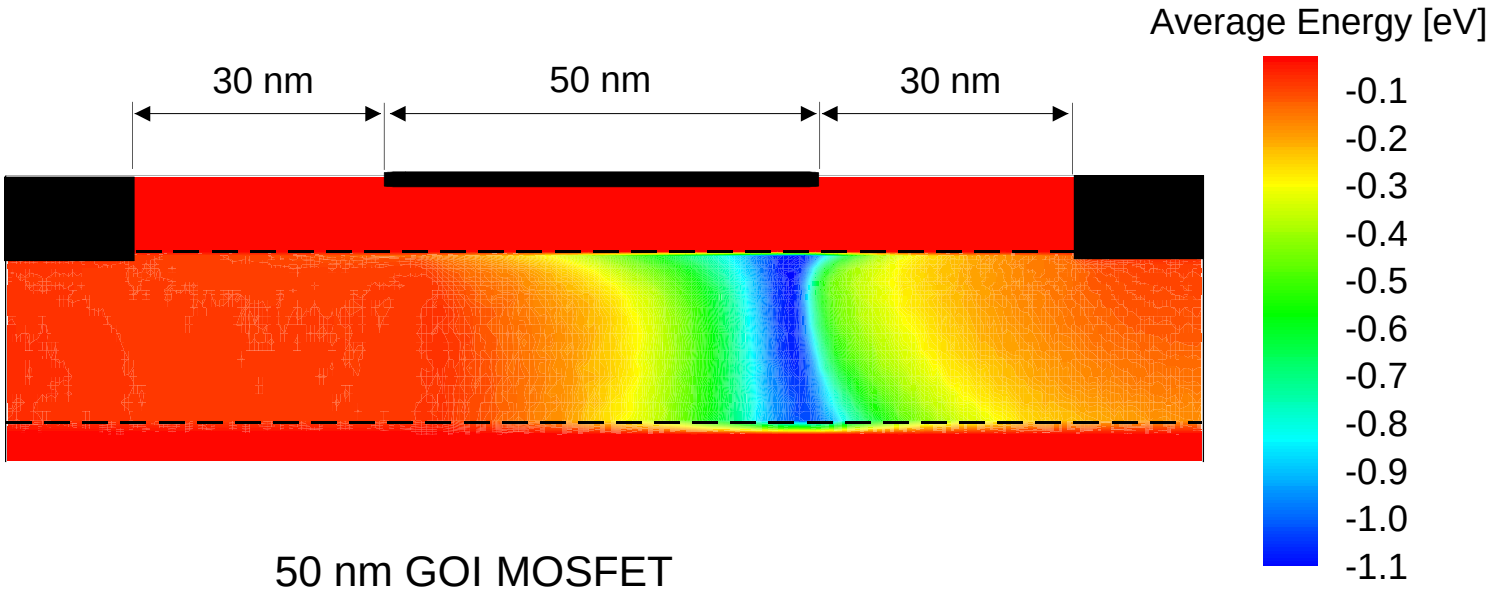
Impact Ionization

- Bulk simulations



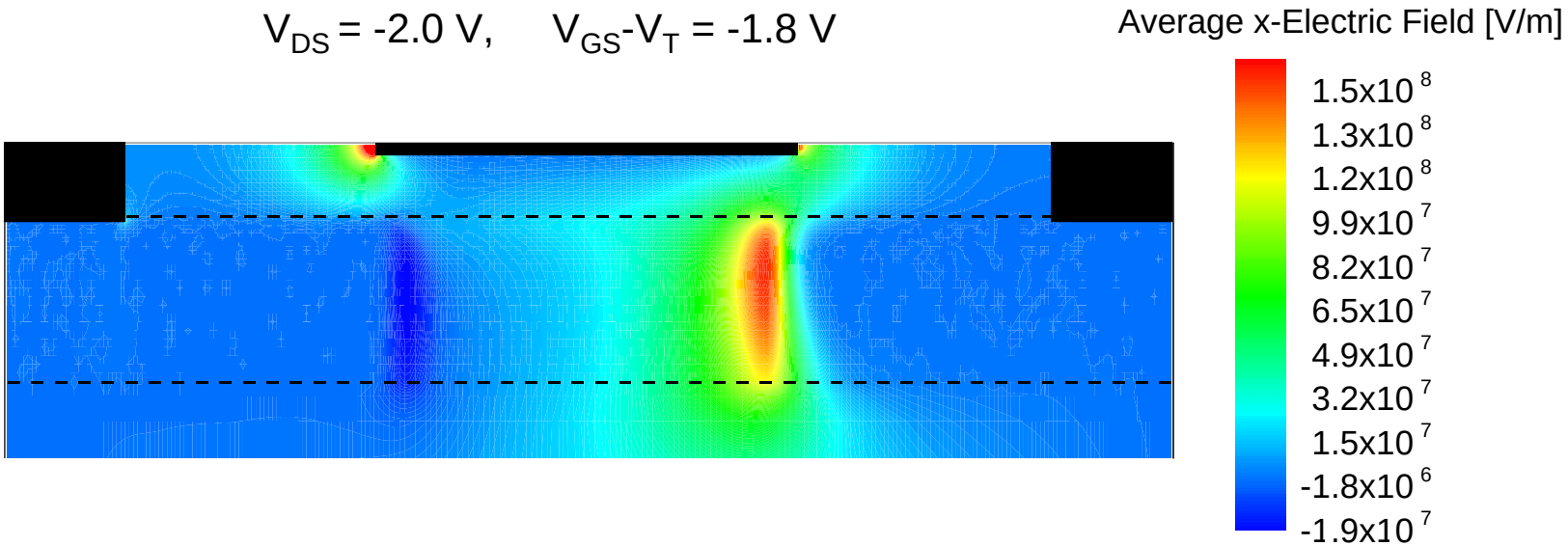
Impact Ionization

- MOSFET simulations



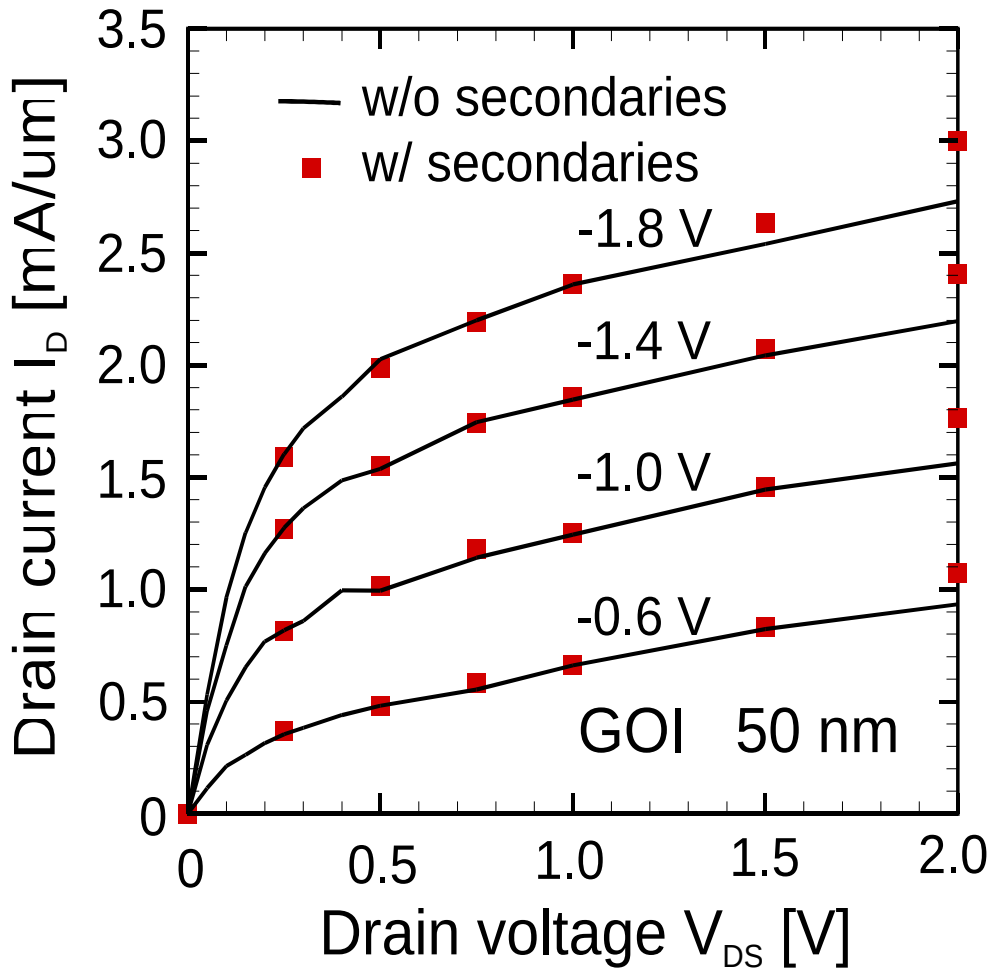
50 nm GOI MOSFET

V_{DS} = -2.0 V, V_{GS}-V_T = -1.8 V



Impact Ionization

- MOSFET simulations

