Monte Carlo Study of the long-range Coulomb interaction in Junctionless Transistors

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INTRODUCTION

Junctionless FET (JL-FET) [1] has attracted significant attention as an alternative to the conventional MOSFET with the potential advantages: This device has no junctions and no doping concentration gradients in Si substrate. As the depletion region in the substrate is simply obtained by introducing the difference of work-functions between the gate material and doped semiconductor under the off-condition, carriers mainly flow away from the gate-insulator interface under the on-condition. This fact is expected that surface roughness scattering, which is dominant scattering process in the conventional MOFET, could be minimized. The device operation requires thin semiconductor body and high-doping concentration. Many numerical or theoretical researches have been devoted to structure sensitivities of JL-FETs. However, highly-doped nature and the Coulomb scattering under the device operation have been paid less attention. In this work, we carry out the self-consistent Monte Carlo simulation (MC) and study the effects of the Coulomb interaction under JL-FET structure.

NUMERICAL METHOD AND DEVICE STRUCTURE

We employ the conventional MC simulation coupled with the Poisson equation self-consistently to incorporate the collective motion of electrons [2]. Relevant scattering processes, namely, optical and acoustic phonons, impurity scattering, short- and long-range Coulomb scatterings are included under the frame work of the nonparabolic band structure of Si. Figure 1 shows the nanowire JL-FET structure employed in the present study with the metallurgical gate with 10 and 50 nm longs, the cross-section of 10 x 10 nm^2, and donor concentration of 10^{19} cm^{-3} in Si nanowire.

RESULTS

First, we show the results of JL-FET with gate length of L_G = 50 nm. Figure 2 shows time-average potential profile over 20 ps at the middle plane of the cross-section under the gate voltage of V_G - V_{FB}= -0.3 V and the drain voltage of V_D = 0.6 V where V_{FB} is the flat-band voltage. The potential shows rather smooth and flat in the source and drain regions though the potential tempolrally flactuates. The collective mode excitations peaked the plasma frequency of electron density of 10^{19} cm^{-3} are observed in the source and drain region, respectively (Fig. 3). Additionally, the drain region has another broad spectrum below the plasma frequency because electrons entering from the channel are far from equilibrium and less potential screening in the drain region. Spatially and temporally averaged Coulomb force along the source-channel-drain direction shows slight difference between results of the self-consistent MC and the MC which is turned off the Poisson equation but uses the time-averaged potential calculated by the self-consistent MC (Fig. 4). The force is enhanced by the plasmons away from the channel region which is known in the study of MOSFET [2] but weakened in the channel region due to the long-range interaction. The potential drop observed at least 10 nm in the drain region induces the latter interaction and it is different from the MOSFET because of the “junctionless” structure and less screening. This behaviour is also observed under the structure with L_G = 10 nm (Fig. 5). As a consequence, these long-range Coulomb interactions indirectly degrade the drain current (Fig. 6).

ACKNOWLEDGMENT

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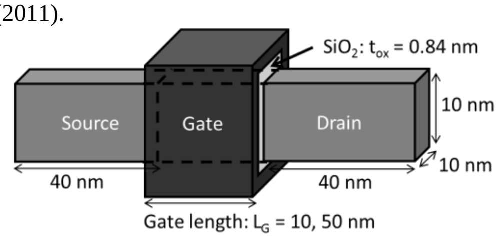

Fig. **1**. Schematic of employed JL-FET structure. Donor concentration in nanowire is 10^{19} cm^{-3}.

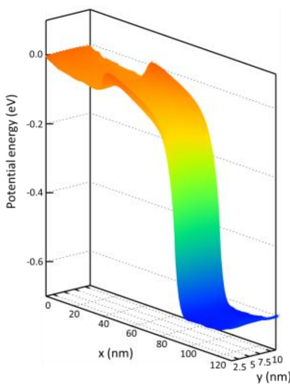

Fig. **2**. Time-averaged potential profile of JL-FET with the gate length of 50 nm in the middle of nanowire cross-section under the bias condition with the gate voltage of V_G - V_{FB} = -0.3 V and the drain voltage of V_D = 0.6 V where V_{FB} is the flat band voltage.

