A computational study on electrical characteristics of a proposed double gate heterojunction SB-CNTFET

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Abstract: In this paper, a coaxial gated SB-CNTFET with double gates heterojunction DGHJ is proposed. By using a non-equilibrium Green's function (NEGF) method, the transport characteristics of a DGHJ-SB-CNTFET is compared to those of conventional SB-CNTFET with homogenous channel. According to simulation results, DGHJ-SB-CNTFET demonstrates much less leakage tunnelling current, larger ON-OFF current ratio (I_{ON} / I_{OFF}), suppression of ambipolar characteristics and better switching parameters. According to these advantages, the proposed structure could be a suitable candidate for low-power and high speed applications.

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1.Introduction:

Carbon nanotube transistors have excellent electrical performance that is as good as or better than state-of-the art silicon devices [1, 2]. However, it is found that the ambipolar behaviour of Schottky barrier carbon nanotube field effect transistors (SB-CNTFETs) limits the performance of these devices [3-8]. The use of SB-CNTFETs in conventional CMOS-circuits will require careful device design to avoid the ambipolar phenomenon resulting in high leakage current at negative gate-to-source voltages (V_{GS}). For better performance, the ambipolar conduction must be suppressed and only one branch of I-V characteristics must be used. Using a large diameter tube reduces the bandgap and significantly increases the OFF current (I_{OFF}) at the ambipolar bias point. At the same time, the ON-current (I_{ON}) is also improved, but the ON-OFF current ratio decreases significantly as the nanotube diameter increases [4, 6]. The small bandgap of a large diameter tube leads to a strong ambipolar conduction even if the gate oxide is thick and barrier heights for electrons and holes are asymmetric [4].Here we use a CNT with variable diameter instead of homogenous tube to construct a double gate heterojunction (DGHJ). The concept of using variable diameter CNT was demonstrated in [9].

In this work, the performance of DGHJ-SB-CNT is explored. We assume ballistic transport and solve the NEGF self-consistently with the Poisson equation. Also, we assume a coaxial geometry as it provides the best electrostatic control by the gate and, therefore, the minimum channel length for electrostatic consideration [10]. A zigzag nanotube is assumed, and an atomistic description in terms of p_z orbitals is used [11]. The detailed methodology of our simulator is mentioned in our previous work [6].

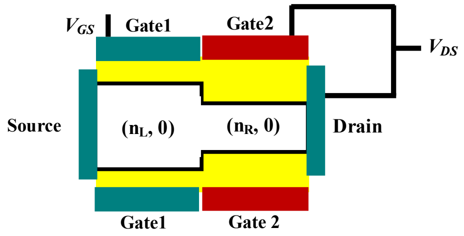

Fig. 1 Schematic cross sections of DGHJ-SB-CNTFET

Simulation Results: A schematic of the proposed DGHJ-SB-CNTFET is shown in Fig. (1). For a fair comparison, all devices studied herein are in the same conditions. At first, the simulated I_{DS}-V_{GS} characteristics of the proposed DGHJ-SB-CNTFET, with the left channel zigzag CNT (14, 0) and the right channel zigzag CNT (11, 0), and conventional (homogenous) SB-CNTFET with zigzag CNT (14, 0) or zigzag CNT (11, 0) are illustrated in Fig. (2).We define ON-current (I_{ON}) when $V_{GS} = V_{DS}$, and OFF current (I_{OFF}) when $V_{GS} = 0$. As shown in Fig. (2), there is no ambipolar conduction in transfer characteristics of the proposed structure. Also, the ON-current (I_{ON}) of the proposed structure is approximately 3 orders of magnitude larger than that of (11, 0) the conventional device, and approximately equal to I_{ON} of (14, 0) conventional device. OFF-current (I_{OFF}) is more than one order of magnitude lower than that of (11, 0) conventional device. As a result, using DGHJ tube increases the ON-current, decreases OFF-current and suppresses the ambipolar conduction.

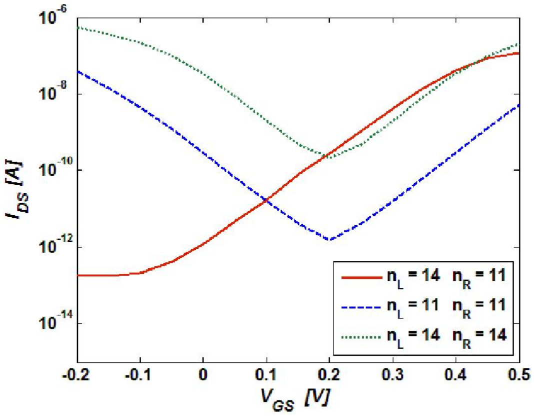

Fig. 2 Comparison of the simulated I_{DS}-V_{GS} characteristics of DGHJ-SB-CNTFET ((14, 0), (11, 0)) with the conventional (homogeneous) SB-CNTFET (11, 0) and (14, 0) at V_{DS} = 0.4 V

To get the best characteristics of DGHJ-SB-CNTFET, it is worthwhile to obtain the optimum n_L and n_R value. Fig. (3) evaluates I_{ON}/I_{OFF} current ratio versus n_L for two different values of n_R. The variation of n_L and n_R changes tunnelling width and has a greater effect on I_{OFF} than I_{ON}. As shown in Fig. (3), n_L = 14 and n_R = 11 is the optimum scaling for DGHJSB-CNTFET with maximum I_{ON} / I_{OFF} current ratio.