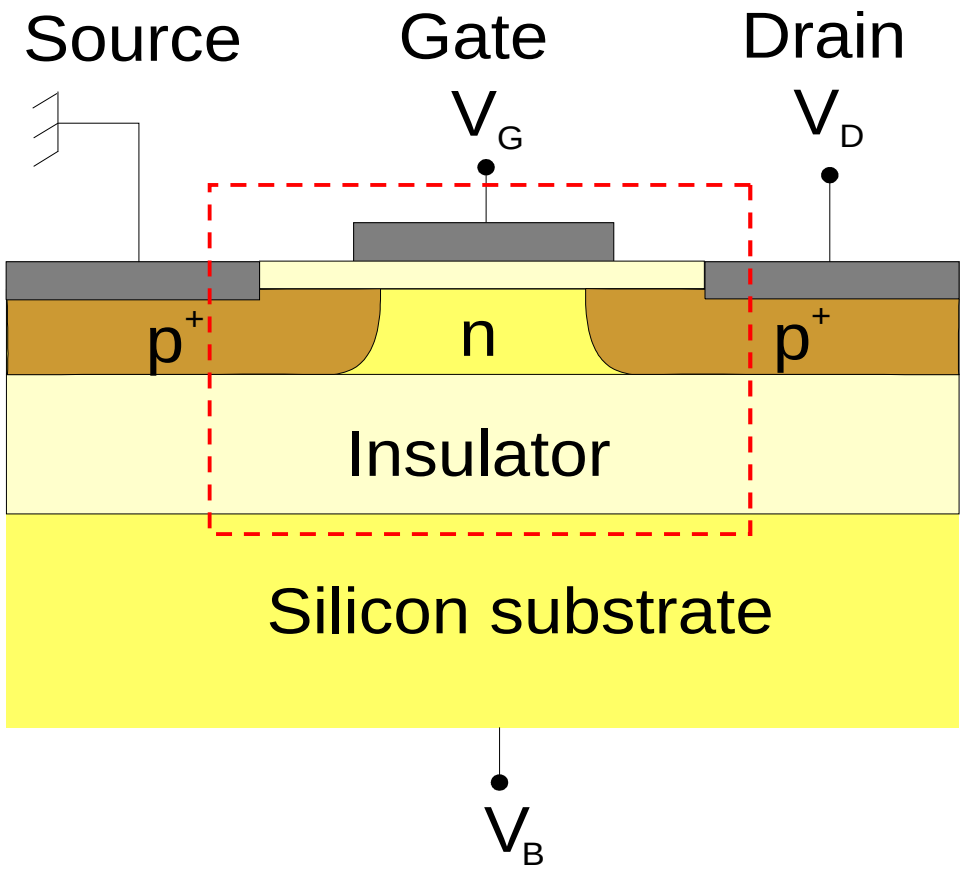


Germanium-On-Insulator Technology

- Motivation
  - Ge holes mobility is 4 times higher than in Si
  - CMOS: p-type Si MOSFET limits performance
  - SiO_2 thickness reached physical limits
  - New insulators: fabrication advantages of Si/SiO_2 lost