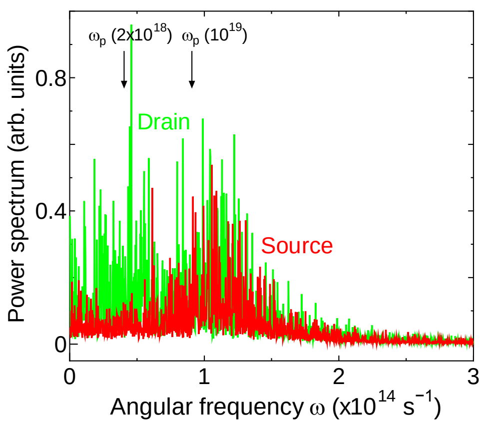

Fig. **3**. Spatially averaged power spectra of potential fluctuations in the source and drain regions. $\omega_p(2x10^{18})$ and $\omega_p(10^{19})$ are the plasma frequencies of electron density of 2 x 10^{18} and 10^{19} cm^{-3}, respectively under the same bias condition and structure used in Fig. 2.

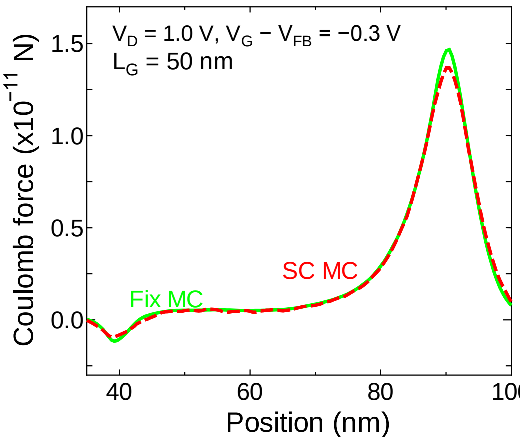

Fig. **4**. Time-averaged Coulomb force of JL-FET with L_G = 50 nm along the source-channel-drain direction from the self-consistent MC (SC MC) and the MC which turns off the long-range interaction (Fix MC) with the gate voltage of V_G - V_{FB} = -0.3 V and the drain voltage of V_D = 1.0 V. The gate locates from 40 nm to 90 nm.

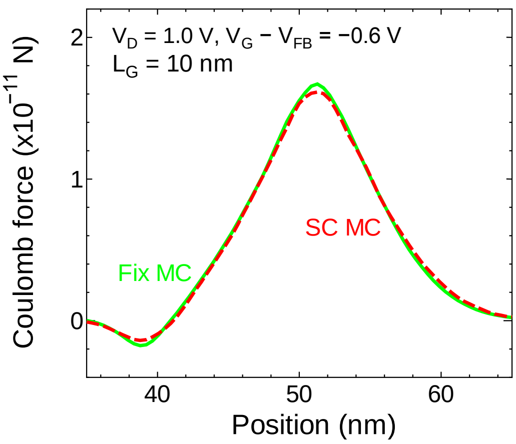

Fig. **5**. Time-averaged Coulomb force of JL-FET with L_G = 10 nm along the source-channel-drain direction with the gate voltage of V_G - V_{FB} = -0.6 V and the drain voltage of V_D = 1.0 V. The gate locates from 40 nm to 50 nm.

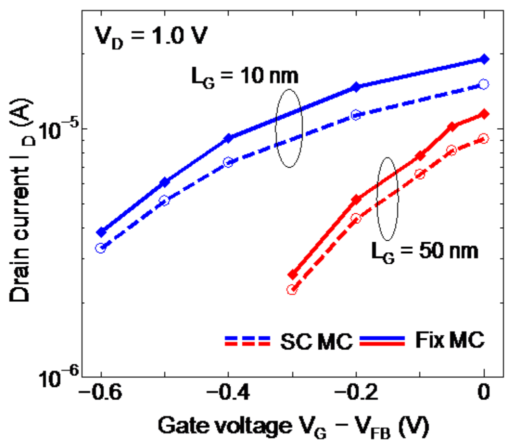

Fig. **6**. Drain currents as a function of the gate voltage from SC MC and Fix MC.