Quantum Transport in Tunneling Field Effect Transistors

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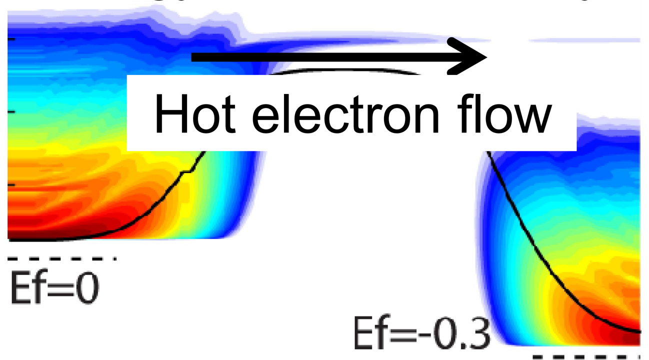
I. Motivation

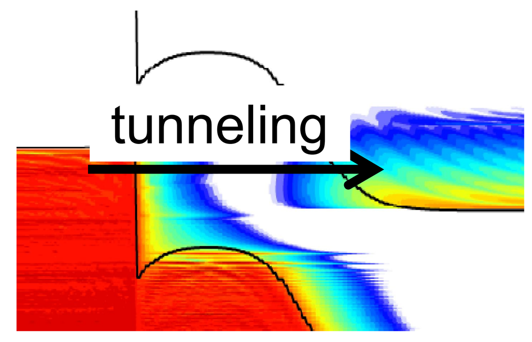
Reduction of the subthreshold slope (SS)

MOSFET: Carrier injection from thermal tail of Boltzmann Distribution SS>60mV/dec
TFET: Bandgap blocks "hot" electrons, current only due to tunneling SS<60mV/dec

