Comparison between double-gate p-type junctionless and inversion-mode transistors

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INTRODUCTION

Junctionless transistors (JLTs) have recently attracted much attention for their supposedly simple manufacturing processes and higher performances in comparison with inversion-mode transistors (IMTs) [1]. Our study predicts that Si-based IMTs exhibit better performances than Si-based JLTs in double-gate p-doped devices for high body thickness.

MODEL

The valence band structure of Si in both devices is described using a six-band *k.p* Hamiltonian including spin-orbit coupling. The transport equations are then solved using the Nonequilibrium Green's function (NEGF) formalism, which is self-consistently coupled to a 2D Poisson solver. Phonon-interactions are incorporated within the self-consistent Born approximation, based on the same approach as the one reported in Ref. [2]. The dimensions and characteristics of the considered transistors are represented in Fig. 1. The source-drain bias is equal to -0.4 V in all the study.

RESULTS AND DISCUSSIONS

Let's first compare 2 nm thick IMT and JLT through the I_D-V_G curves shown in Fig. 2, where the gate work functions are adjusted to have the same OFF currents. The performances are qualitatively similar, although a slight improvement is found for the JLT over the IMT in the scattering regime with a smaller average subthreshold slope (SS): SS_{IM}=73.6 mV/decade and SS_{JL}=69.1 mV/decade.

Furthermore, the ON current reduction due to phonon scattering is lower with respect to the ballistic current in the case of the JLT. Current spectra in the scattering regime at different positions along the transport direction x are shown in Figs. 3 and 4 for both IMT and JLT respectively. The magnitude of the lowest energy peak in the spectrum at x=24 nm, due to multiple relaxation processes of holes, represents 53 % of the one at x=9 nm (labeled as 100%) in IMT. This ratio is only 44 % in JLT, which demonstrates a larger impact of phonon scattering in the IMT.

We now investigate the influence of body thicknesses (T_{Body}) in JLTs and IMTs. The results are represented in Figs. 5 and 6 where the gate work function is not modified. We see that the spread of current characteristics is smaller in IMTs (Fig. 5) than in JLTs (Fig. 6). In order to reach an ON regime as well as an OFF regime (with a current of order 10^{-3} A/m) for all body thicknesses, we apply gate voltages ranging from -1.8 V to -0.2 V (ΔV_G=1.6 V) for the JLT, while ranging from -1.0 V to 0 V (ΔV_G=1.0 V) for the IMT. JL devices are then more sensitive to channel thickness, which makes us assume a larger sensitivity to surface roughness. We also observe that IMTs exhibit higher ON currents and similar or lower subthreshold slopes for body thicknesses larger than 3 nm. For instance at T_{Body}=5 nm, the IMT has an ON current of 1568 A/m and a SS of 89 mV/decade compared to 1375 A/m and 98 mV/decade respectively in its junctionless counterpart.

CONCLUSION

In this study we have shown the superiority of p-type double-gate Si IMTs over JLTs for high body thicknesses, *i.e.* larger than 3 nm, in presence of phonon scattering.

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REFERENCES

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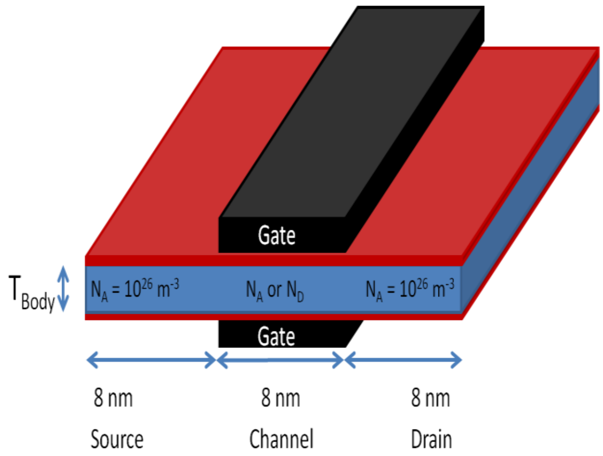

Fig. **1**. Representation of double-gate transistors. For JLT the channel doping (acceptors) is $N_A=10^{26}$ m^{-3}. For IMT the channel doping (donors) is $N_D=10^{17}$ m^{-3}.

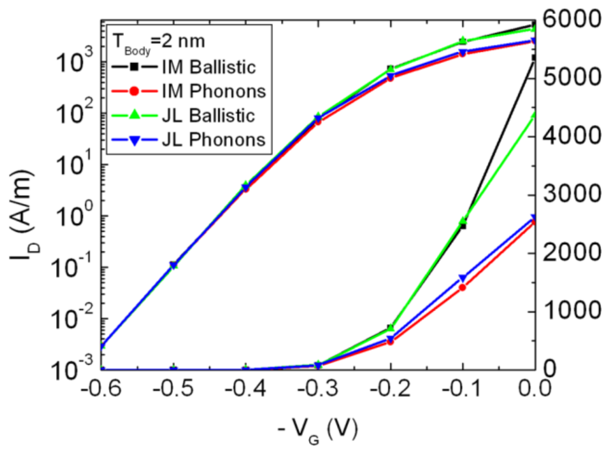

Fig. 2. I_D-V_G characteristics of IMT (squares for ballistic and circles for scattering regime) and JLT (triangles for ballistic and reverse triangles for scattering regime).

