Quantum Transport in GaSb/InAs Nanowire TFET with Semiclassical Charge Density

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INTRODUCTION

Tunneling Field Effect Transistors (TFETs) have been investigated intensively because of its ability to reduce the 60meV/dec subthreshold swing (SS) which limits power scaling in conventional MOSFETs. However, tunneling field effect transistors (TFETs) suffer from low I_{on}, which reduces the speed of TFETs. To increase the I_{on} and hence the tunneling probability one seeks for efficient ways is to reduce then bandgap [1]. Materials with broken-gap (BG) band alignment e.g. GaSb/InAs are promising to build TFETs because of a zero band overlap.

CHANLLENGES

A full self-consistent quantum simulation including electron-phonon scattering can in principle describe TFETs with high accuracy. However, it requires an extremely high computational intensity to solve such NEGF equations [2]. Usually coherent transport simulations are performed to obtain the upper device performance limit.

Fig.1a shows structure of a BG diode. A reasonable approximation for the band profile of the diode operating at Vd=-0.2V is shown in Fig.1b. Due to BG band alignment there are triangular wells in both sides of the heterostructure. In real the structure, carriers will get thermalized and fill the triangular well. Fig.1c shows the electron density with dissipative transport. However for coherent transport, carriers cannot lose energy and the carrier density in the well is not realistic Fig.1d. This results in severe convergence problem in coherent self-consistent calculations where some notch states are occupied under a high potential float-up and empty under a low potential float-up.

METHOD

In this work, a method combining the semiclassical density and Non-Equilibrium Green's Function (NEGF) is developed to achieve an efficient simulation of GaSb/InAs TFET. This model assumes an equilibrium carrier distribution. States are filled according to quasi-Fermi levels, which could vary spatially and mimic strong scattering. By Eq.1 the triangular well in Fig.1d could be populated, similar to the case of dissipative transport (Fig.1c).

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

Different from a diode, which takes bulk effective mass (m*) and bandgap, confinement in NWTFET require modification of the semi-classical parameters [3, 4]. Fig. 2a shows geometry of a NWTFET. Taking one unit cell from lead (Fig.2a) and calculating the bandstructure in the transport direction, one can obtain the effective bandgap after confinement. The effective mass is calculated from the doping density (N_D) and the doping degeneracy (η_c) in the contacts according to Eq. 1. The doping degeneracy is calculated using the sp3s* tight-binding model self-consistently for the same unit cell of NWs shown in Fig.2a with equilibrium boundary condition. The modification of density of states due to confinement is included in the process.

Calculated band edges and doping degeneracy energies for different NW diameters are plotted in Fig.2b,c and used in later calculations. Calculations are performed with NEMO5 [5].

RESULTS

BG hereostructures may loose their BG characteristic due to quantization at diameters smaller than 10nm as shown in Fig. 2. However, one can shift the overall bandstructure by the tight-binding onsite energy to obtain different band alignments [6] (Fig.3a).

Fig.3a shows I_d-V_g characteristics of 5nm

NWTFET with BG, SD and its original band alignments. Ion is biggest in BG band alignment case, but SS is not changed. Fig.3b shows IV curves for two NWTFETs of 2.5nm and 5nm diameters with the same amount of band shift (100meV). In this case, the Ion of two NWTFETs are very similar due to same band alignment, but SS are different due to density of states and property of tunnelling barrier, which is related to the complex bandstructure.

CONCLUSION

In this work, a method based on combined semiclassical electrostatic potential and NEGF calculation is developed and applied to transport calculation of broken-bandgap NWTFETs. By extracting parameters from full quantum calculation in homogeneous lead, confinement effects are considered through additional band offset and effective mass. IV characteristics of 5nm NW is calculated by this method. Effects of band alignment are simulated by shifting bandstructure of InAs.

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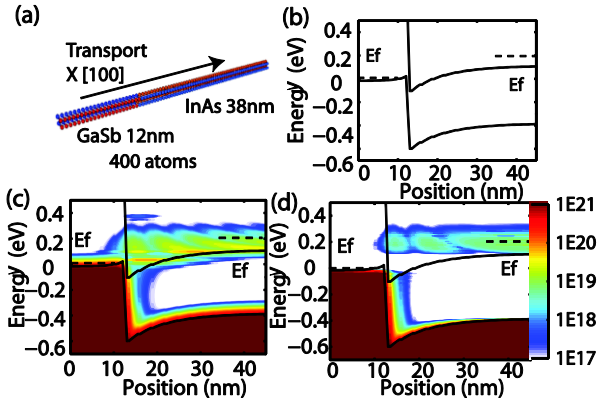

Fig. 1. Simulation geometry and transport in GaSb/InAs diode at Vd=-0.2V. (a) Device structures for BG diode. (b) Band profile at Vd = -0.2V. (c) Electron density with phonon scattering for band profile in Fig.1a. (d) Coherent transport electron density for band profile in Fig.1a.

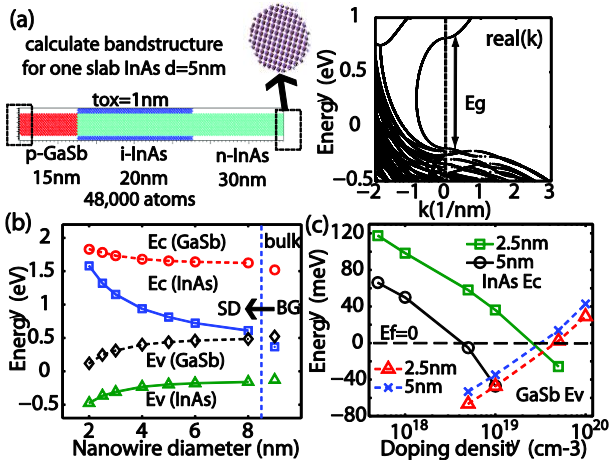

Fig. 2. Determine band edges and doping degeneracy in NWs. (a) Calculate drain contact bandstructure from one unit cell. (b) Band edges extracted from bandstructure in Fig.2a for different diameters. (c) Assuming Ef = 0, equilibrium band edges in NWs with diameters of 2.5 nm and 5 nm.

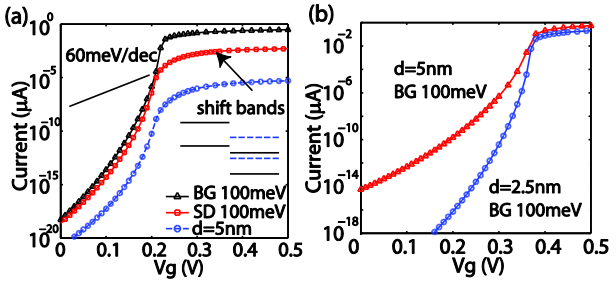

Fig. 3. Id-Vg of NWTFET with different band alignment and diameters. (a) IV of 5nm NWTFET with shifted InAs bandstructure. (b) IV for 2.5nm NW and 5nm NW TFET with shifted 100meV broken-gap (BG) band alignment.

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