



Quasi-2D Solution to Three-Terminal Undoped Symmetric Double-Gate Schottky-Barrier MOSFETs

*Guojun Zhu, Guan Huei See, Xing Zhou, Zhaomin Zhu, Shihuan Lin,
Chengqing Wei, Ashwin Srinivas, and Junbin Zhang*

Nanyang Technological University
Singapore

(zhug0002@ntu.edu.sg)

June 3, 2008



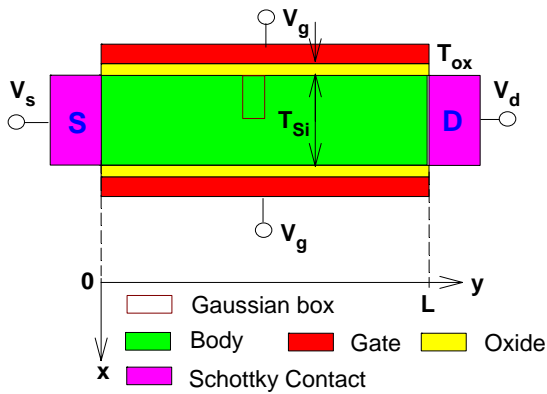
Outline

- **Schottky Barrier MOSFETs**
- **Quasi-2D potential solution**
- **Terminal current formulation**
- **Results & Discussion**
- **Conclusions**

The Schottky Barrier Double-Gate Structure

WCM 2008

MSM / Nanotech



Why Schottky Barrier MOSFETs

- Scalability (Abrupt junction)
- Low parasitic resistance

Current transport mechanism

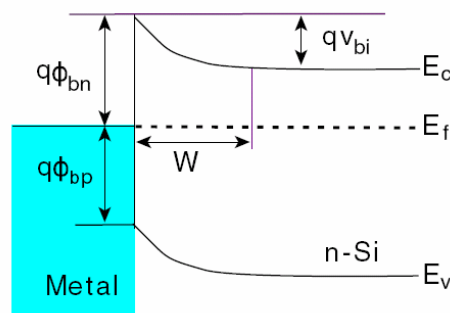
- Thermionic + tunneling
- No drift-diffusion

Operation of Schottky Diode

WCM 2008

MSM / Nanotech

- Schottky diode (Thermionic + Tunneling Current)



- Complicated if it is Schottky Barrier MOSFET

Energy Band Model

WCM 2008

MSM / Nanotech

- Apply Gauss' Law to the Gaussian Box

$$C_{ox} [V_g - V_{FB} - \phi_s(y)] + \frac{\epsilon_{Si} X_o}{\eta} \frac{d^2 \phi_s(y)}{dy^2} = -Q_i$$

- Apply boundary conditions

$$V_c(y) = \phi_s(y) + \delta\phi_{s,s}(y) + \delta\phi_{s,d}(y)$$

$$\delta\phi_{s,s}(y) = (V_{bi,s} + V_s - \phi_s) \frac{\sinh((L-y)/\lambda_s)}{\sinh(L/\lambda_s)} \quad \lambda_{s(d)} = \sqrt{\frac{\epsilon_{Si} T_{ox} X_o}{\eta \epsilon_{ox}}}$$

$$\delta\phi_{s,d}(y) = (V_{bi,d} + V_d - \phi_s) \frac{\sinh(y/\lambda_d)}{\sinh(L/\lambda_d)}$$

Energy Band Model

WCM 2008

MSM / Nanotech

- Quasi-2D is known to be valid only in subthreshold region
- Can be extended to tunneling dominant region

$$\lambda_{tun,s(d)} = \sqrt{\frac{2\epsilon_{Si} \Phi_{B,s(d)}}{qN_{eff}}} \quad N_{eff} = \frac{Q_{i,s} + Q_{i,d}}{qX_o}$$