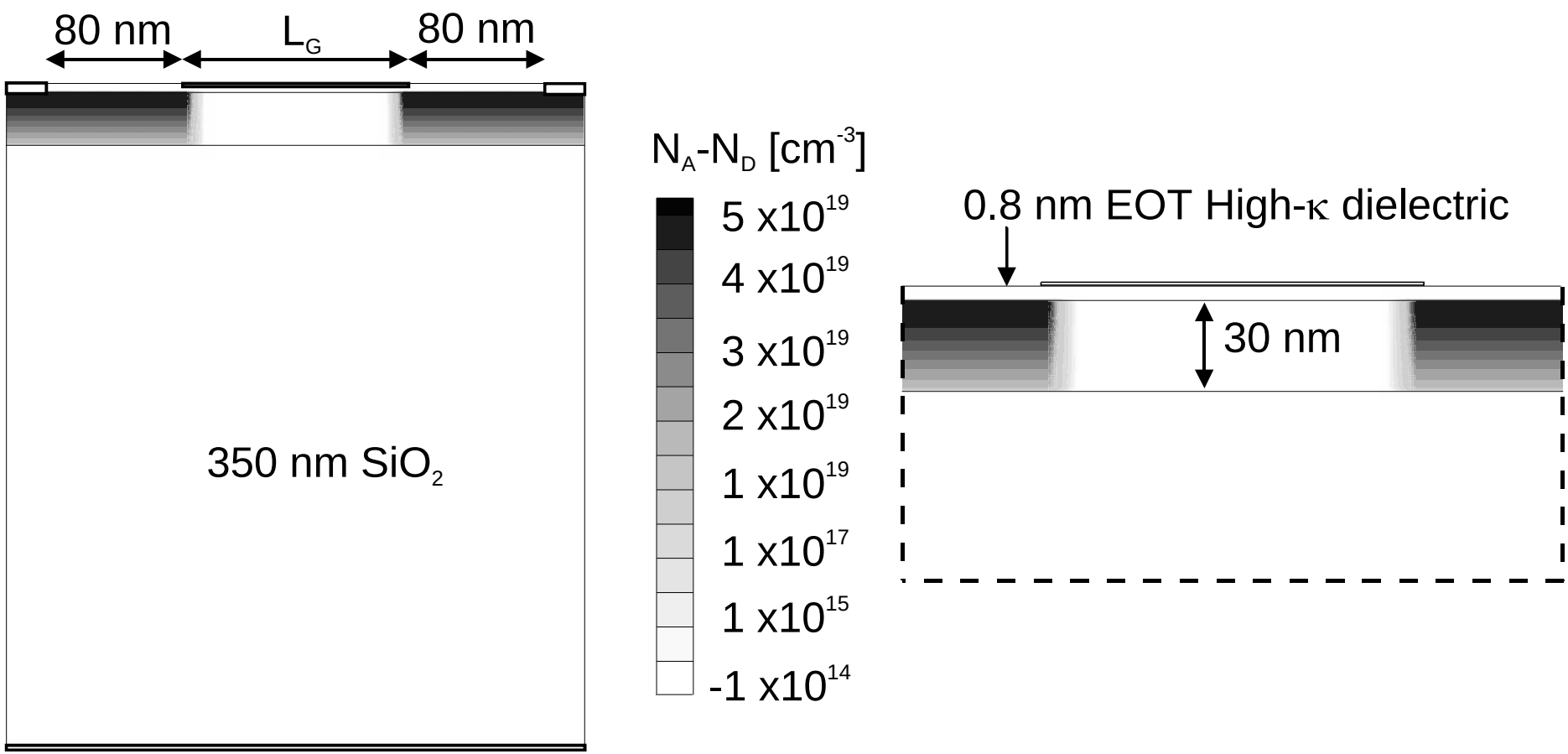
Germanium-On-Insulator Technology

- SOI MOSFETs



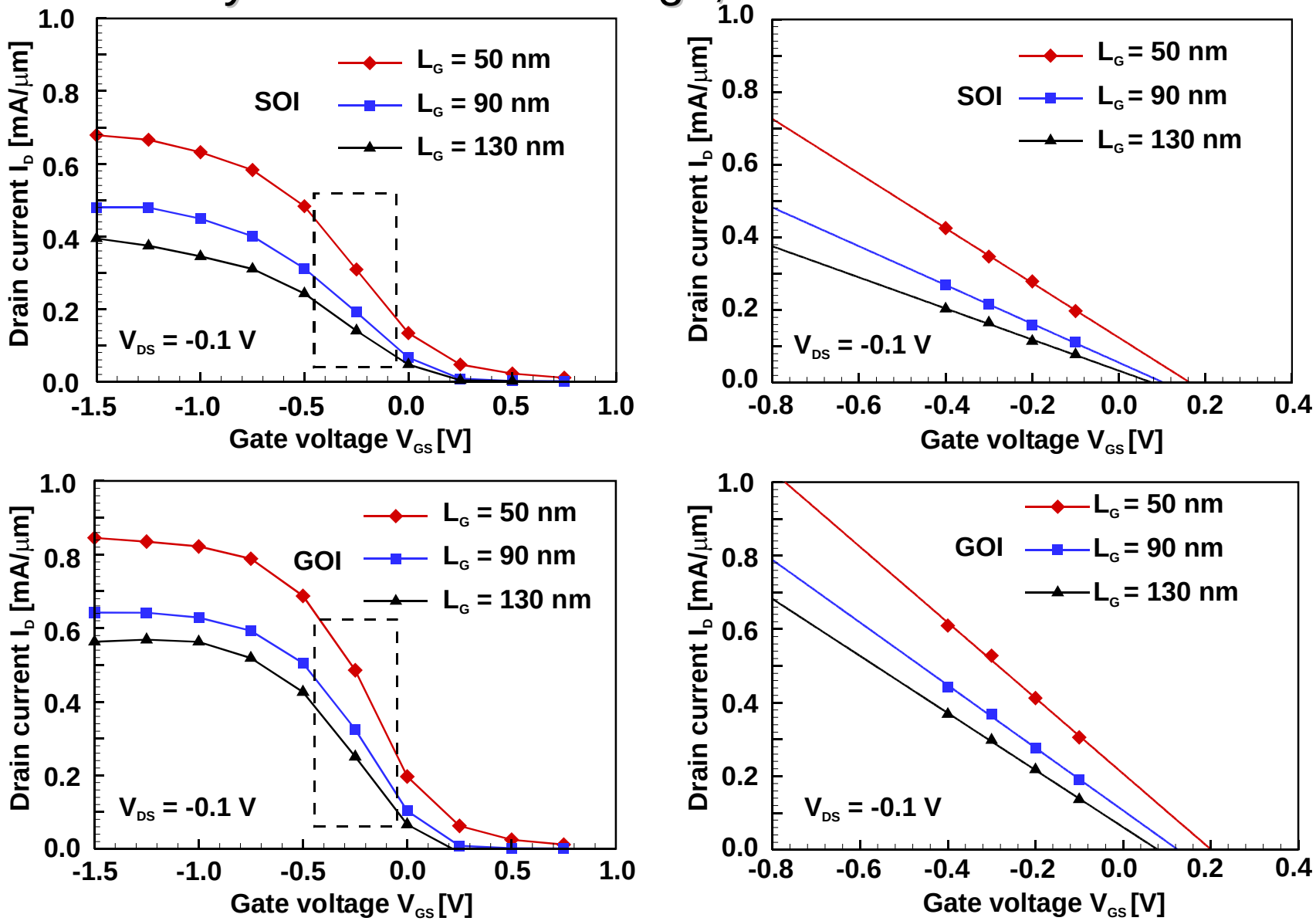
Germanium-On-Insulator Technology

- Device layout



Germanium-On-Insulator Technology

- Static analysis: threshold voltage, transconductance



