Quantum Effects in Nanoscale MOSFET Devices at Low Temperature

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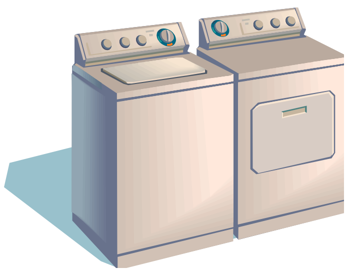
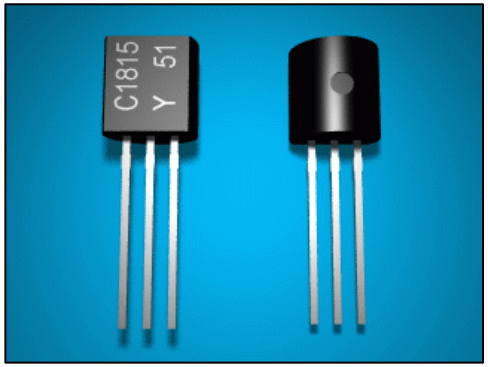
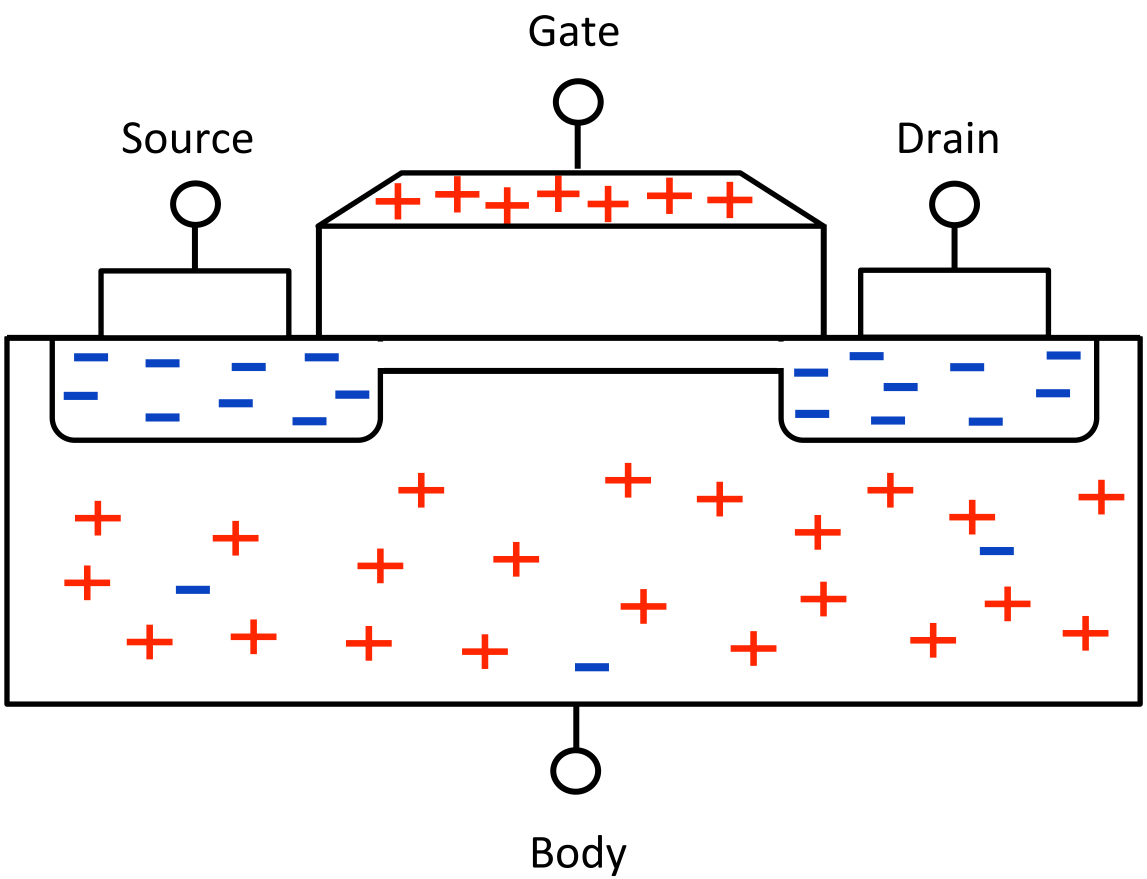
Transistors: Key to Technology





