Remote soft-optical phonon scattering in Si nanowire FETs

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ABSTRACT

In this work we calculate the impact of remote SO soft optical phonon scattering on the transfer characteristics of a gate-all-around Si nanowire transistor. The polar SO phonons are confined to the HfO_2/Si interface. Nanowire transistors with two different cross sections are considered. Our results show that the impact on the drain current is of the same order and of the same importance as other commonly considered bulk-type phonons.

MODEL AND SIMULATION

The effect of interface phonons has been widely investigated for bulk-like MOSFETs [1] since the deployment of high-κ materials as gate insulators. It has been shown that SO-phonon scattering is responsible for a substantial amount of degradation of the MOSFET channel mobility [1]. The objective of the present study is: (a) to develop a theoretical model for SO phonons in 3D nanowire structures with rectangular and circular cross-sections; (b) to apply this model to Si gate-all-around nanowire transistors that differ in cross-sectional area. We adopt a NEGF formalism in the effective mass approximation and use mode-discretization to describe the electron transport. Apart from the SO phonons the phonon scattering models used are the same as in [2]. Two types of SO phonon are considered following the strategy of [1]. The form factor (FF) between two cross-section sub-bands in the electron-SO phonon self-energy is calculated by integrating the square of the corresponding wave functions times a function which decays away from the interface. This multiplicative pre-factor function is shown in Fig. 1 for a 2.2x2.2 nm^2 cross section.

The Si nanowires simulated have dimensions 14/10/14 nm for source/gate/drain; n-doping in source and drain is 10^{20} cm^{-3}; drain bias is 0.4 V. Fig. 2 shows the I_D-V_G characteristic of the 2.2x2.2 nm^2 cross-section nanowire. The four curves correspond to simulations with (1) ballistic; (2) SO-phonons; (3) bulk-phonons; (4) SO + bulk phonons. Results for the 4.2x4.2 nm^2 cross-section nanowire are shown in Fig. 3. The SO phonon-induced reduction of the on-current ($1-I_{SO}/I_{bal}$) is smaller than the reduction due to the other phonon mechanisms for the small cross-section nanowire; however, Fig. 3 shows that for the large cross-section transistor the SO phonon current reduction is very similar to the reduction due to the other phonon mechanisms. This is partly due to this transistor having a larger ratio of FF_{SO}/FF_{other} (form factor for SO phonons/form factor for other phonons) than the smaller cross-section transistor. The current reduction for both devices as a function of the gate bias is shown in Fig. 4. At low gate bias the current reduction due to SO and other phonons are considerable even if they are smaller than the corresponding high gate bias reduction. Fig. 5 and Fig. 6 show the current spectra, considering only SO phonons for the small and large cross-section devices respectively (V_G=0.7 V). The average energy of the electrons that contributes to the current changes strongly throughout the device in Fig. 5 as compared to Fig. 6, indicating a large effective electron-phonon coupling in the small cross-section device. In conclusion, this work demonstrates that remote SO phonon scattering is important for nanowire transistors with relatively thick (HfO_2) oxide interfaces. This research was partially supported by EPSRC under a Career Acceleration Fellowship Grant No. EP/I004084/2.

REFERENCES

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[2] M. Aldegunde, et al, *J. Appl. Phys.*, vol.110, no. 9, p. 094518, 2011.

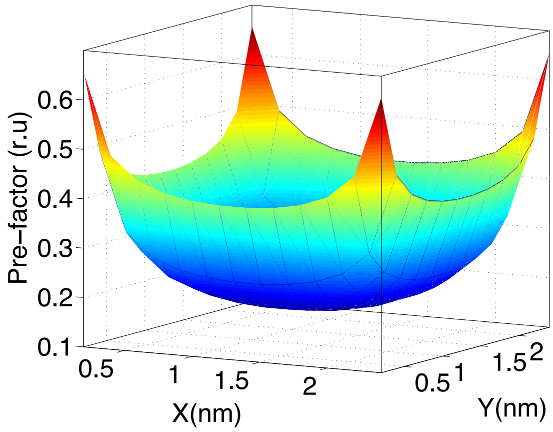

Fig. **1** Form pre-factor as function of the position for the 2.2x2.2 nm^2 cross-section nanowire