Germanium-On-Insulator Technology

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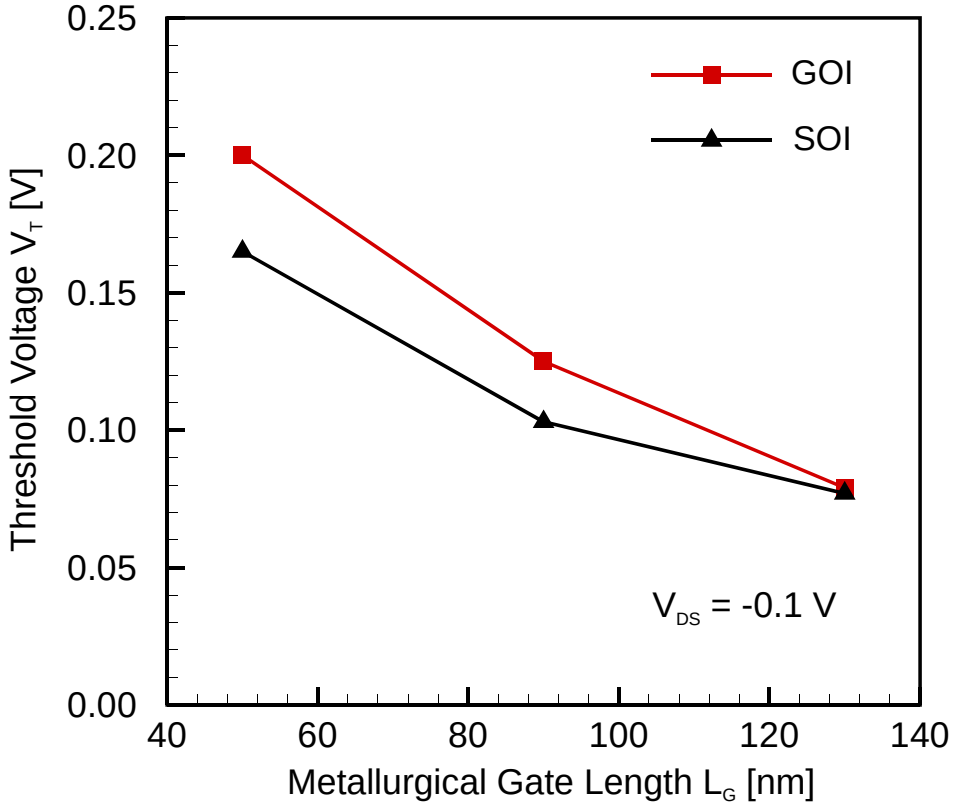
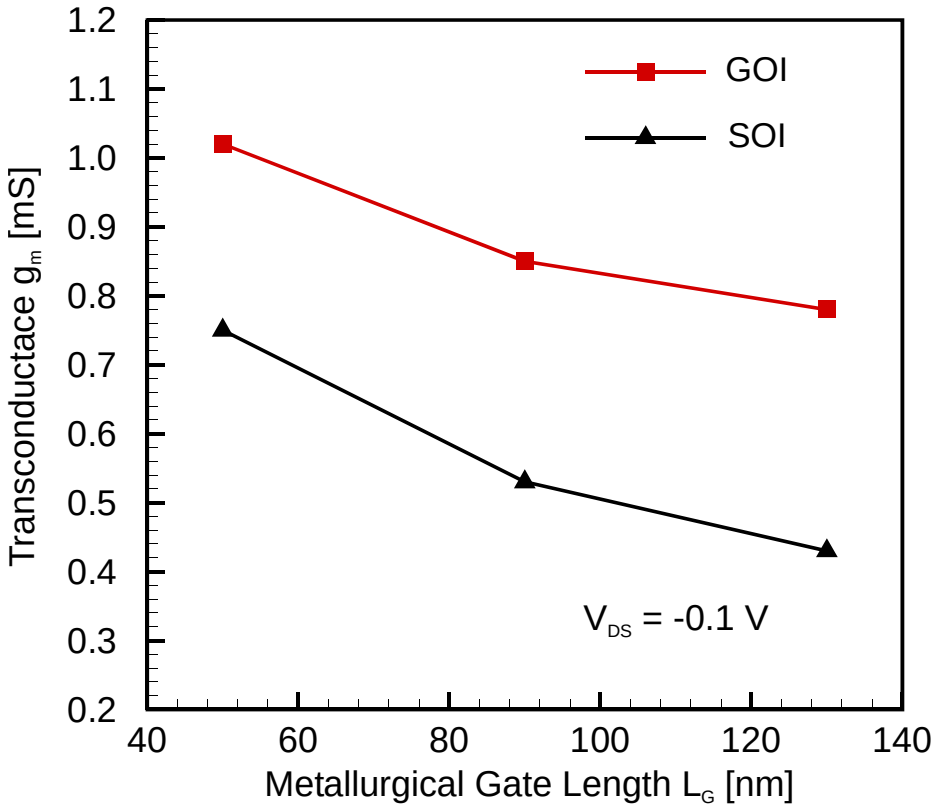
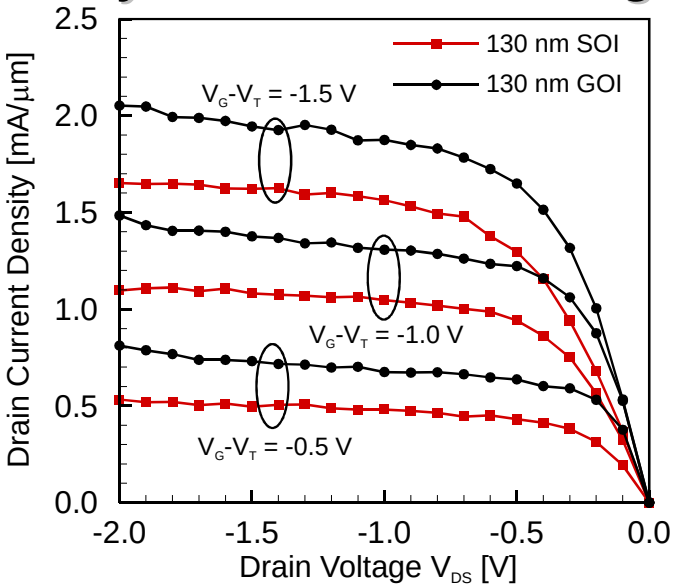
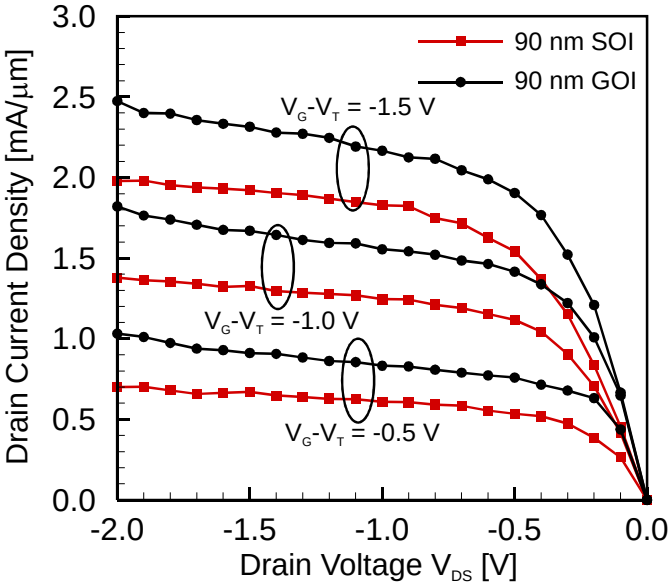