$$Q_{i,s(d)} = \sigma_{s(d)} C_{ox} (V_g - V_{sfb,s(d)} - \phi_{seff,s(d)})$$

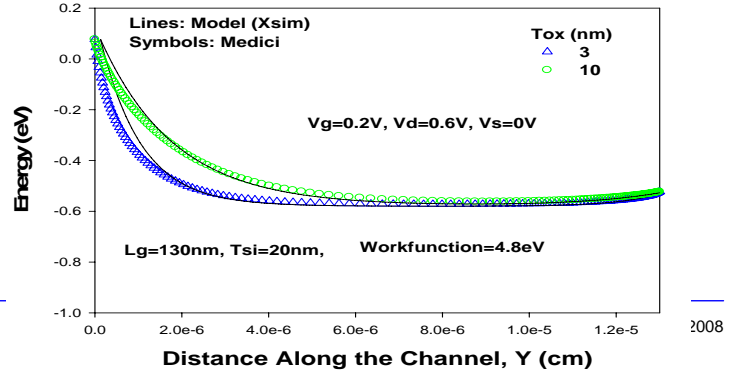
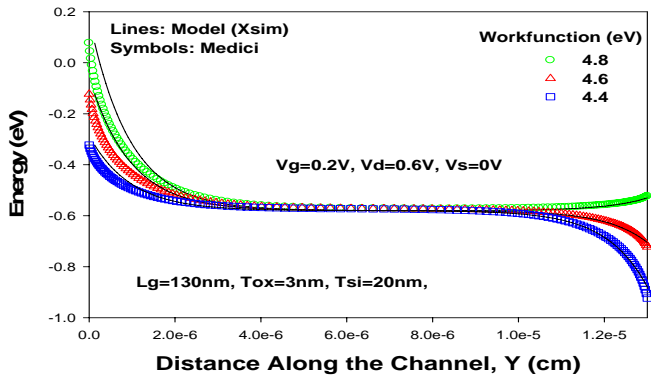
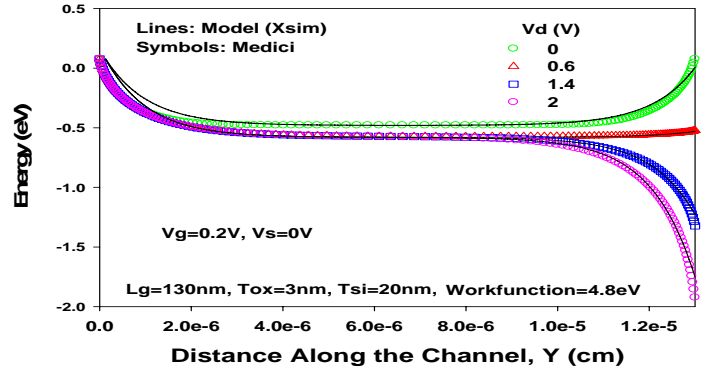
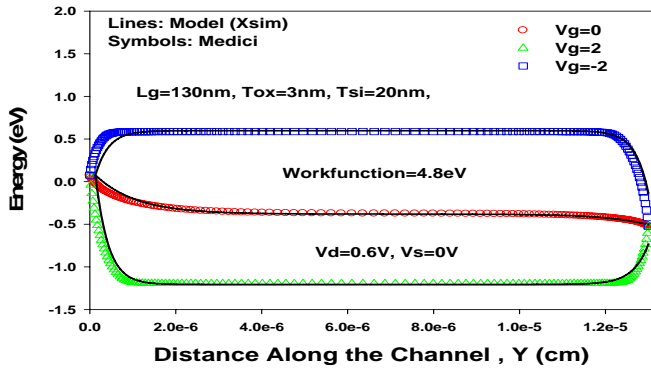
$$V_{sfb,s(d)} = V_{FB} + V_{bi,s(d)} + \frac{\sqrt{2q\epsilon_{Si} n_i}}{C_{ox}} e^{\frac{V_{bi,s(d)}}{2V_{th}}}$$

$$\lambda_{s(d)} = \frac{1}{2} \left[\lambda_{tun,s(d)} + \lambda_{sub} + \delta_{s(d)} - \sqrt{(\lambda_{tun,s(d)} - \lambda_{sub} - \delta_{s(d)})^2 + 4\delta_{s(d)} \lambda_{tun,s(d)}} \right]$$

