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Investigation of the performance and characteristics of linear doped Tunneling carbon nanotube field effect transistor

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Abstract

Tunneling carbon nanotube field effect transistor with linear doped (LD-T-CNTFET) is presented for investigating band to band tunneling and improving the device characteristics with a non-equilibrium Green's function (NEGF) method. The LD-T-CNTFET structure includes two linear doped regions between the intrinsic channel and the highly doped source and drain regions which are called the linear doped drain and source T-CNTFET. Simulations have shown that LD-T-CNTFET characteristics are attributed to the linear doped region length. In comparison with a T-CNTFET, an LD-T-CNTFET with linear doped drain and source regions has shown a smaller off current (IOFF), a smaller sub-threshold swing, a lower on-current and tunneling current.

Keywords: *Band to band tunneling (BTBT), Tunneling carbon nanotube field effect transistor (T-CNTFET), linear doped drain and source (LD), non-equilibrium Green's function (NEGF).*

1. Introduction

Silicon based technology will reveal its limitations by 2020, when the channel length of MOSFET is less than 10nm [6]. As integrated circuit densities continue to increase, several emerging devices have been studied to find a suitable replace for silicon [2]. Carrying high current, ballistic transport, mechanical stability and dynamic load are made of carbon nanotubes as a suitable material to replace silicon as the channel field effect transistors [5]. The structural and electrostatic features of these nanotubes make them interesting for the future integrated circuit applications [2]. An important challenge for CNTFET study is to develop high performance transistors that operate at significant lower voltages. To maintain currents high, at lower voltages, it is likely that devices will need to operate with the sub-threshold swing below the conventional MOSFET limit of 60 mV/Decade _at room temperature_. Band-to-band tunneling _BTBT_ transport in devices has been suggested and illustrated as a means to produce low-voltage transistors. The BTBT FET device concept is currently being prospected in many material systems including those based on carbon nanotubes _CNTs_ and silicon. CNTs are particularly promising for such devices because their small effective masses and direct band-gap promote band to band tunneling [2]. Today, both p- and n-type CNTFETs have been fabricated. Experiment with quasi-planar gate geometries has demonstrated near-ballistic transport in p-type CNTFETs, and on-currents that exceed those of silicon-based transistors [7]. In order to enhance properties, Reza Yousefi and *et al* investigated LD-CNTFET and compared it with CNTFET in [3]. They found that LD region at source and drain sides lead to reduction of band to band tunneling at CNTFET

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structure, but it causes to improve CNTFET characteristics. In this paper, by using linear doped regions between the intrinsic channel and the highly doped source and drain regions of a T-CNTFET, we have evaluated a new linear doped drain and source T-CNTFET (LD-T-CNTFET).The simulations have been done by self-consistent solution between the Poison and the Schrodinger equations with open boundary condition [2]. We will improve T-CNTFET characteristics by using linear doped bottom edge source and drain. Then, we compared the simulation results obtained from the LD-T-CNTFET model with those of the T-CNTFET. Although LD-T-CNTFET decreases band to band tunneling. While comparing the IDS–VGS characteristics of LD-T-CNTFETs with those of T-CNTFETs, we also included the effects of variations in the lengths of LD regions. Finally, we investigated on-current, off-current and tunneling current.

2. Device structure

The views of T-CNTFET and LD-T-CNTFET structures have been shown in fig.1 and fig.2. Both devices to be fabricated by using the same CNT and the same gate material. The CNT is assumed to be constructed with a zigzag (16, 0) of 0.63-nm radius and length of L=15nm. A coaxial gate is placed around the channel region of the nanotube which is separated by HfO2 as dielectric layer has a 2-nm-thick and also the relative dielectric constant Ɛr=16. Two structures include p-doped source and n-doped drain region with 30nm length which have been doped by 2nm-1 doping whereas the doping concentrations in the LD regions are considered to linearly differ up to 2nm−1.