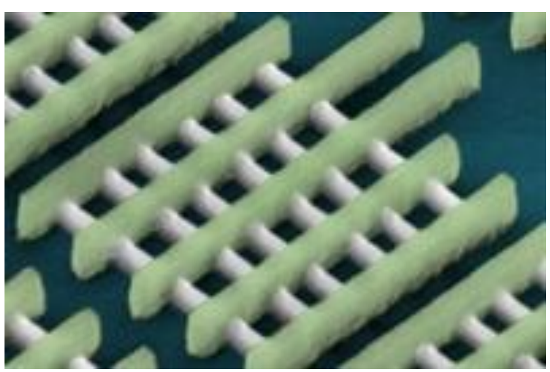
How a Transistor Works

Electron flow: Source → Drain

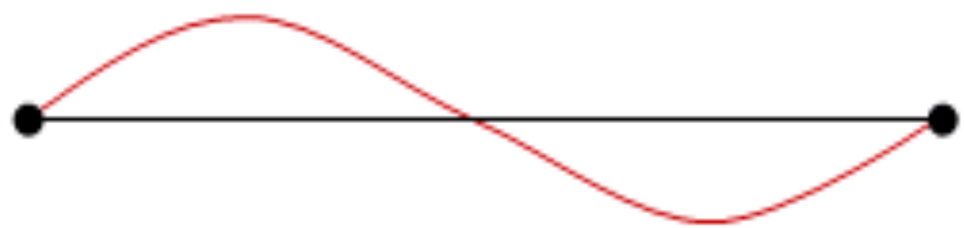


Approaching the Quantum Limit

- Wave-particle duality
- de Broglie wavelength:
    - 4.5 nm at room temperature
    - 39 nm at 4K