Energy Band Model

WCM 2008

MSM / Nanotech

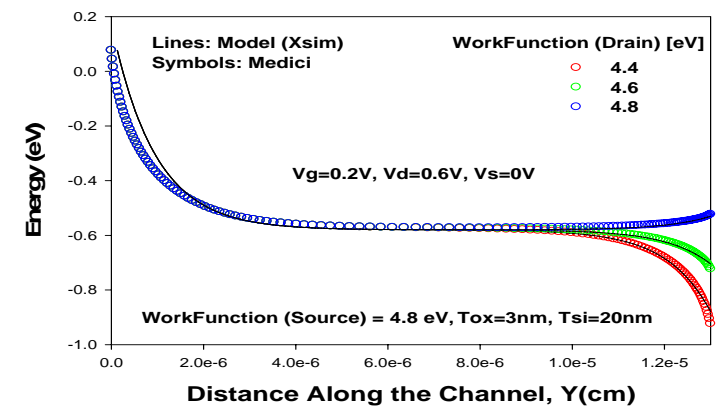
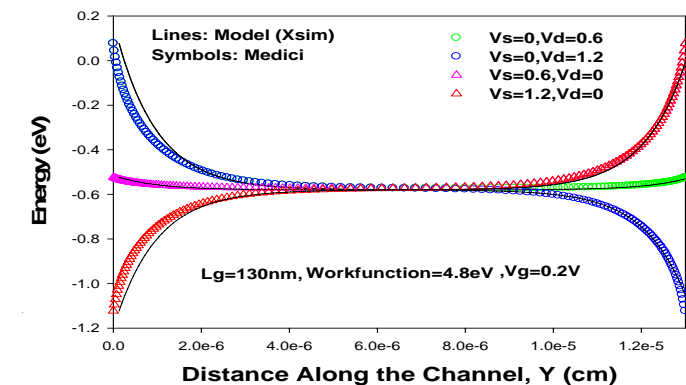
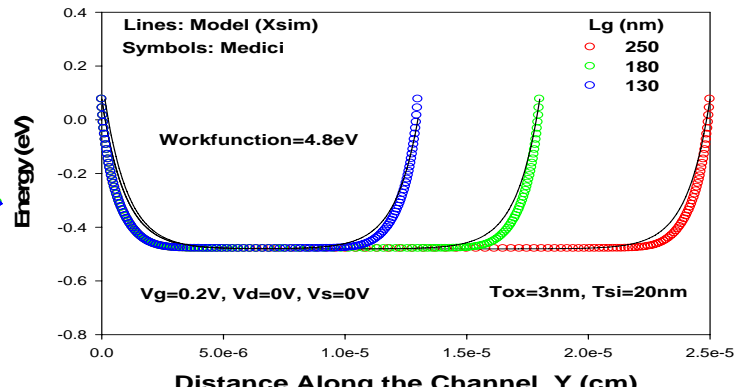
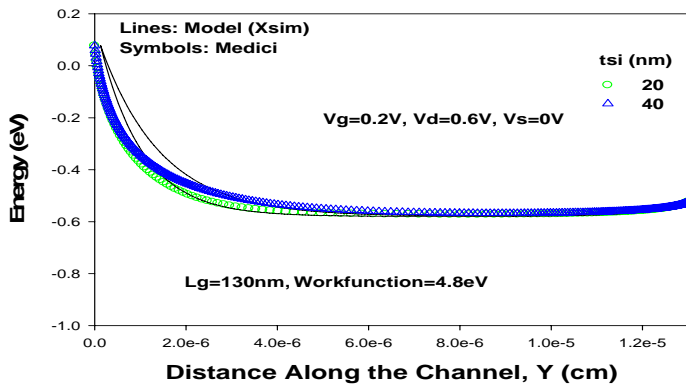


2008

Energy Band Model

WCM 2008

MSM / Nanotech



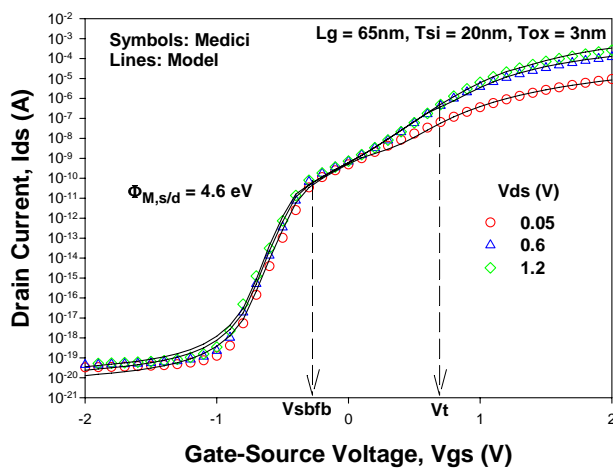
Terminal Current Calculation

- Apply tunneling method like WKB/MG/Airy function et al. (Miller-Good is used in our model)