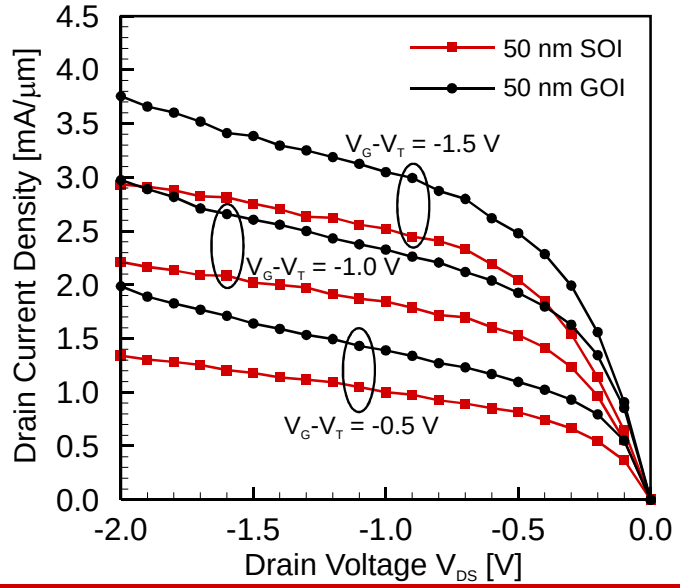


Germanium-On-Insulator Technology

- Static analysis: current-voltage characteristic

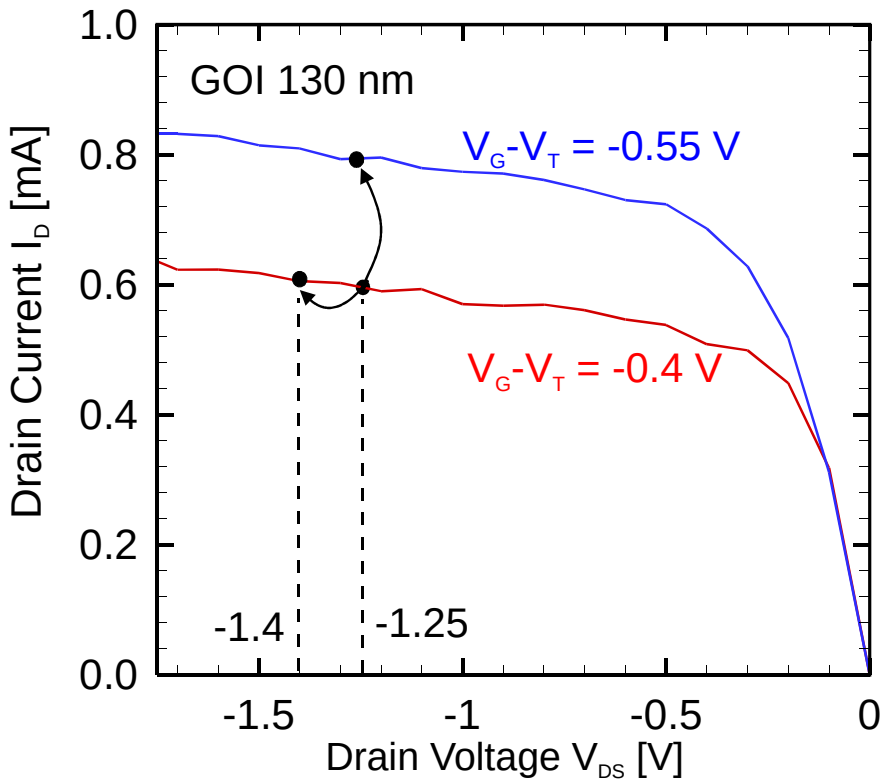


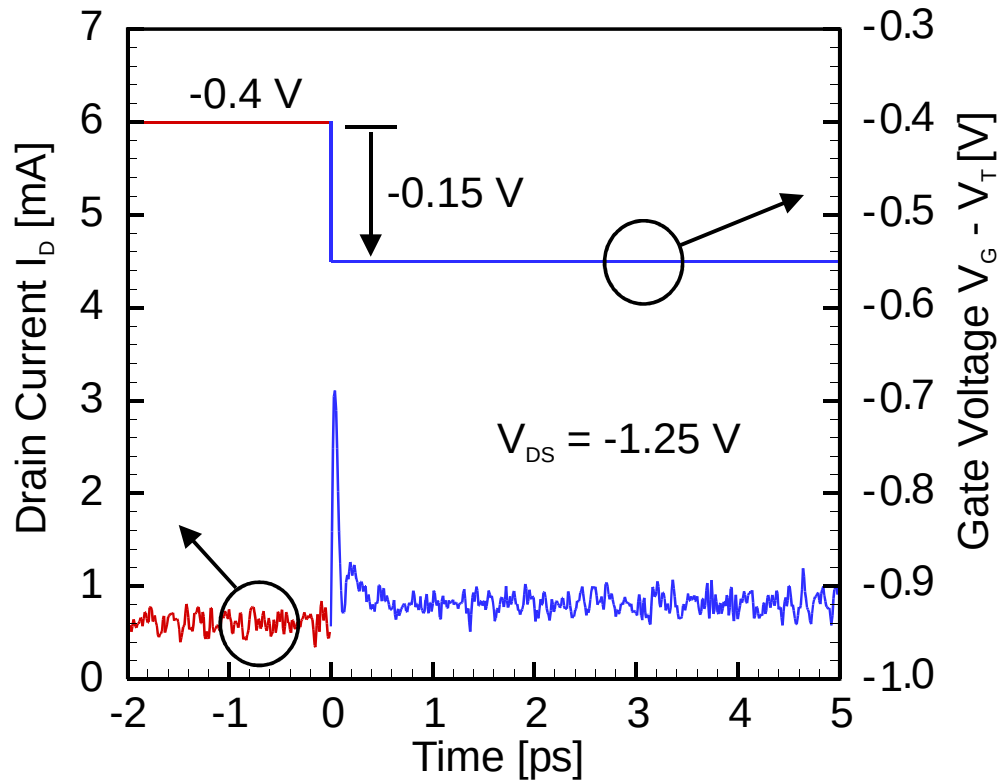




Germanium-On-Insulator Technology

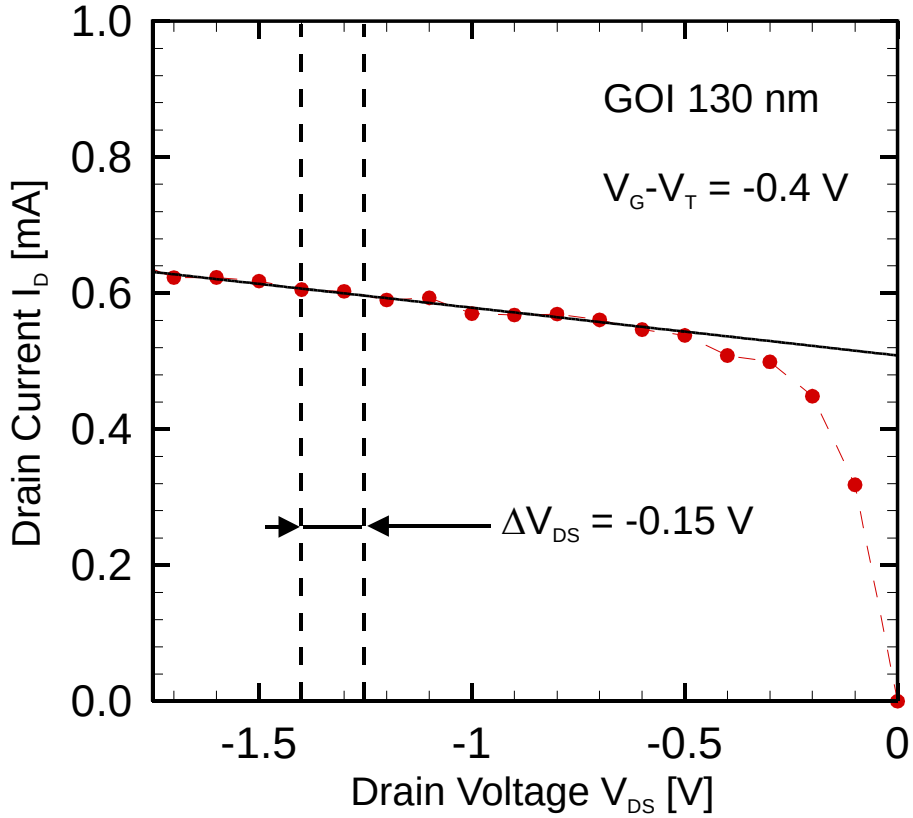
- Frequency analysis: e.g. step perturbation