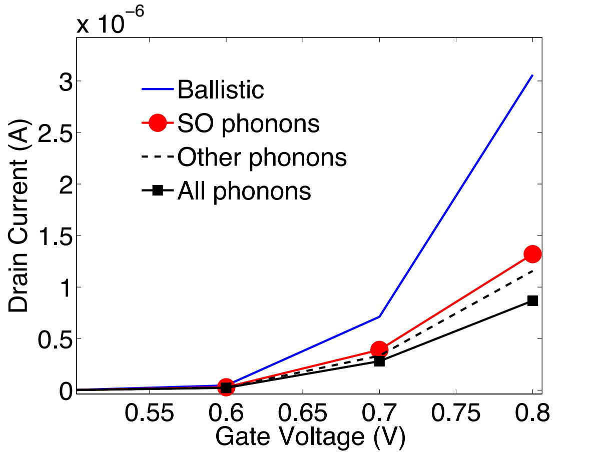

Fig. **2**. I_D-V_G for the 2.2x2.2 nm^2 cross-section nanowire (V_D=0.4 V)

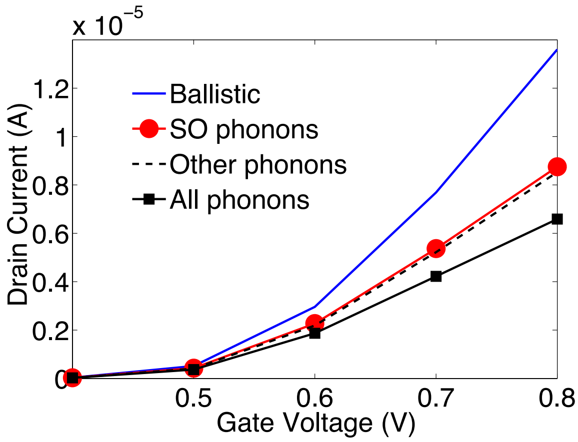

Fig. 3. I_D-V_G for the 4.2x4.2 nm^2 cross-section nanowire (V_D=0.4 V)

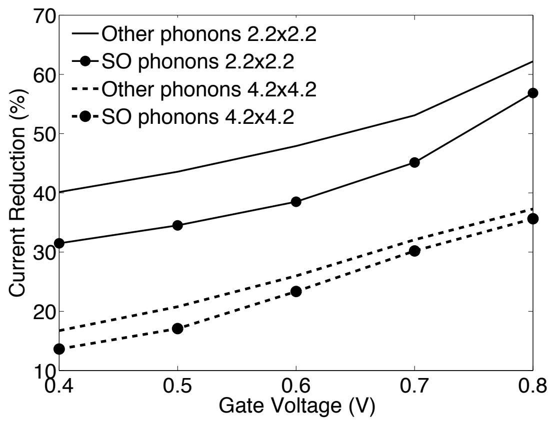

Fig. 4. Current reduction as a function of gate bias.

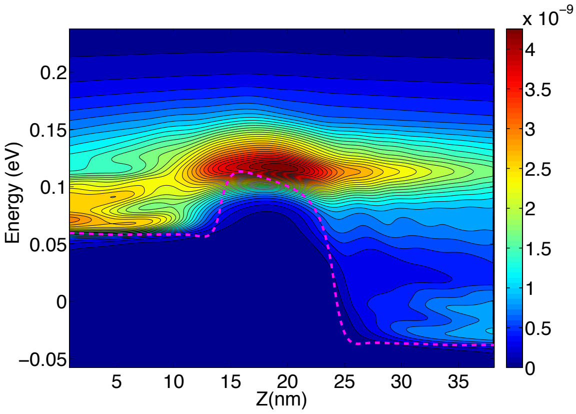

Fig. 5. Current spectra considering only SO phonons for the 2.2x2.2 nm^2 cross-section nanowire at V_G=0.7V.

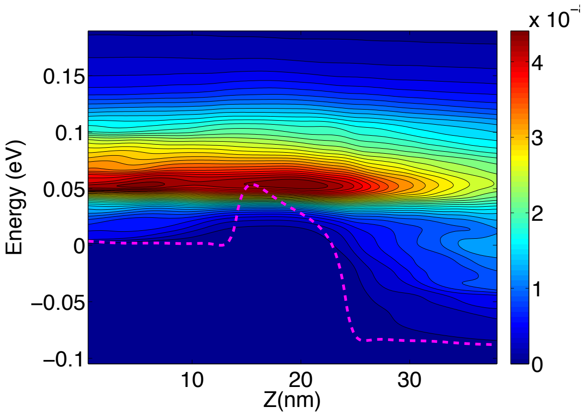

Fig. 6. Current spectra considering only SO phonons for the 4.2x4.2 nm^2 cross-section nanowire at V_G=0.7V.