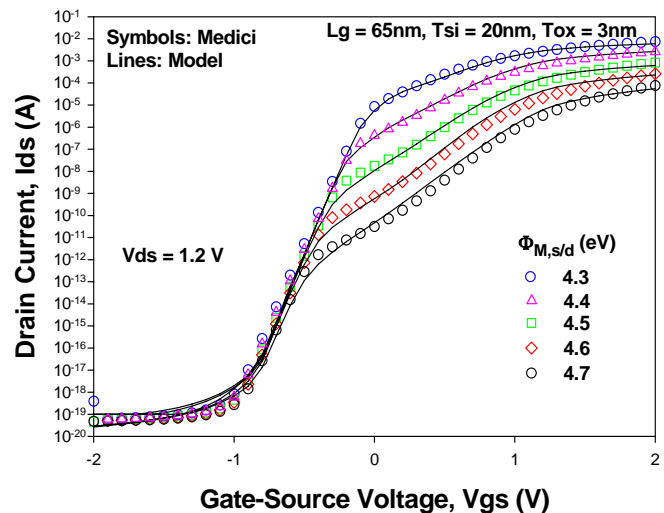
$$\begin{aligned}
 I_{ds,n} &= I_{d,n} - I_{s,n} \\
 &= -\frac{AA^*T}{k_B} \left[\int_{q(\Phi_{B,d} - \Delta\Phi_{B,d} + \Phi_{C,d})}^{E_\infty} T_t(E) \cdot f_C \{E; -q(V_d - V_{\min})\} dE \right. \\
 &\quad \left. - \int_{q(\Phi_{B,s} - \Delta\Phi_{B,s} + \Phi_{C,s})}^{E_\infty} T_t(E) \cdot f_C \{E; -q(V_s - V_{\min})\} dE \right]
 \end{aligned}$$

Results and Discussion

V_{ds} variation

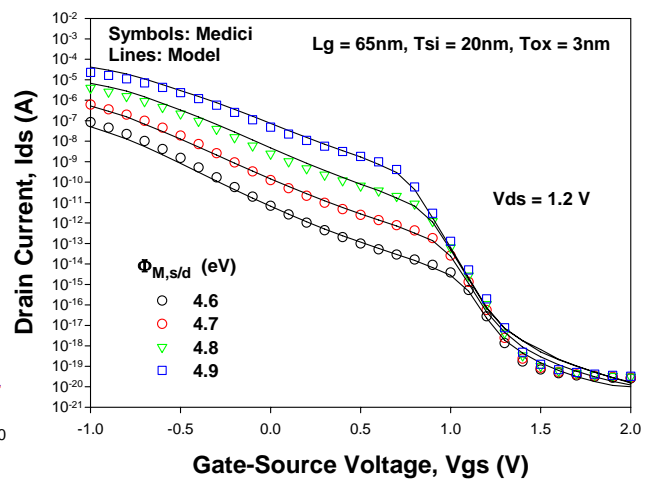
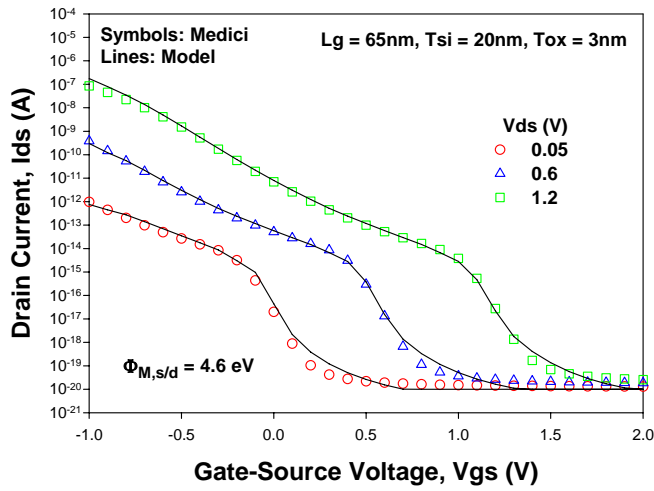


