Shape Effects on the Performance of Si and Ge Nanowire FETs Based on Size Dependent Bandstructure

Chee Shin Koong, Ganesh Samudra, and Gengchiau Liang*
Department of Electrical and Computer Engineering, National University of Singapore, Singapore; Phone: +65-6516-2898 #E-mail: elesg@nus.edu.sg

1. Introduction

With the demand for high performance devices and packing density, scaling of Si based MOSFETs was aggressively driven into the nano-scale regime. In near future, however, conventional Si MOSFETs will be facing physical limitation [1]. Therefore, in order to overcome this challenge, search for other potential channel materials or device structures such as high carrier mobility materials and nanowires have been at the forefront of research during last decades. Among these different candidates, nanowire (NW) FETs have been explored to characterize the device performance experimentally and theoretically [2-5]. Although the most easily realisable and widely studied NW is circular Si NW as channel material, it was recently shown that triangular cross-section NW could also be fabricated [4]. This has opened up possibilities of characterizing device performance by changing channel cross-section. A theoretical study on this topic using the effective mass model or classical transport model has been carried out [5], but it lacks the detailed information of electronic structures in the nano-scale regime. These details actually hold the information on the key parameters which dominate the device performance.

In this work, we study the effects of the shape, orientation and size on ultimate performance of Si and Ge NW FETs, based on the full band calculations and ballistic transport for the first time. A sp^3d^5s^* tight-binding (TB) approach [6] is employed to investigate the electronic properties of Si and Ge NWs, where the device structure is shown in Fig. 1, in terms of E-k dispersion in order to accurately capture orientation as well as quantum effects in a nano scale system. Based on the calculated E-k dispersion, we engaged a semi-classical top-of-barrier MOSFET model [7] to evaluate the ballistic I-V characteristics of NW FETs in order to evaluate the ultimate performance of these semiconductor NW FETs with various effects. The effective insulator capacitance for various NW sizes and shapes are calculated using COMSOL (Fig. 2—left).

We found that both shape and orientation affect the performance of Si and Ge NW MOSFETs through the gate capacitance and quantum effects. Moreover, their best performance configurations differ depending on the size.

2. Results

Based on the bandstructure calculations, the variations of the bandgap energy at gamma point caused by the spatial quantum confinements are extracted, as shown in the right plot of Fig. 2. Next, performance of Si and Ge NW MOSFETs under different channel orientations and shapes are investigated based on their bandstructure. The best...
performance configurations (in terms of orientation and shape) of Si and Ge NW FETs with the size of 3nm and EOT=1.6nm are selected in Fig. 3. For nFETs, the triangular shape, <110> Si and square shape, <110> Ge MOSFETs show the best performance. For pFETs, both Si and Ge MOSFETs show best performance along <110> with square shape cross-section. It can be attributed to the largest insulator capacitance offered by the square shape NW. However, in the Si nFET case, effective mass of triangular shape NW is much smaller than the others; therefore, its performance was enhanced. Next, we compare the performance of Si and Ge NW FETs under their best performance configurations with EOT=1.6nm and 0.5nm as shown in Fig. 4. Although Ge NW MOSFETs always outperform Si NW, the deviation in the case of EOT=0.5nm is smaller than the case of EOT=1.6nm. It is due to the quantum capacitance becoming small in the 1D system while the insulator capacitance increases as EOT decreases. When the insulator capacitance is comparable to the quantum capacitance, the latter starts to play an important role in the gate capacitance. When the quantum capacitance dominates the gate capacitance, the performance of the MOSFETs only depends on the number of degeneracy of Ek instead of effective mass [8]. The best performance of each case is summarized in Table. 1.

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### References