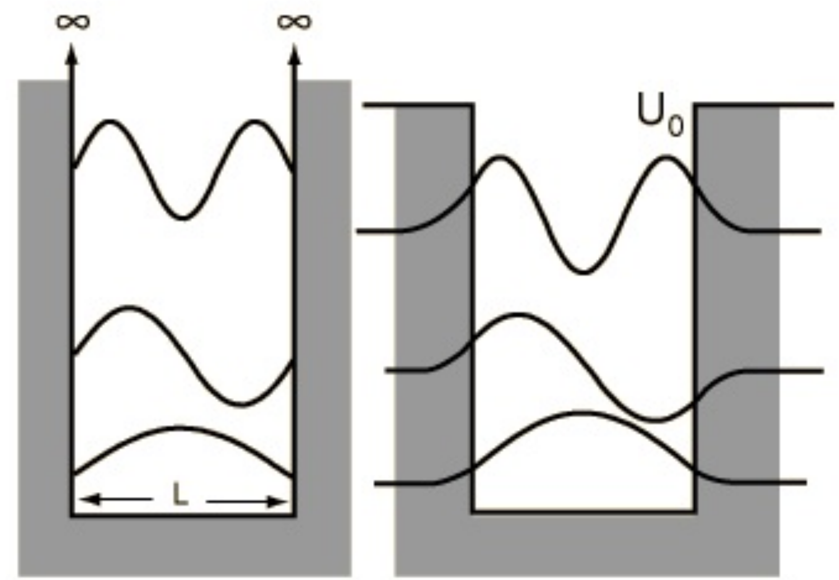
22nm



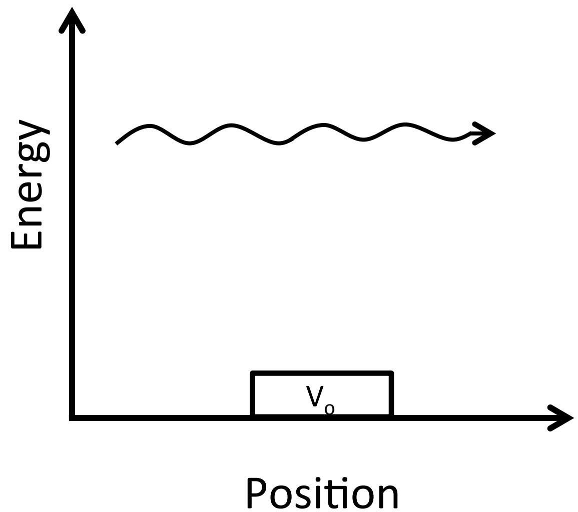
39nm

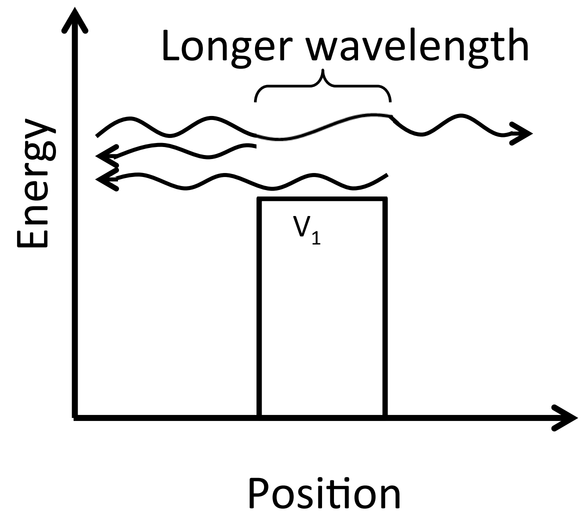
Quantum Effects in Modern Devices?

- Measurements indicate quantum behavior
- 2 types:
  - Interference
  - Confinement