S/D workfunction variation



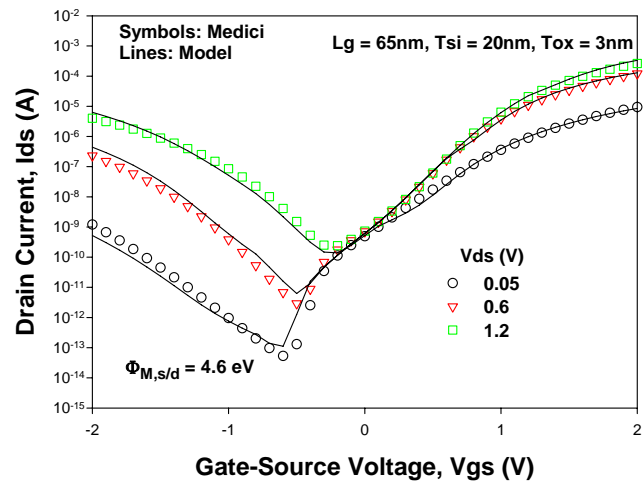
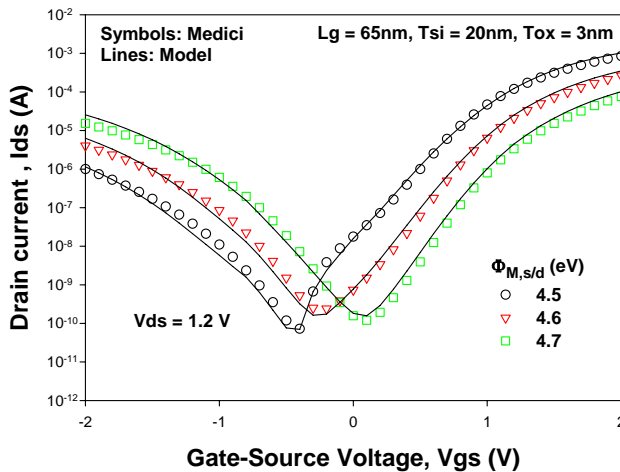
Results and Discussion

Hole current only



Results and Discussion

Ambipolar current

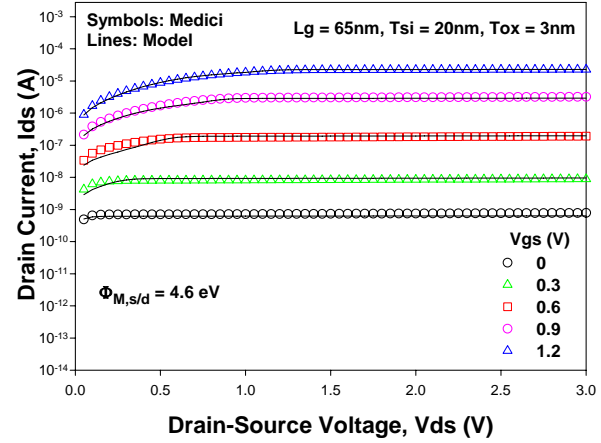
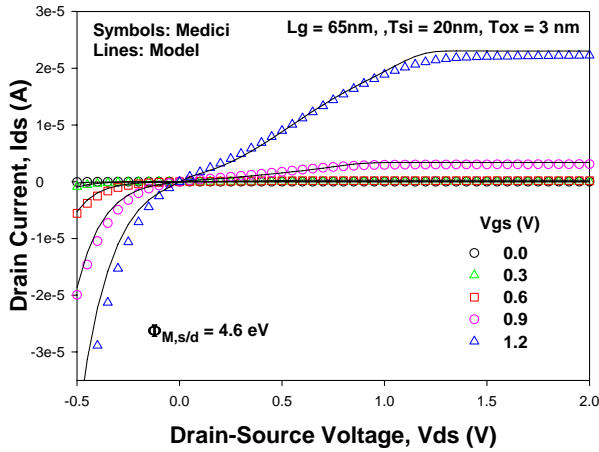