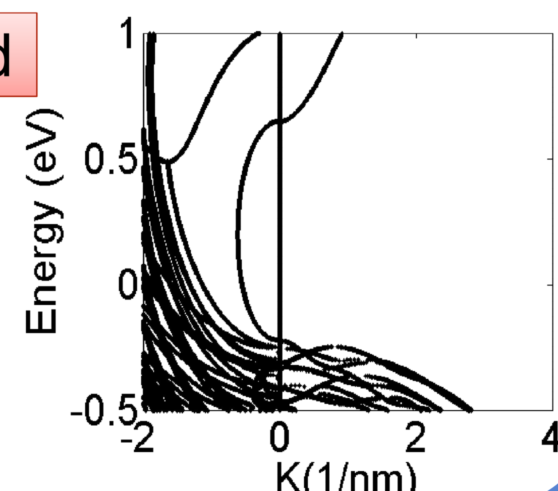
Si MOSFET
Energy resolved density



GaSb/InAs TFET
Energy resolved density

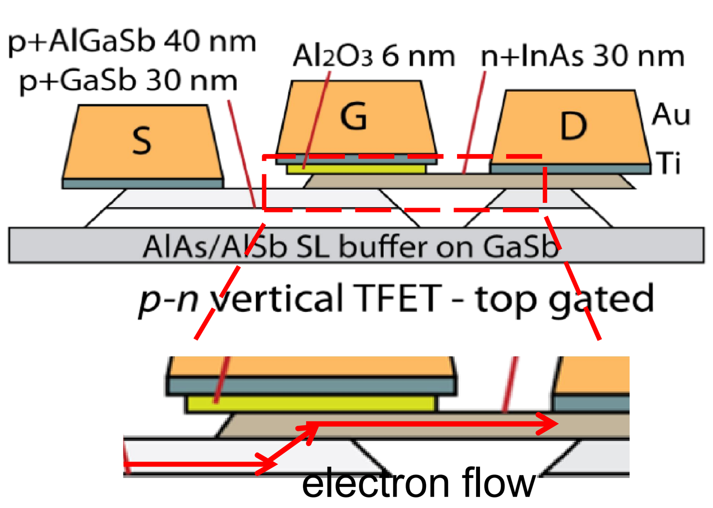


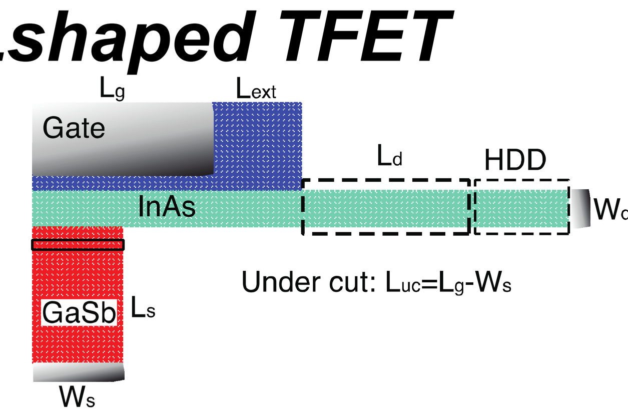
Accurate&efficient prediction of TFETs required



Accurate TFET simulations require correct…
- ➢Bandgap for accurate tunneling barrier heights
- ➢Density of states to determine contact Fermi levels
- ➢Complex bandstructure for correct tunneling probability

Device structure -- Lshaped TFET





- ➢ Complicated geometry → Electron flows along non-homogeneous path
- ➢ Tunneling effect dominates

Two common methods for TFET calculations:

Drift Diffusion (DD) + Wentzel–Kramers–Brillouin (WKB)

☺ Low numerical load ☹ Fails to reliably predict tunneling

Atomistic tight-binding based NEGF

☺ Suitable for nano-scale devices
☺ Include complex bandstructure effects
☺ Applicable for complicated geometries
☺ Tunneling effect included automatically
☹ Large computational burden

- Tight-binding based NEGF method is required to accurately depict the Lshaped TFET performance
- Full quantum self-consistency is numerically expensive

II. Approaches

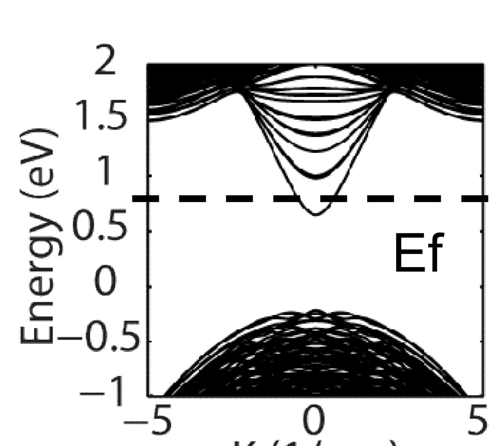
Hybrid solver: Drift-Diffusion & NEGF

1) DD: Band edges for the carrier injection

Bandstructure depends on material and device geometry: Band edges are extracted from the lead unit cell

2) DD: Fermi level in the leads

Self-consistent calculations with different doping densities: Differences between band edges and Fermi levels are determined



3-dimentional DOS for DD simulation

3) DD: Density of states (DOS)

3D DOS with parabolic band is assumed in the drift diffusion model: Effective DOS matching the same Fermi level and density as calculated

$$n = N_C \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_C)$$

4) NEGF: Transport properties calculated using converged semiclassical Poisson potential

Resulting electrostatic potential is used as the final potential for the NEGF calculation