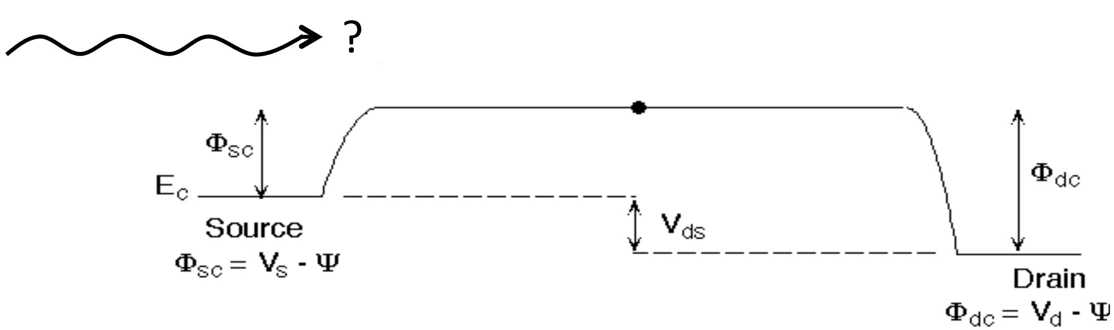


Quantum Interference in Transistors

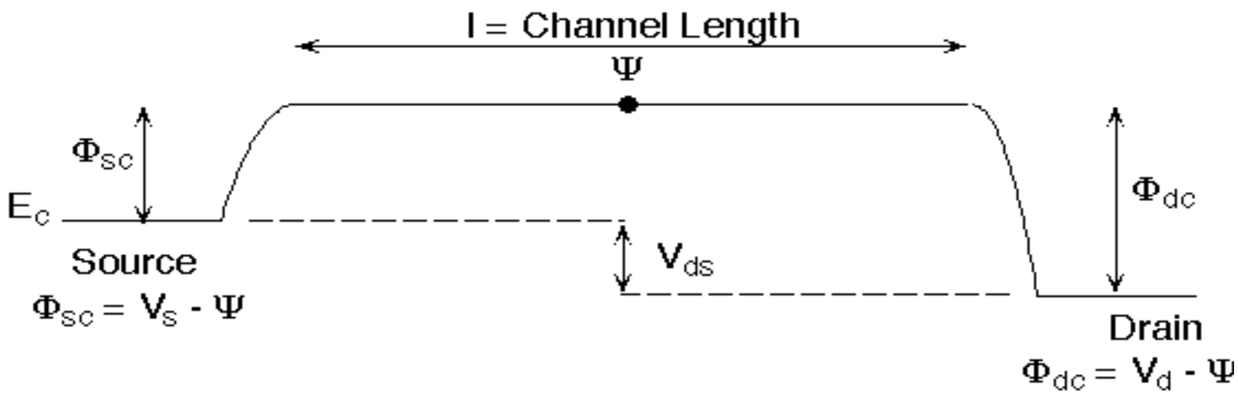


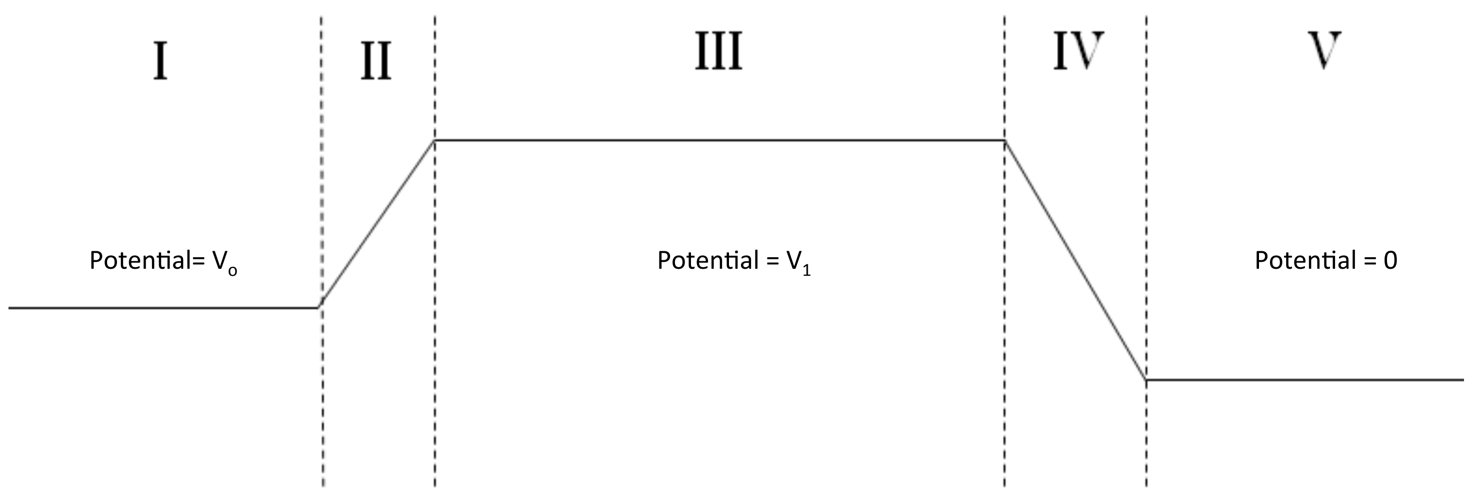


How can we apply this to nanoscale MOSFETs?