Results and Discussion

WCM 2008

MSM / Nanotech

Electron current only

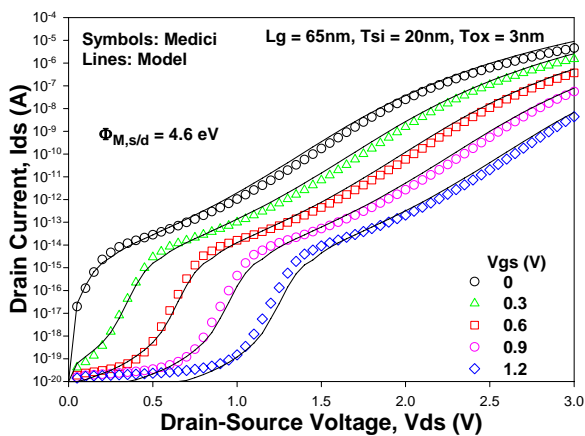


Results and Discussion

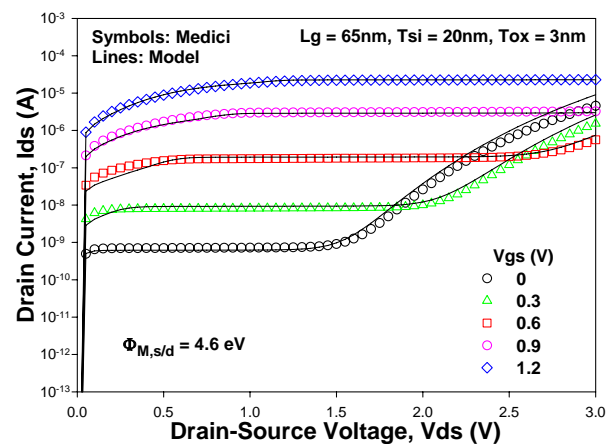
WCM 2008

MSM / Nanotech

Hole current only

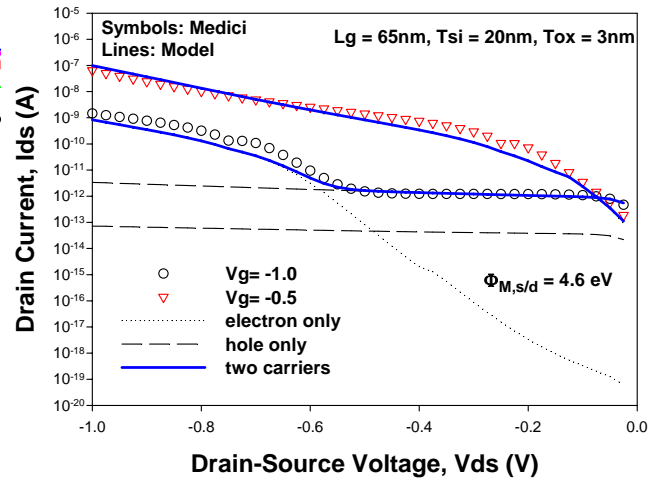
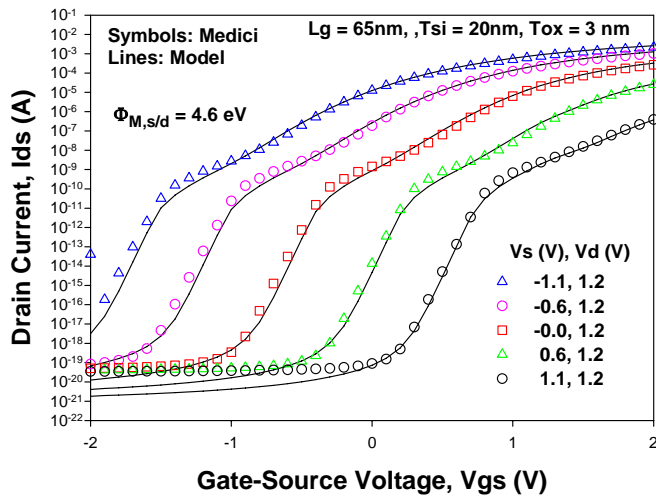