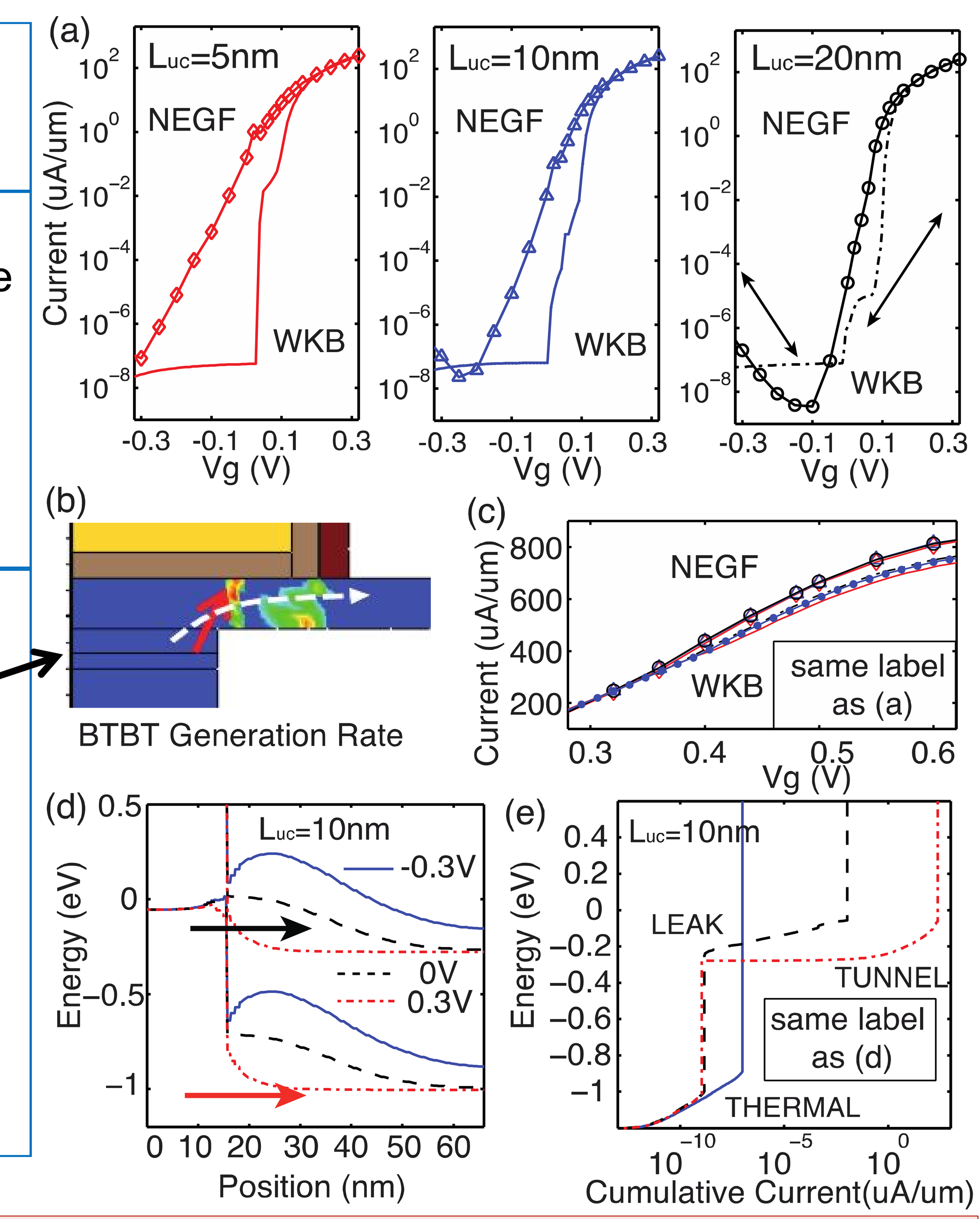
III. Results and Discussions

Comparison of WKB and NEGF

- ➢ Both WKB and NEGF show degradation of SS with shorter undercut

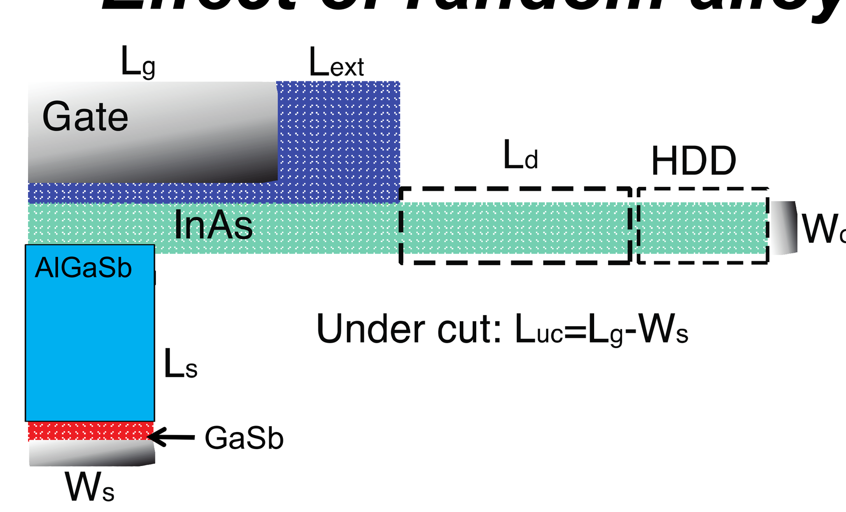
Difference:
- ➢ Current slope: abrupt change in WKB; smooth change in NEGF
- ➢ Ambipolar current: not observed in WKB; observed in NEGF

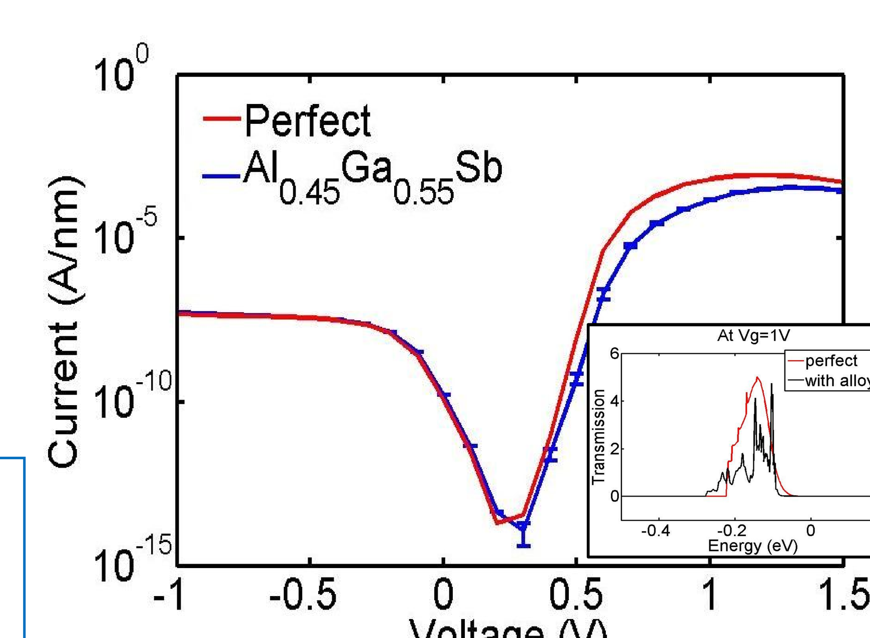