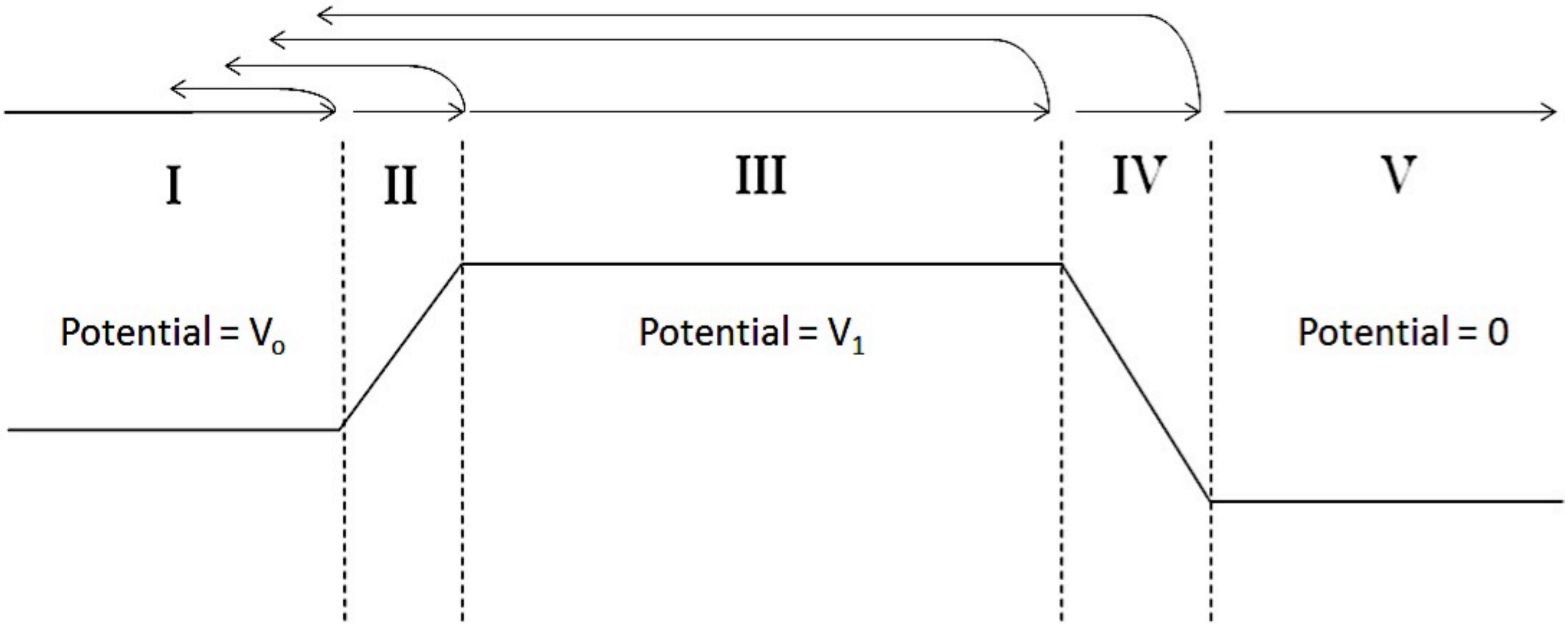


Transistor Model

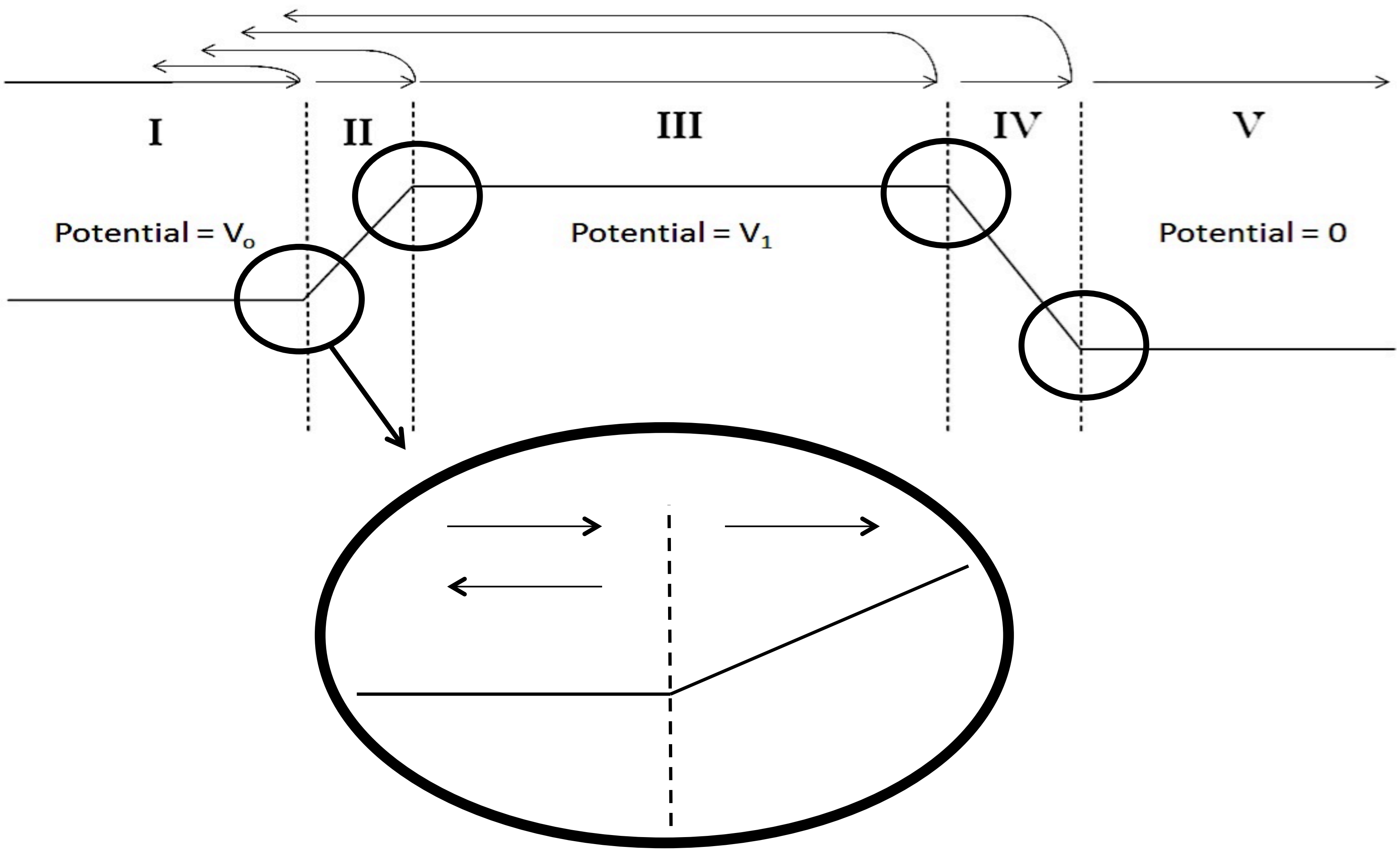




Wave Reflection at Barriers



Matrix Formulation



$$\begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} e^{ik_1 a} & e^{-ik_1 a} \\ ik_1 e^{ik_1 a} & -ik_1 e^{-ik_1 a} \end{pmatrix}^{-1} \begin{pmatrix} Ai(z_a) & Bi(z_a) \\ Ai'(z_a) & Bi'(z_a) \end{pmatrix} \underbrace{\begin{pmatrix} Ai(z_b) & Bi(z_b) \\ Ai'(z_b) & Bi'(z_b) \end{pmatrix}^{-1} \begin{pmatrix} Ai(z_b) & Bi(z_b) \\ Ai'(z_b) & Bi'(z_b) \end{pmatrix}}_{=I}$$

$$\underbrace{\begin{pmatrix} Ai(z_c) & Bi(z_c) \\ Ai'(z_c) & Bi'(z_c) \end{pmatrix}^{-1} \begin{pmatrix} Ai(z_c) & Bi(z_c) \\ Ai'(z_c) & Bi'(z_c) \end{pmatrix}}_{=I} \begin{pmatrix} Ai(z_d) & Bi(z_d) \\ Ai'(z_d) & Bi'(z_d) \end{pmatrix}^{-1} \begin{pmatrix} e^{ik_{II} d} & e^{-ik_{II} d} \\ ik_{II} e^{ik_{II} d} & -ik_{II} e^{-ik_{II} d} \end{pmatrix} \begin{pmatrix} E \\ F \end{pmatrix}$$

$$\therefore \begin{pmatrix} A \\ B \end{pmatrix} = \begin{pmatrix} e^{ik_1 a} & e^{-ik_1 a} \\ ik_1 e^{ik_1 a} & -ik_1 e^{-ik_1 a} \end{pmatrix}^{-1} \begin{pmatrix} Ai(z_a) & Bi(z_a) \\ Ai'(z_a) & Bi'(z_a) \end{pmatrix} \underbrace{\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}}_{\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}} \begin{pmatrix} Ai(z_d) & Bi(z_d) \\ Ai'(z_d) & Bi'(z_d) \end{pmatrix}$$