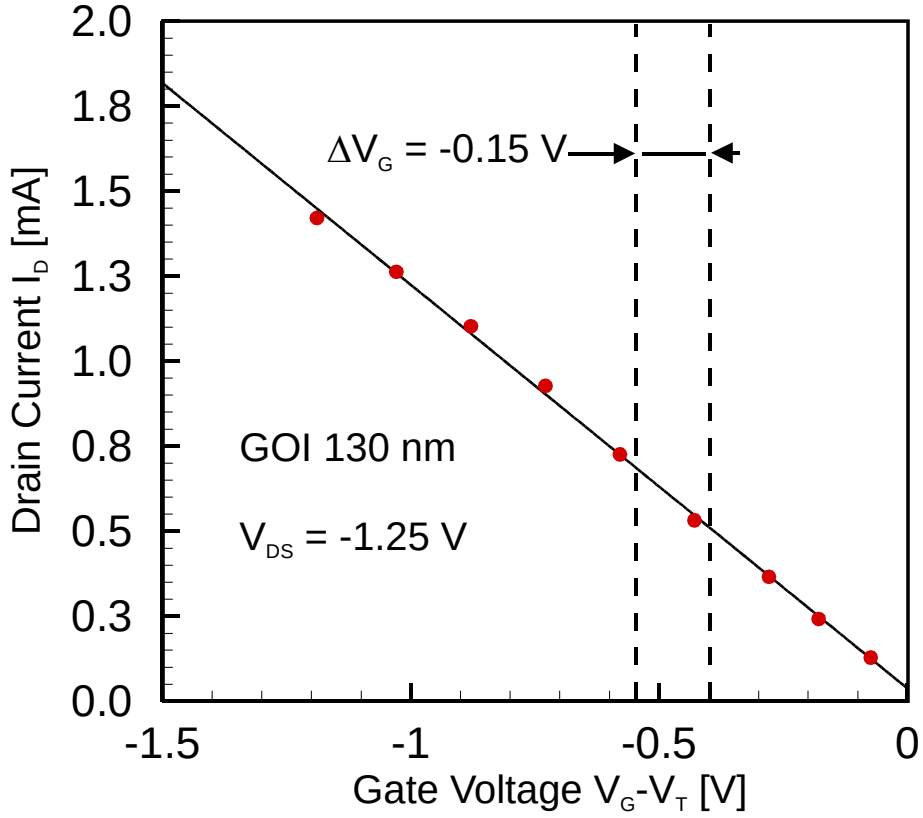




Germanium-On-Insulator Technology

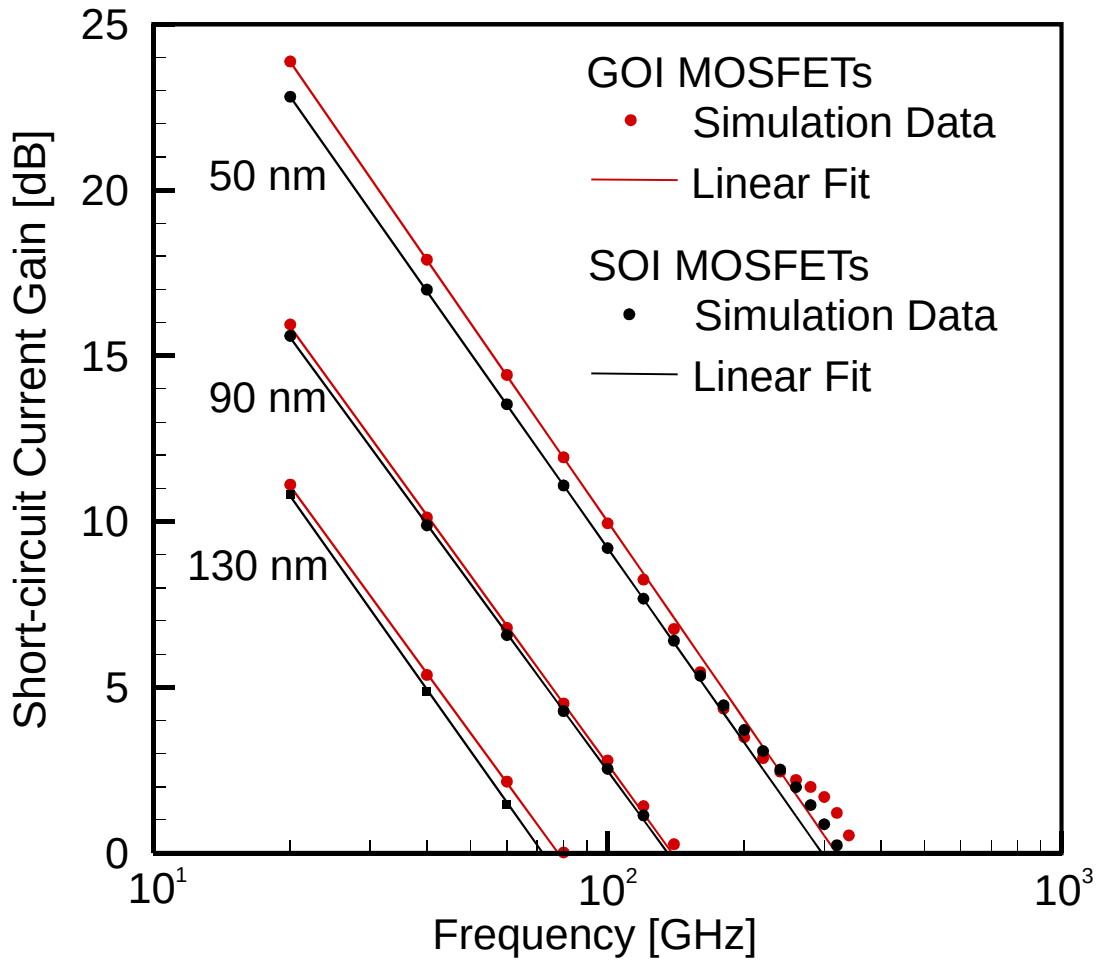
- Frequency analysis: linearity





Germanium-On-Insulator Technology

- Frequency analysis: unity gain frequency
  - Short-circuit current gain: $h_{21} = \left.\frac{i_d}{i_g}\right|_{v_d=0}$



Gate Length [nm]	Unity Gain Frequency [GHz]	
	GOI	**SOI**
50	319	297
90	139	136
130	78	72

Germanium-On-Insulator Technology

- Performance summary
  - Small feature size MOSFETs:
    - → Highly inhomogeneous transport inside the channel
    - → Performance improvement significantly lower than mobility increase
  - Higher unity gain frequencies (5-10%)
  - Larger drive currents (20-30%)
  - Improved transconductance though channel conductance is degraded
  - Higher sensitivity to impact ionization