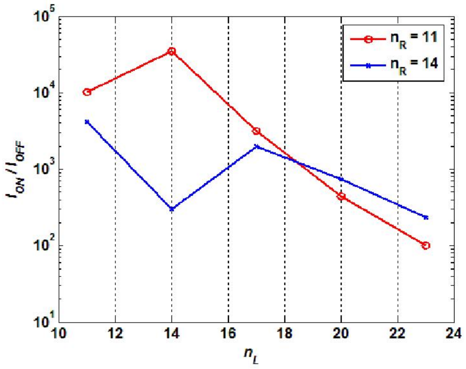

Fig. 3 Variation of ON-OFF-current ratio as a function of n_L

For further comparison, we evaluate the I_{ON} /I_{OFF} current ratio versus V_{DS}. As observed in Fig. (4), for the whole range of V_{DS}, the I_{ON} / I_{OFF} ratio for the DGHJ-SB-CNTFET is larger than that for the conventional SB-CNTFET. In the best case (the worst case) the I_{ON} / I_{OFF} ratio for the DGHJ-SB-CNTFET is approximately 3 orders (1 order) of magnitude larger than that of conventional device. In contrast to conventional results, there is no peak in I_{ON} / I_{OFF} ratio of the proposed structure along the whole range of V_{DS}. This means that, there is no any ambipolar behaviour for the proposed structure for the whole range.

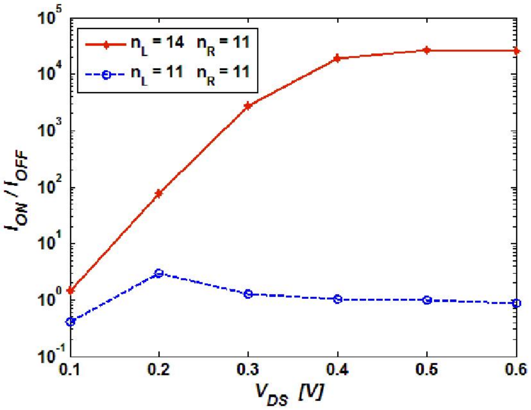

Fig. 4 I_{ON} / I_{OFF} versus V_{DS} for two structures

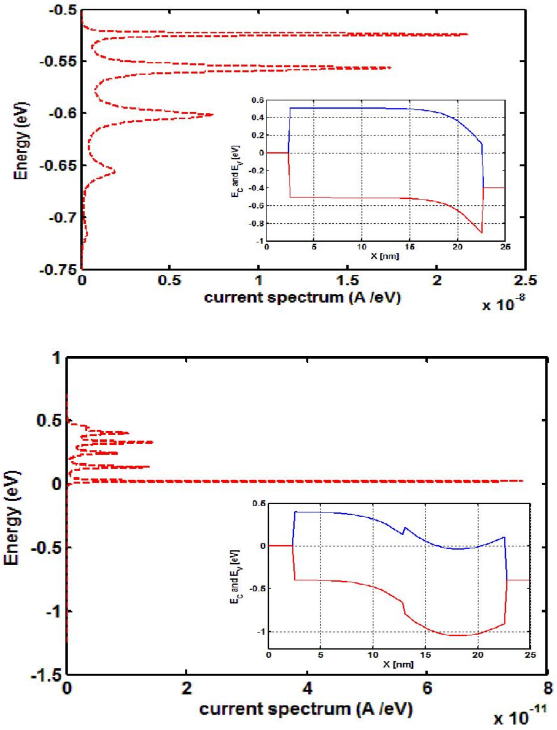

Fig. 5Energy-resolved current spectrum for (a) conventional SB-CNTFET, and (b) DGHJ-SB-CNTFET at the OFF-state (V_{GS} = 0 and V_{DS} = 0.4 V) (Also shown: Conduction band profile along the channel position)

Next, we compare the band diagram and energy-resolved current spectrum for aforementioned devices at a given biasing conditions in OFF-state. Less leakage current of DGHJ-SB-CNTFET has two main reasons. The first one is that, in the presence of the DGHJ, the drain-channel barrier is broaden and therefore tunnelling probability reduces (Fig. (5-a) and (5-b)). The second reason is based on less current spectrum and consequently less quantum transmission in the channel of the proposed structures as shown in the inset of Fig. (5).