Reason:
- ➢ Tunneling path: straight line (red) in WKB; non-straight line (white) in NEGF
- ➢ Maximum tunneling length: predefined in WKB; calculated in NEGF
- ➢ Effective mass: constant in WKB; automatically determined from full band calculations in NEGF



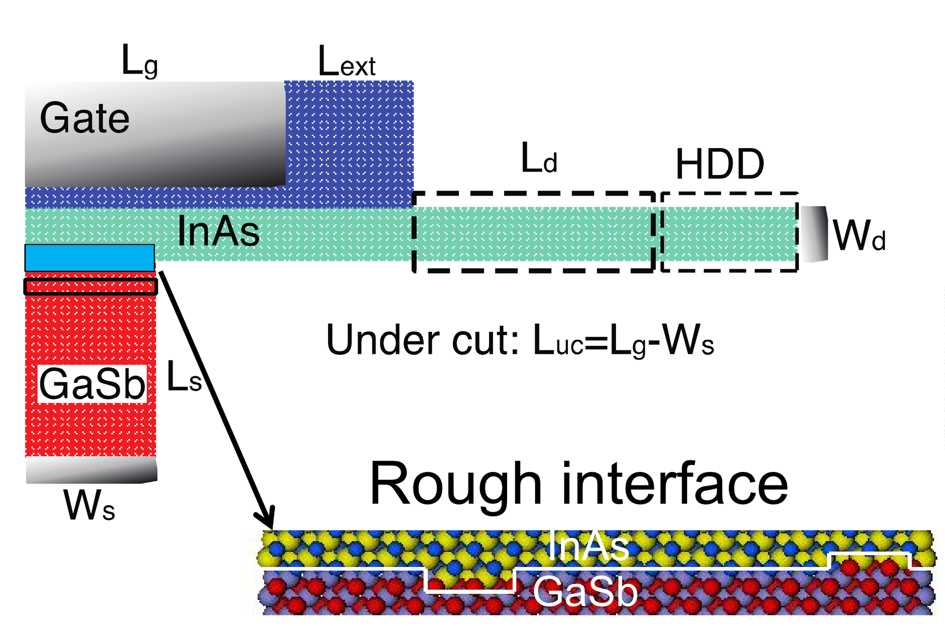
NEGF provides more accurate description of TFET behavior