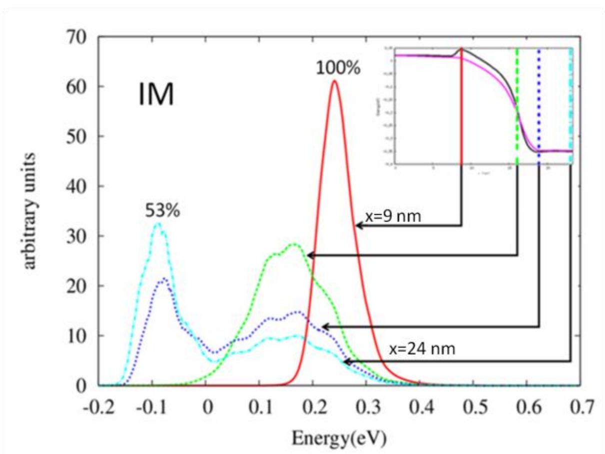

Fig. 3. Current Spectra in IMT at different positions along the transport direction (x) at high gate voltage. Inset: associated potential energy in IMT and JLT. $T_{Body} = 2$ nm.

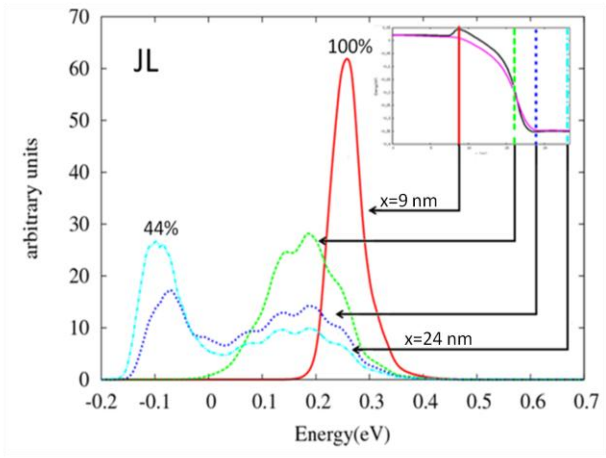

Fig. 4. Current Spectra in JLT at different positions along the transport direction (x) at high gate voltage. Inset: associated potential energy in IMT and JLT. $T_{Body} = 2$ nm.

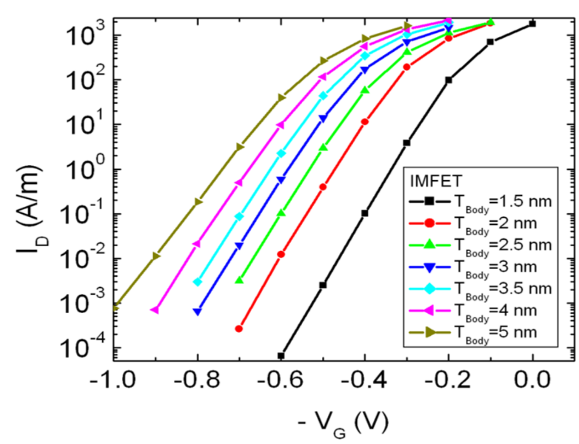

Fig. 5. I_D-V_G characteristics of IMT (or IMFET) for various body thicknesses (T_{Body}).

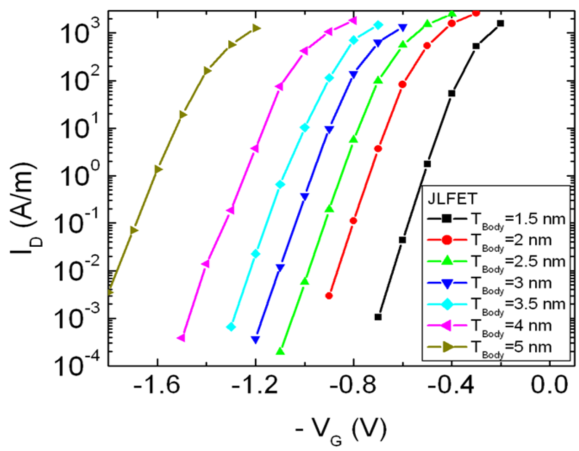

Fig. 6. I_D-V_G characteristics of JLT (or JLFET) for various body thicknesses (T_{Body}).