Ambipolar current



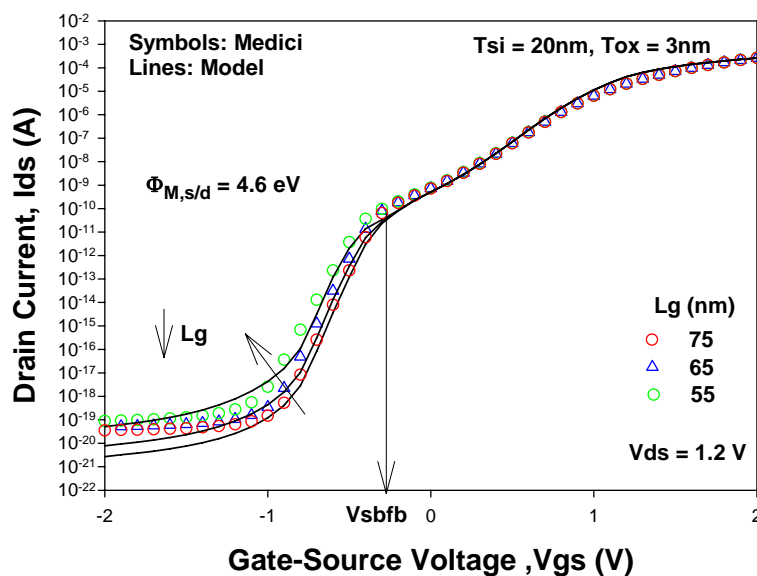
Results and Discussion

Electron current only



Results and Discussion

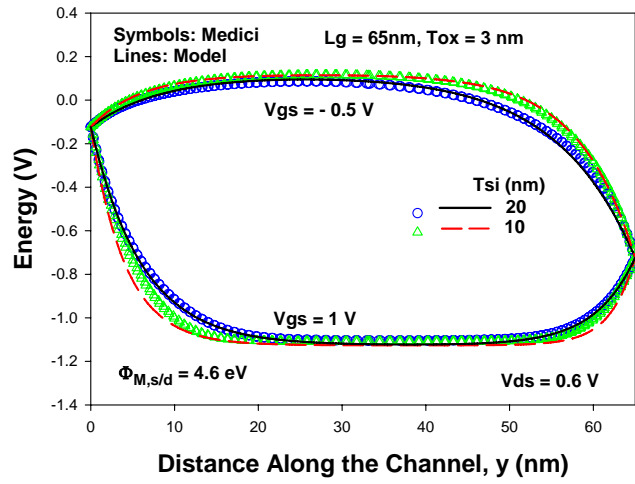
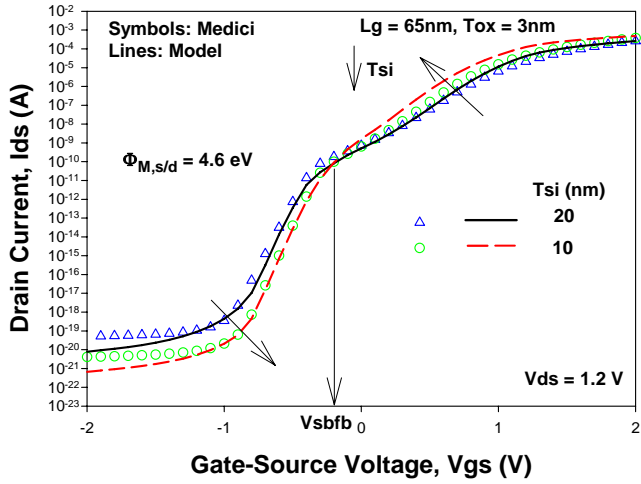
Gate length variation



Effects of Body Thickness

WCM 2008

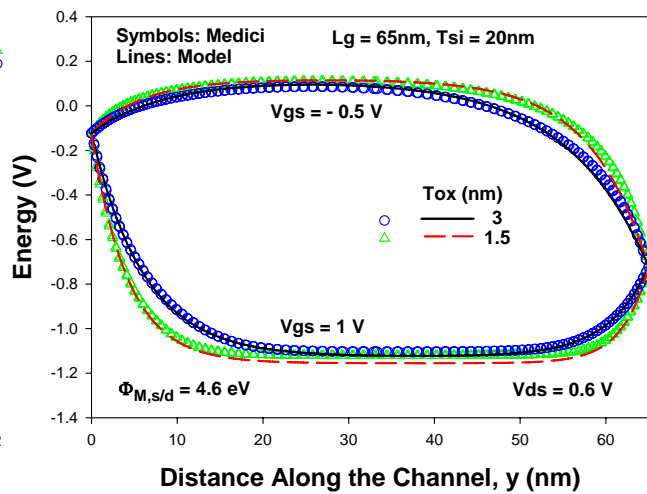
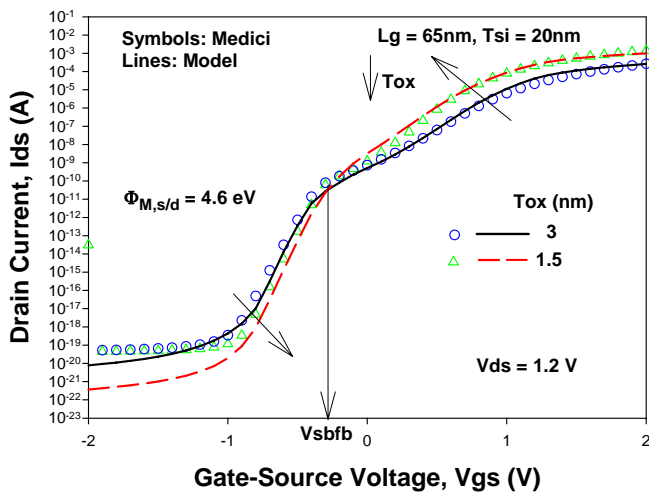
MSM / Nanotech