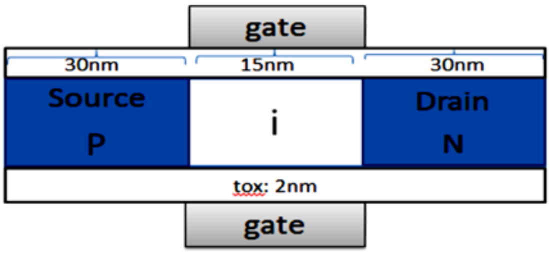

Figure 1: Schematic cross-sectional view of the coaxial T-CNTFET.

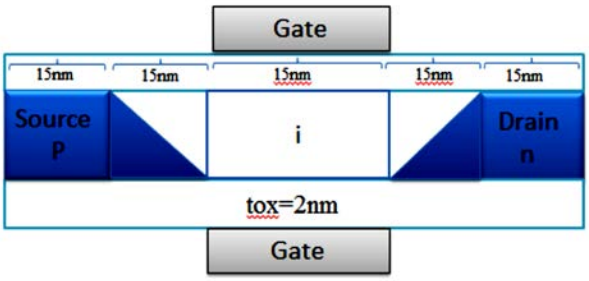

Figure 2: Schematic cross-sectional view of the coaxial LD-T-CNTFET.

3. Computational method

The proposed device simulates by self-consistent solution of the poison and Schrodinger equations within the NEGF formalism. The nanoscale system out of equilibrium simulate by NEGF method. The electrostatic potential is obtained from the Poisson equation to compute the Hamiltonian of the system as in [2]. The self-energy matrix can be interpreted as a boundary condition of the Schrodinger equation. In this paper, we have investigated a self-energy for semi-infinite leads as boundary conditions, which enables to consider the CNT as connected to infinitely long CNTs at its ends as in [4]. To decrease the computational cost of simulation is used the mode-space approach.

The two dimensional nanotube lattice of a (n, 0) zigzag CNT transformed to n decoupled one dimensional modes by doing a transform from the real space to the mode space in the circumferential direction. Under typical bias conditions, the few modes that are relevant to electronic transport are treated. In this paper we have used single-pi model for all simulations. We are considered the nanotube conduction and valence bands symmetric, so the charge -lies at the middle of band gap- is a neutral. The potentials at source/drain and gate electrodes are assumed fixed as the boundary conditions. The iteration between the atomistic quantum transport equation and the electrostatic equation continues until self-consistency is obtained as in [3].

4. Discussion and results

Fig.3 and fig.4 show the energy-position-resolved local density of states (LDOS) of the T-CNTFET and LD-T-CNTFET, respectively. As can be observed from fig.3 with increasing VGS, the bands at the source side will bend more, making the tunneling barrier increasingly smaller (thus, transmission goes up). On the other hand, applying a negative VGS opens a tunneling path at the drain side of the channel, and results in ambipolar conduction. This ambipolar behavior confines the performance of the device. Due to the ambipolar behavior the off-current is high. In order to avoid the ambipolar behavior of the T-CNTFET and improve the performance of these devices, we evaluate LD-T-CNTFET structure. As can be seen from fig.4, the LD region of the source side has increased the source-channel barrier also the LD region of the drain side widened the drain-channel barrier at VDS=0.4V.

If the drain voltage is applied to the LD-T-CNTFET, while drain voltage decrease, the energy barrier near the drain contact will be increased due to the LD region drain-channel. Consequently, the tunneling current of the holes at the drain contact is decreased. As electrons/holes injection at source contact can be decreased/increased through the LD region of source-channel, LD region of drain-channel decreases/increases holes/electrons current at the drain contact. Fig.5 demonstrates the IDS-VGS characteristics for an LD-T-CNTFET and a T-CNTFET, under different VDS biases. As can be observed from fig.5, for the different VDS, the tunneling current for the LD-T-CNTFET is lower than that for the T-CNTFET. This behavior is appropriate to the reality that the LD region lowers the possibility of tunneling between the heavily doped source and drain regions by increasing the barriers between the channel-source and the LD region of the drain side widened the drain-channel barrier at VDS=0.4V. If the drain voltage is applied to the LD-T-CNTFET, while drain voltage decrease, the energy barrier near the drain contact will be increased due to the LD region drain-channel.