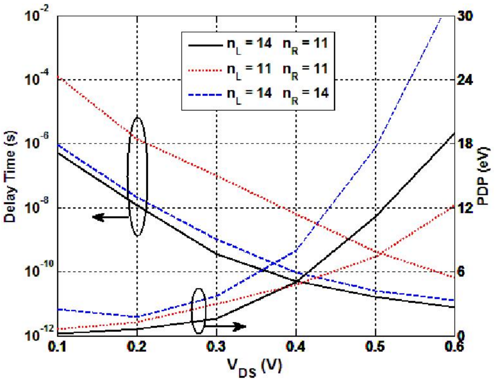

Fig. 6 Delay time and PDP, as a function of V_{DS} for three structures

Finally, we want to compare the switching behaviours of each device. The first key parameter in the switching behaviours is the delay time defined by $\tau = (Q_{ON} - Q_{OFF}) / I_{ON}$ indicating how fast a transistor switches. Where $Q_{ON/OFF}$ is the total charge during the ON/OFF state.

One the other hand, as the second main switching parameter, the power-delay product (PDP) determined by PDP = $(Q_{ON} - Q_{OFF}) V_{DS}$, is a figure of merit correlated with the energy efficiency of a logic gate. Known as switching energy, PDP, is the product of the power consumption and the delay time. It has the dimension of energy and measures the energy consumed per switching event [12-13].

We evaluated delay time and PDP versus V_{DS} for the two structures as shown in Fig. (6). In comparison to conventional structure, the DGHJSB-CNTFET has both the shorter delay time and the smaller PDP for the suitable range of V_{DS} (about 0.35 V) valid for low power applications.

Conclusion:

In order to simulate the electronic properties of the proposed DGHJ-SB-CNTFET structure, the NEGF function with an uncoupled mode space has been used and the simulated characteristics have been compared with those of conventional SB-CNTFET. By using DGHJ the quantum transmission across the channel has been reduced; therefore, leakage tunnelling current of DGHJ-SB-CNTFET is deeply reduced. The proposed structure has noticeable advantages over conventional one: larger I_{ON} / I_{OFF} current ratio, shorter delay time, smaller PDP and no ambipolar characteristic. Because of these superior behaviors and much less leakage current, the DGHJ-SB-CNTFET could be suitable for the high speed and low-power applications.

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References

1. Appenzeller J., J. Knoch, R. Martel, V. Derycke, S.J. Wind, and Ph. Avouris, "Carbon Nanotube Electronics," IEEE Transactions on Nanotechnology, Vol. 1, No. 4, pp. 184-189, Dec. 2002
2. Novak J. P., M. D. Lay, F. K. Perkins, and E. S. Snow, "Macroelectronic applications of carbon nanotube networks," Solid State Electronics. Vol. 48, pp. 1753-1756, 2004
3. Lundstrom M. and J. Guo "Nanoscale Transistors Device Physics, Modeling and Simulation," Springer press, 2006
4. Guo J., S. Datta and M. Lundstrom, "A numerical study of scaling issues for Schottky barrier carbon nanotube transistors," IEEE Trans. on Electron Dev., Vol. 51, No. 2, pp. 172-177, Feb. 2004.
5. Hazeghi A., H.-S. Philip Wong, "Schottky-Barrier Carbon Nanotube Field Effect Transistor modeling," IEDM, 2006
6. Ossaimee M. I. , S. H. Gamal, K. Kirah and O. A. Omar, “Ballistic Transport in Schottky Barrier Carbon Nanotube FETs”, Electronics Letters, Circuit theory and design, Vol. 44, issue 5, Feb. 2008.
7. Radosavljevic M., S. Heinze, J. Tersoff, and Ph. Avouris, “Drain Voltage scaling in carbon nanotube transistors”, arXiv:cond-mat/0305570, v1, 23 May 2003
8. Appenzeller J., J. Knoch, M. Radosavljevic, and Ph. Avouris, “ Multimodetansport in Shottky-barrier carbon nanotube field effect transistors”, Phys. Rev. let. V. 92, no. 22, 4 June 2004
9. Popov A.P., and I.V. Bazhin, “Electronic structure of carbon nanotubes of variable diameter”, Hydrogen Materials Science and Chemistry of Carbon Nanomaterials, pp. 707 – 712, 2007
10. Guo J., S. Goasguen, M. Lundstrom, and S. Datta,“Metal-insulator-semiconductor electrostatics of carbon nanotubes”, Appl. Phys. Lett., v. 81, pp. 1486-1488, 2002.
11. Javey J., J. Guo, Q. Wang, M. Lundstrom, and H. Dai, “Ballistic carbon nanotube field-effect transistors”, Nature, vol. 424, pp. 654-657, 2003
12. Siyuranga O., S. Koswatta, D. Nikonov, and M. Lundstrom, “Computational study of carbon nanotube p-i-n tunnel FETs”, IEDM Technol, Dig. pp. 518-521, 2005
13. Guo J., A. Javey, H. Dai, and M. Lundstrom, “Performance analysis and design optimization of near ballistic carbon nanotube field-effect transistor”, IEDM Technol, Dig. pp. 703-706, 2004

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