Effect of confinement in III-V nanowire field effect transistors

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ABSTRACT

Using quantum transport simulations the effect of confinement in III-V gate-all-around nanowire field effect transistors (NWFETs) of different dimensions has been investigated. The Non-Equilibrium Green's Function (NEGF) formalism in the effective mass approximation (EMA) has been used, and both ballistic and dissipative transport have been considered. The effective masses have been extracted from tight-binding (TB) simulations.

INTRODUCTION

NWFETS are one of the promising candidates being considered towards the end of the International Technology Roadmap for Semiconductors (ITRS). [1] III-V nanowires are also being considered because of their high mobility compared to Si. In this work, GaAs [2] and InGaAs NWFETs of cross-section 2.2 x 2.2 nm^2 and 4.2 x 4.2 nm^2, and channel length 6 nm, 10 nm and 20 nm are considered. An example of the structure of the devices is given in Fig. 1.

MODEL

The NEGF formalism is a widely used tool to study dissipative quantum transport (i.e. inelastic electron-phonon transport) in nanotransistors. The self-consistent Born approximation (SCBA) with local self-energies has been deployed. The EMA has been used, decomposing the 3D problem and allowing phonon scattering to be implemented efficiently. All scattering parameters have been taken from [3], acoustic, optical and polar optical phonon scattering have been considered. The effective masses have been extracted form TB simulations. [4] The EM Hamiltonian is given by Eq. (1).

$$H_v(\vec{r}) = -\frac{\hbar^2}{2}\nabla_i\left(\frac{1}{m_v}\right)_{ij}\nabla_j + V(\vec{r}) \tag{1}$$

RESULTS

The effect of changing the cross-section on the relative position of the valleys can be observed by comparing Fig. 2. and Fig. 3, which show the energy-resolved current spectra for a 2.2 x 2.2 nm^2 and 4.2 x 4.2 nm^2 GaAs NWFET respectively. For the 2.2 x 2.2 nm^2 NWFET the low mass Γ-valley is elevated in energy such that it is higher than the heavier L and X-valleys. This results in greatly reduced current in the Γ-valley for the 2.2 x 2.2 nm^2 device in comparison to the 4.2 x 4.2 nm^2 device. The I_d-V_g characteristics for each valley for both cross-sections can be seen in Fig. 4. and 5. The transverse potential energy profile and the electrostatic potential energy is shown in Fig. 6 . We have also calculated the percentage tunnelling and current reduction. For a 2.2 x 2.2 nm^2, 6 nm channel GaAs scattering caused a 41% increase in tunnelling and a 72% reduction in the on-current at low drain.

CONCLUSION

In this work, III-V NWFETs of different dimensions have been investigated. It was found that the strong quantisation caused the relative position of the valleys to vary with the cross-section, with the low mass Γ-valley becoming elevated in energy for the 2.2 x 2.2 nm^2 cross-section devices. This resulted in very low current in the 2.2 x 2.2 nm^2 NWFETs.

REFERENCES

[1] http://www.itrs.net.
[2] A. Price and A. Martinez, "*Investigation on phonon scattering in a GaAs nanowire field effect transistor using the Non-Equilibrium Green's Function formalism*," J. Appl. Phys. (2015 awaiting publication).
[3] M. Lundstrom, "*Fundamentals of carrier transport*," Cambridge University Press (2000).
[4] Y. M. Niquet, A. Lherbier et al. Phys. Rev. B **73**, 165319 (2006).

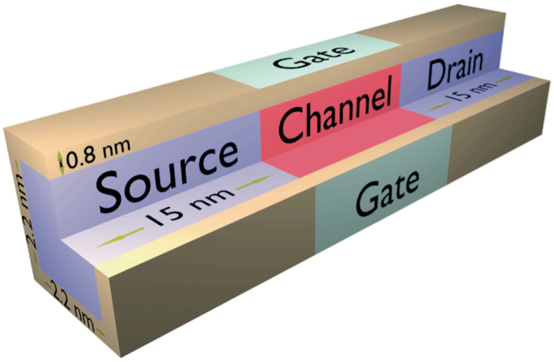

Fig. 1. Example of device structure for a 2.2 x 2.2 nm^2 cross-section NWFET.

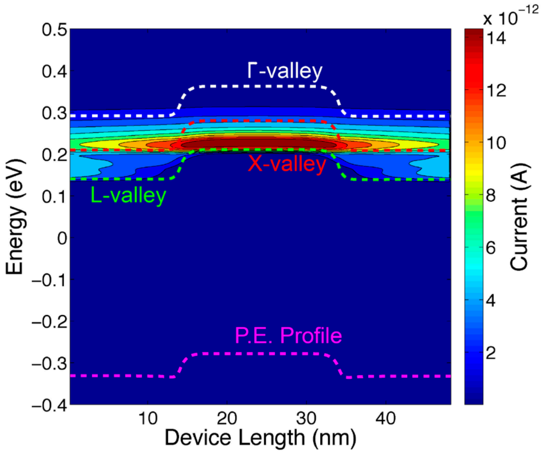

Fig. 2. Energy-resolved current spectrum for a 2.2 x 2.2 nm^2 cross-section, 20 nm channel length, GaAs NWFET with scattering, $V_G = 0.8$ V and $V_D = 1$ mV.