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"M"

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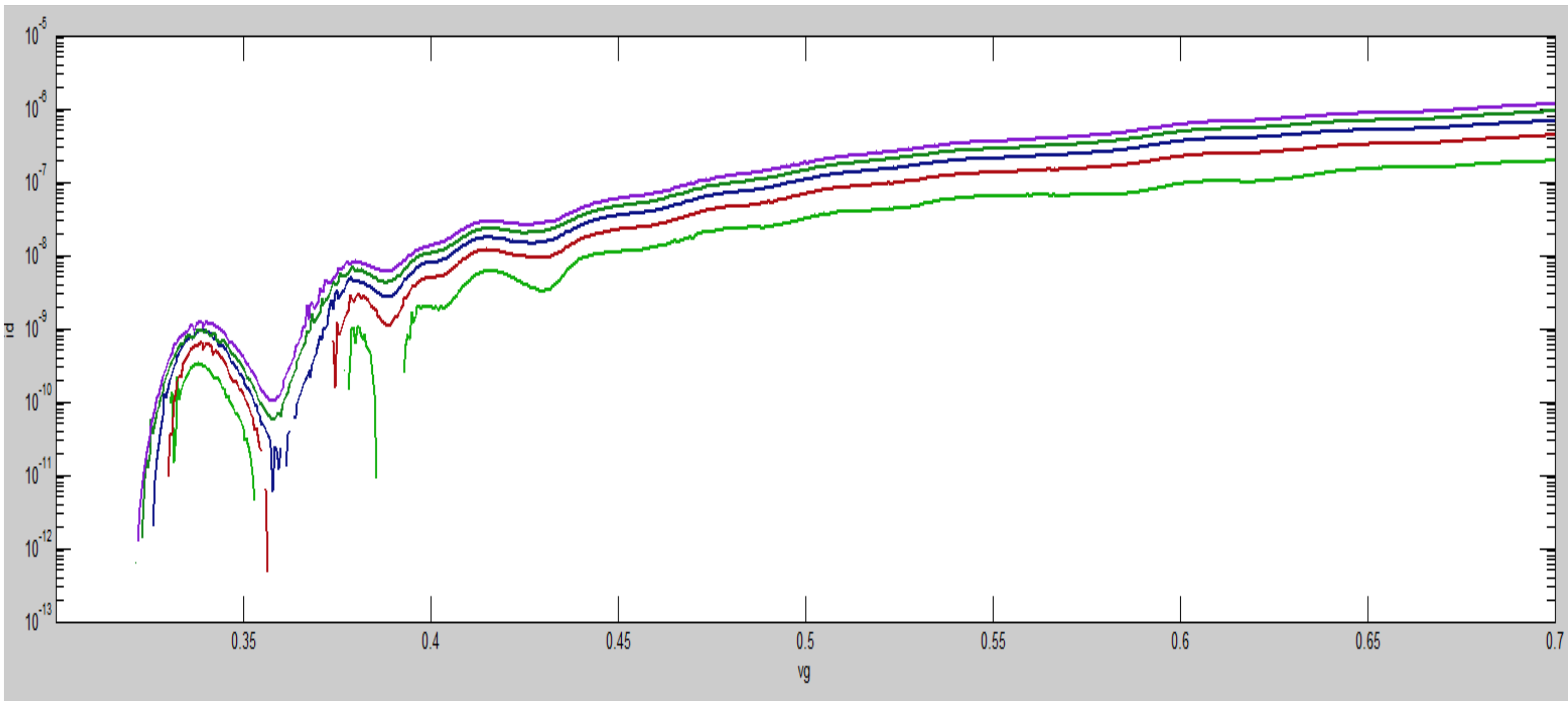
Data Analysis



Drain Current

Gate Voltage

Acknowledgements

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