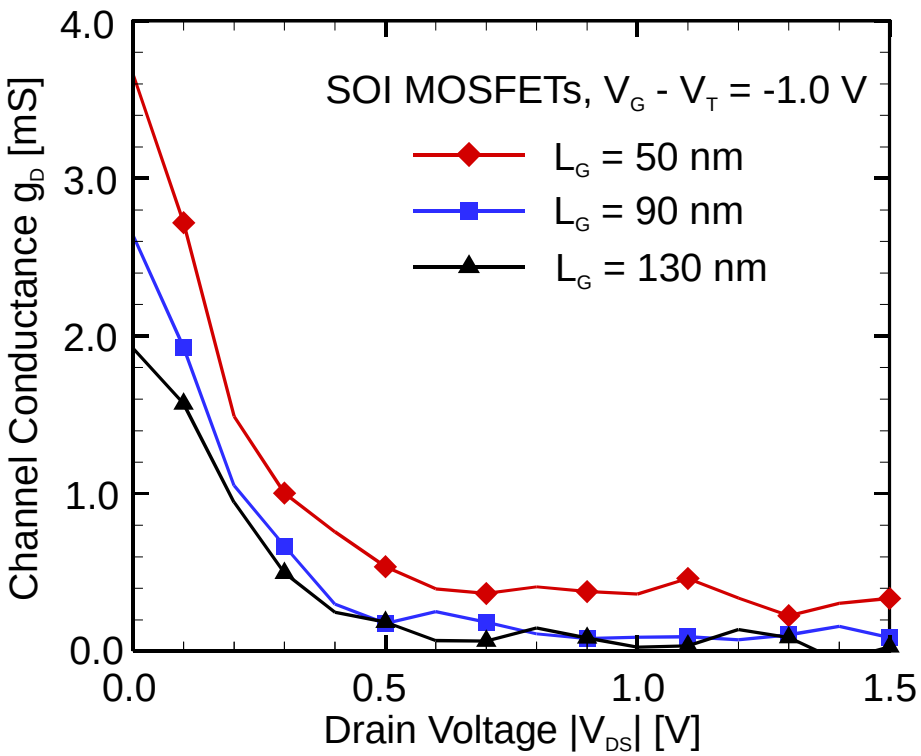
Conclusion and discussion

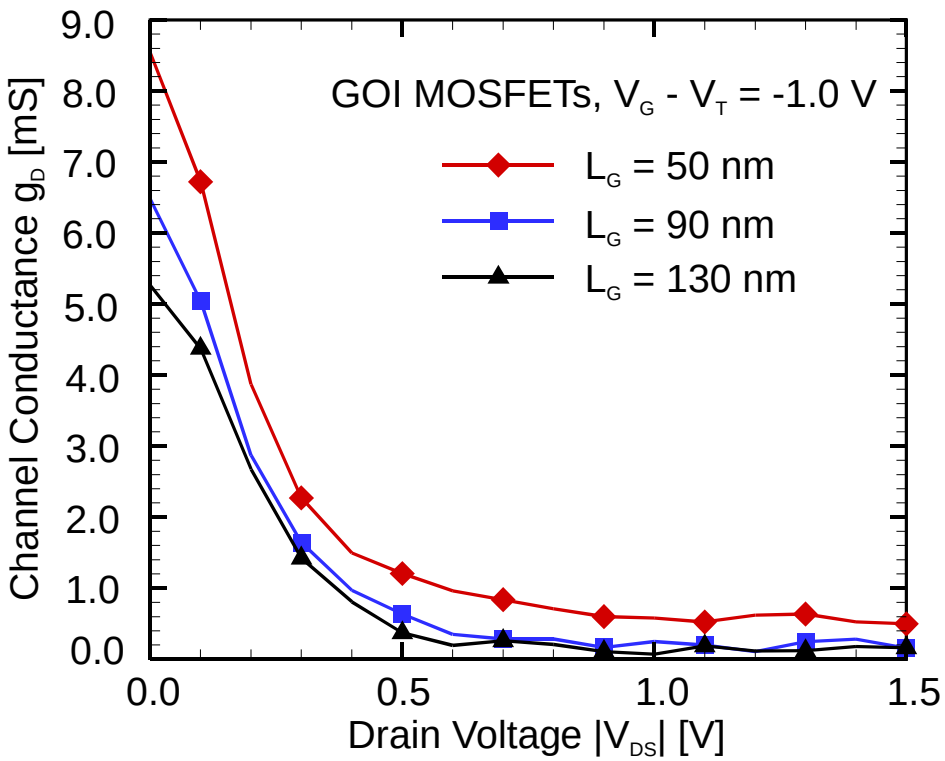
Germanium-On-Insulator Technology

- Appendix: static analysis - channel conductance

$$g_D = \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_G = CTE}$$

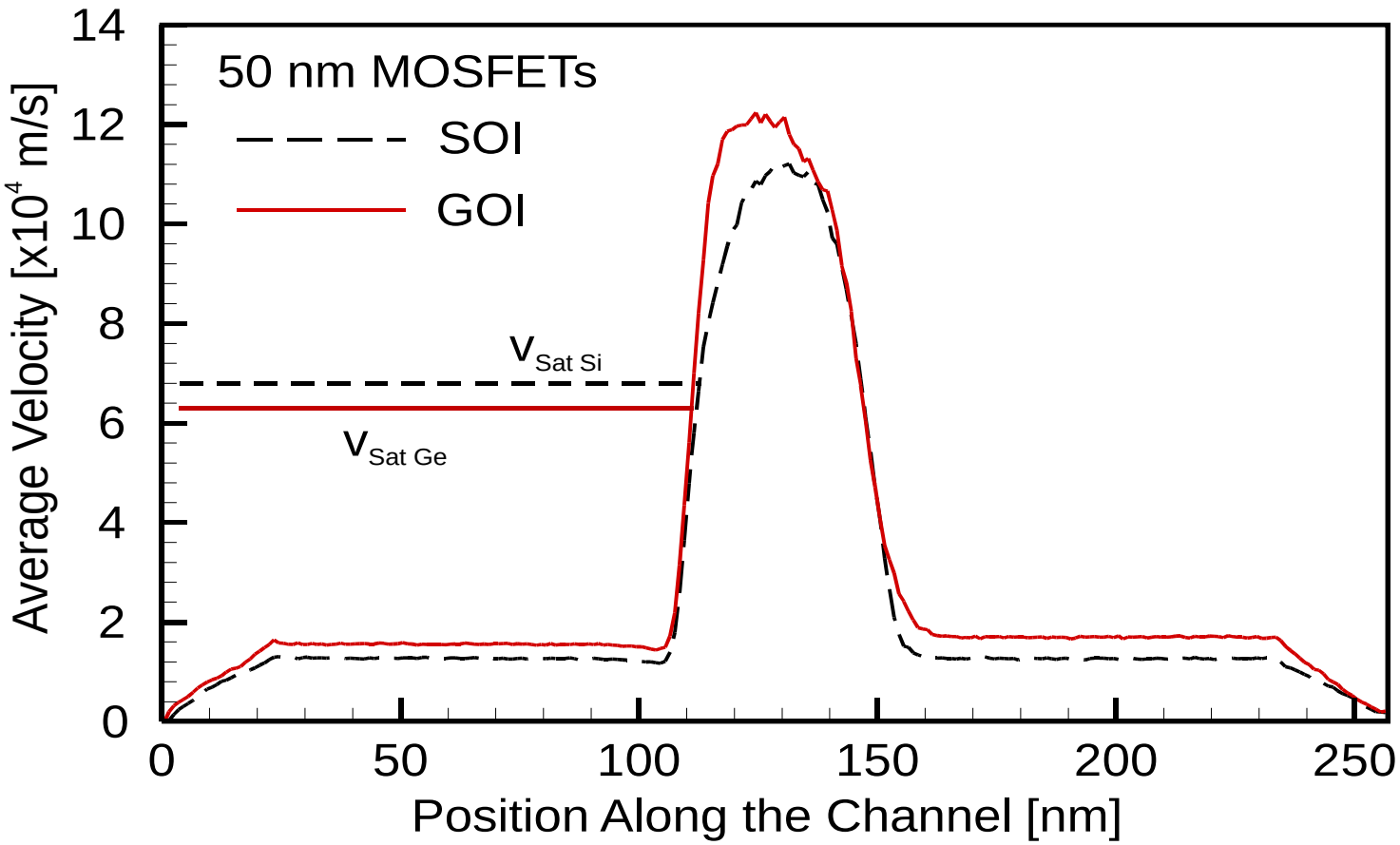
Ideal MOSFET at low drain biases: $g_D = \frac{Z}{L}\mu_P C_i (V_G - V_T)$