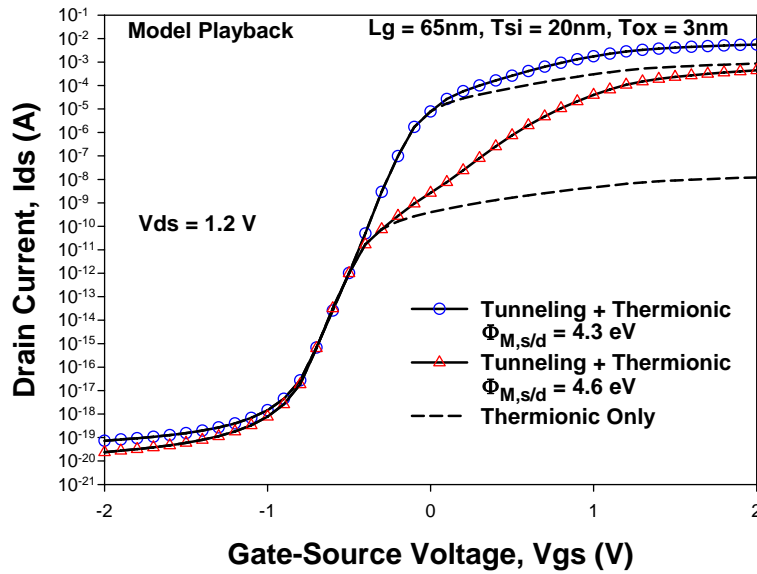
Effects of Oxide Thickness

WCM 2008

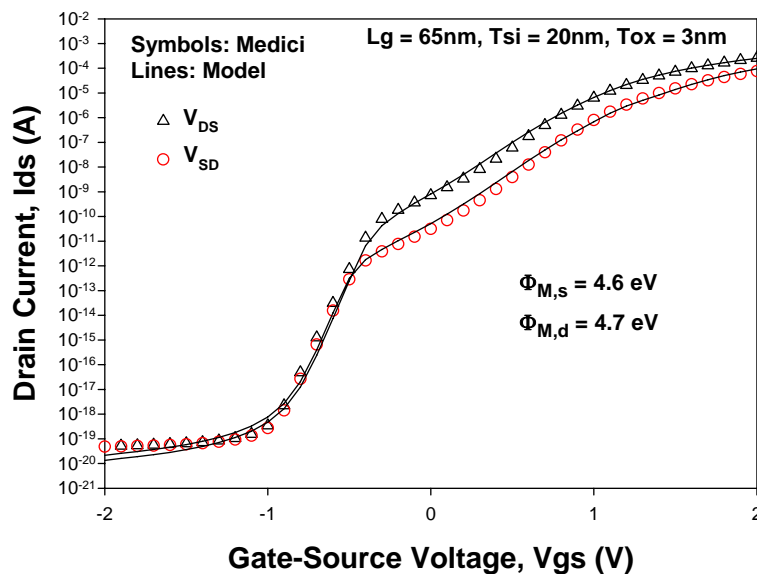
MSM / Nanotech



Components of the Current



Able to Handle Asymmetrical Structure!



Conclusions

- A compact Energy band and Drain current model is developed**

- The modeling methodology can be easily to handle other promising structures like SB Nanowire**