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On the other hand, LD region drain-channel increases barrier height at the drain contact and decreases tunneling current. This can be demonstrated by the comparison of the corresponding energy band structures drawn for a given VGS and VDS biasing condition (Fig.4). The significant decrease of off-current for the LD-T-CNTFET compared with T-CNTFET can be seen in fig.6 that shows transconductance characteristics of LD-T-CNTFET and T-CNTFET structures at logarithmic mode. We also demonstrated the IDS–VDS characteristics for both structures with VGS = 0.6 V, VGS = 0.4V and VGS = 0.2V in fig.7. As can be seen in this figure, for a given VGS, the drain current of the LD-T-CNTFET is smaller than that of the T-CNTFET which is attributed to the lower transmission rate in the LD-T-CNTFET.

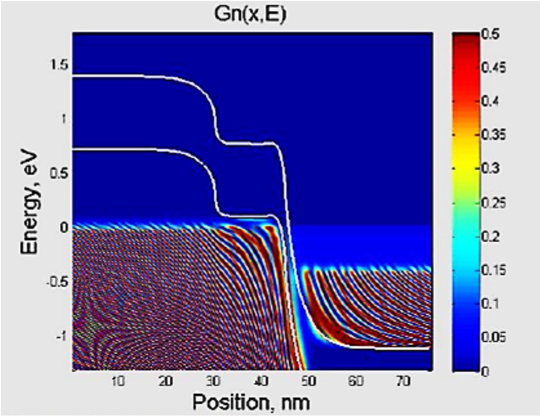

Figure 3: Color-scaled plot for the number of electrons per unit energy along the CNT axis for T-CNTFET, the biasing conditions for TCNTFE is VGS=-0.6V and VDS=0.4V.

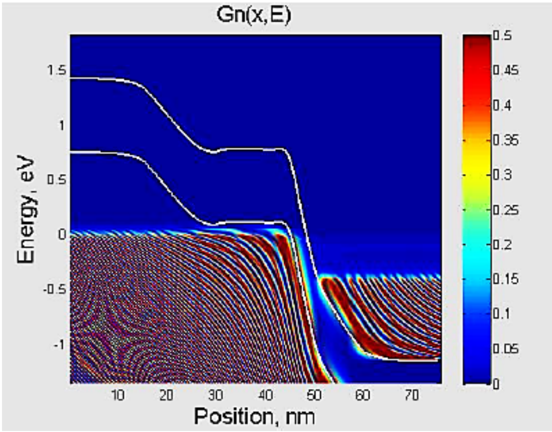

Figure 4: Color-scaled plot for the number of electrons per unit energy along the CNT axis for LD-T-CNTFET, the biasing conditions for LD-T-CNTFET is VGS= -0.6V and VDS=0.4V.