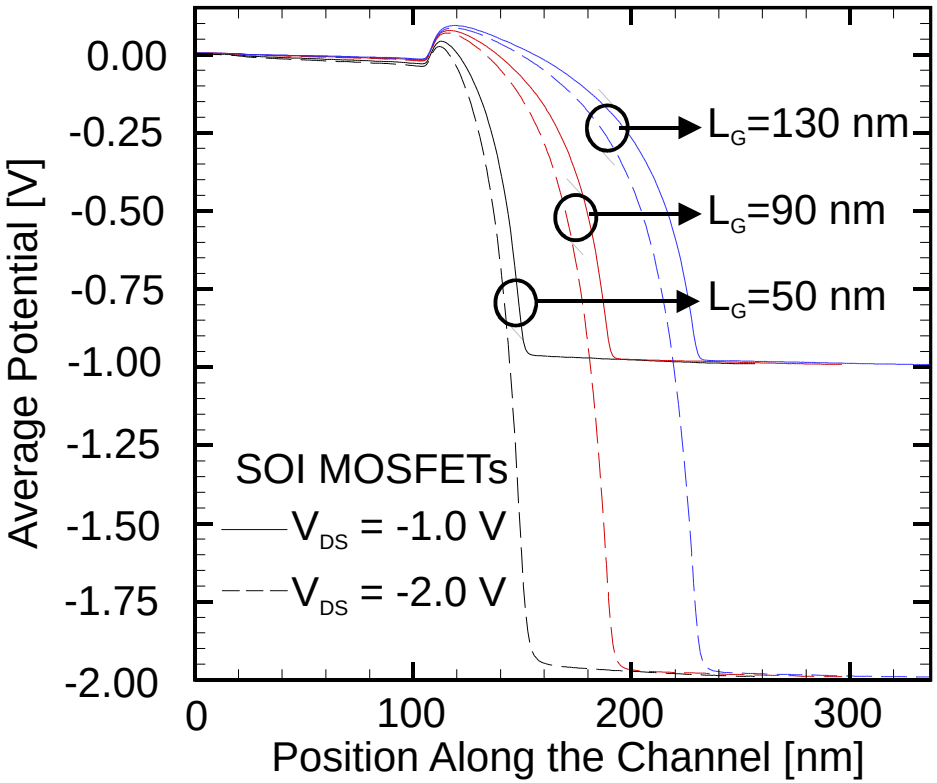
Germanium-On-Insulator Technology

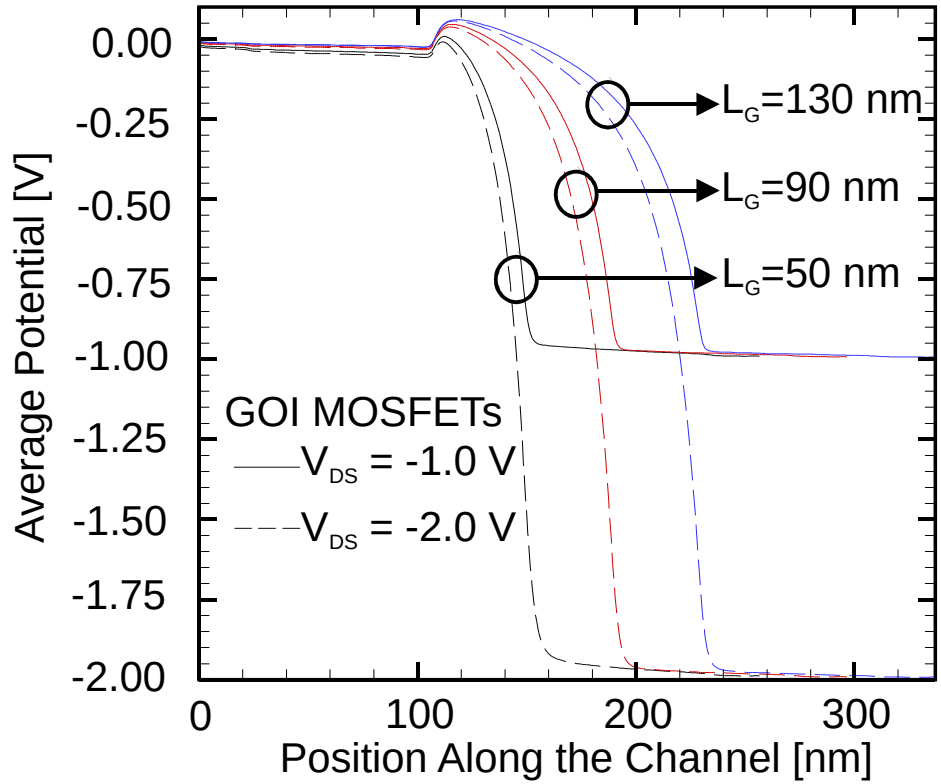
- Appendix: static analysis - average velocity
  - Highly inhomogeneous velocity
    - → Impact of low field mobility on predicted performance increase is considerably reduced

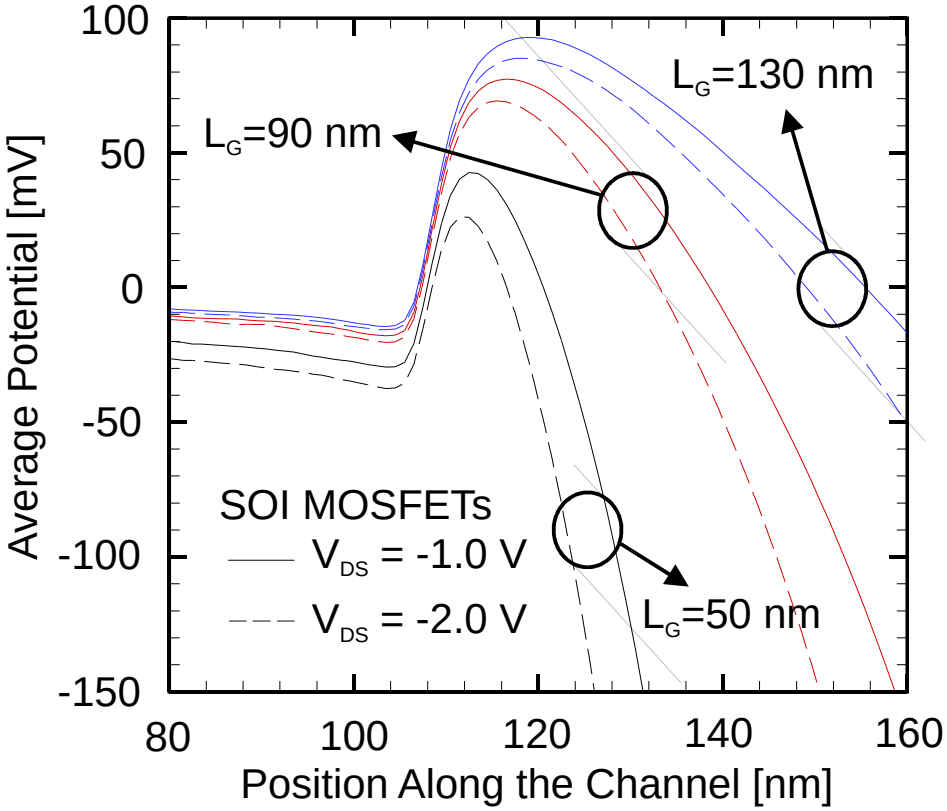
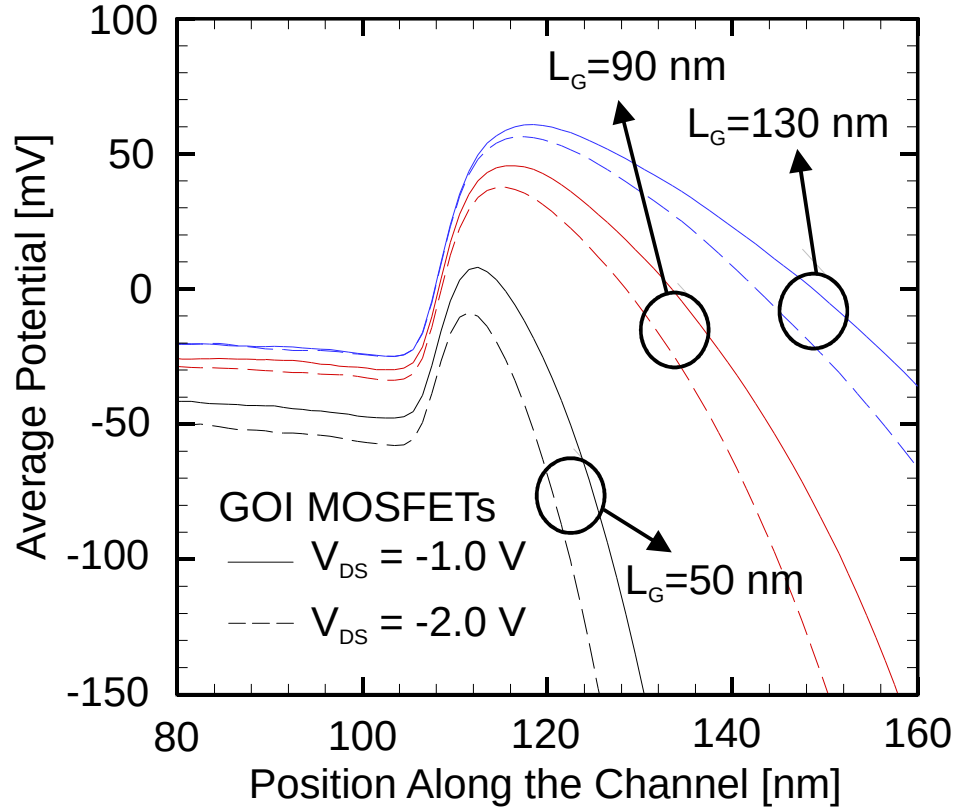


Germanium-On-Insulator Technology

- Appendix: static analysis - Drain Induced Barrier Lowering





Germanium-On-Insulator Technology

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