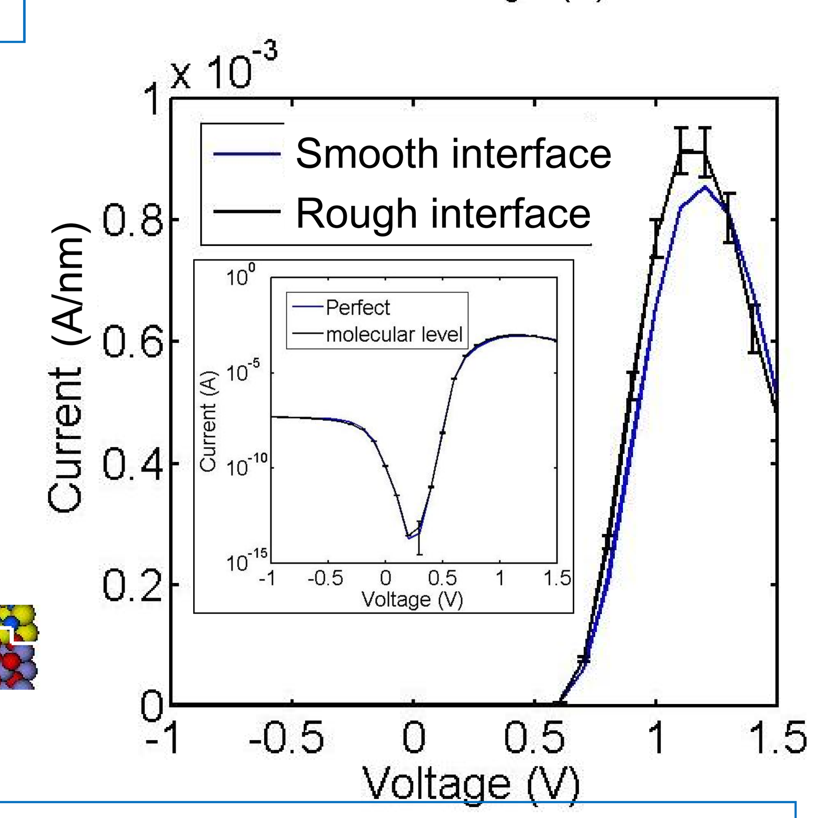
Effect of random alloy, interface roughness





- AlGaSb random alloy with different Al fractions for the interface assumed
- Random alloy can decrease on-state current by ~10 times





- GaSb/InAs interface are assumed to have a 1 Monolayer thick roughness
- Roughness increases the on-state current by ~9%

IV. Conclusions

- ➢NEGF results predict TFET performance more reliable than WKB calculations
- ➢Randomness of alloys decreases the on-state current by a factor of ~10
- ➢GaSb/InAs interface roughness increases the on-state current by ~9%

Acknowledgement

Support by the NEMO5 team including J. Fonseca and J. M. Sellier and technical discussions with H-H. Park and the MIND research team around A. Seabaugh and P. Fay including Y. Lu, R. Li and G. Zhou are acknowledged.

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