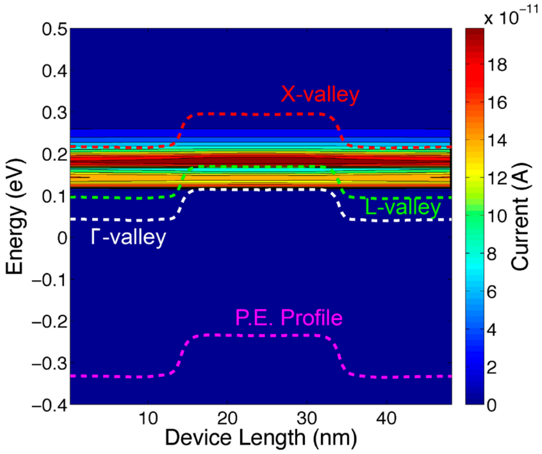

Fig. 3. Energy-resolved current spectrum for a 4.2 x 4.2 nm^2 cross-section, 20 nm channel length, GaAs NWFET with scattering, $V_G = 0.8$ V and $V_D = 1$ mV

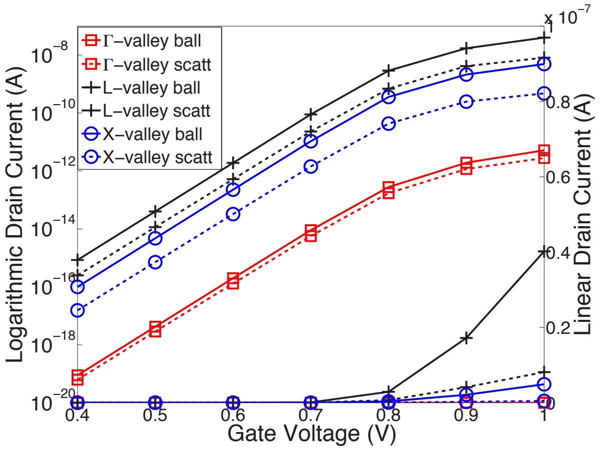

Fig. 4. I_d-V_g characteristics for each valley for a GaAs core, 2.2 x 2.2 nm^2 cross-section, 20 nm channel length NWFET at low drain bias, $V_D = 1$ mV, with and without scattering.

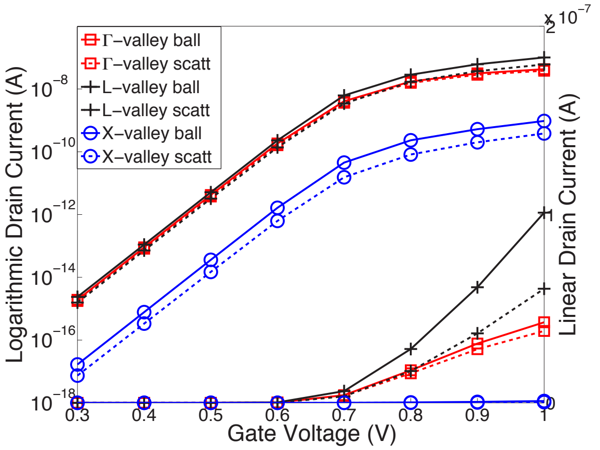

Fig. 5. I_d-V_g characteristics for each valley for a GaAs core, 4.2 x 4.2 nm^2 cross-section, 20 nm channel length NWFET at low drain bias, $V_D = 1$ mV, with and without scattering.

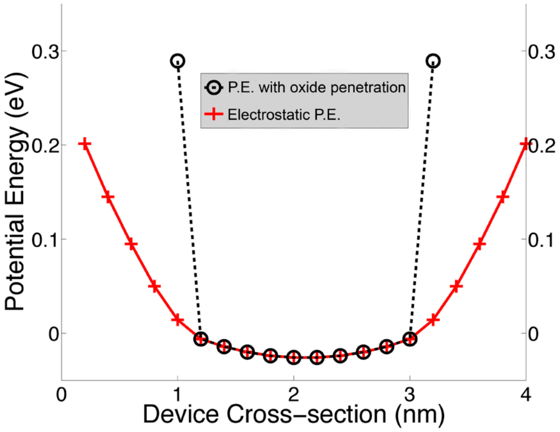

Fig. 6. Transverse potential energy profile with 0.2 nm oxide penetration, and electrostatic potential energy up to the boundary of the metal at low gate, $V_G = 0.3$ V