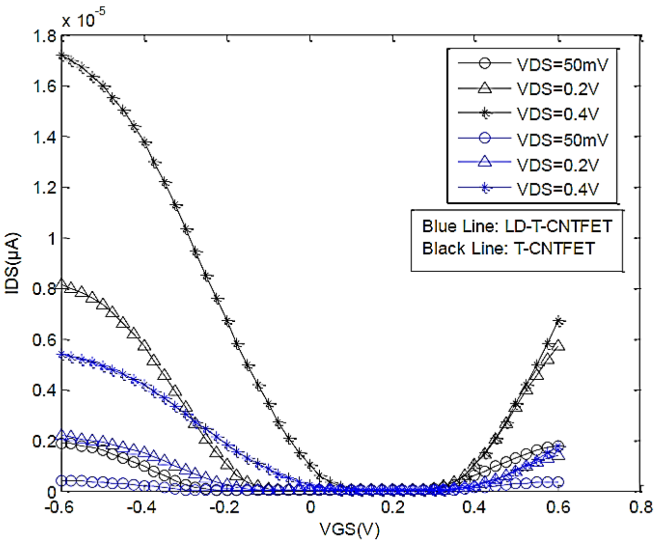

Figure 5: Trans-conductance characteristics of LD-T-CNTFET and T-CNTFET structures at different VDS

(linier mode).

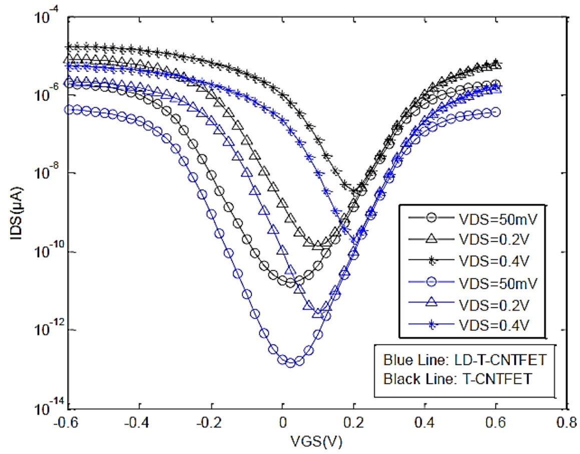

Figure 6: Trans-conductance characteristics of LD-T-CNTFET and T-CNTFET structures at different VDS (logarithmic mode).

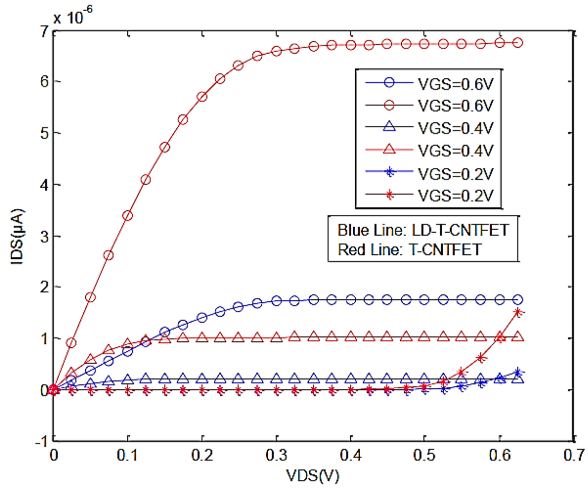

Figure 7: IDS-VDS characteristics of LD-T-CNTFET and T-CNTFET structures at VGS=0.4V.

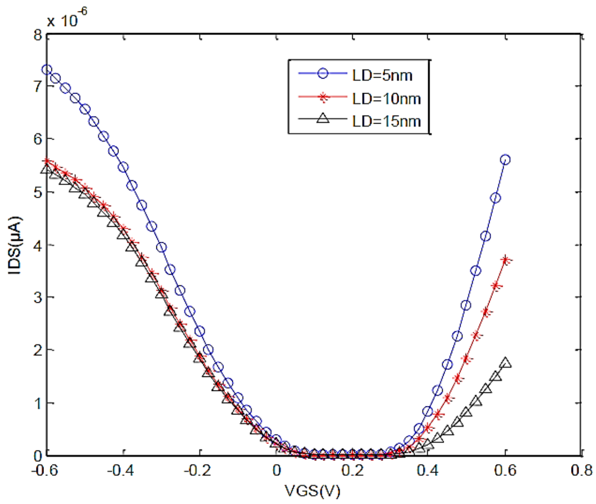

Figure 8: Transconductance characteristics of LD-T-CNTFET with vary length of the LD regions and concentration of the LD regions 2nm-1. (Linear mode).

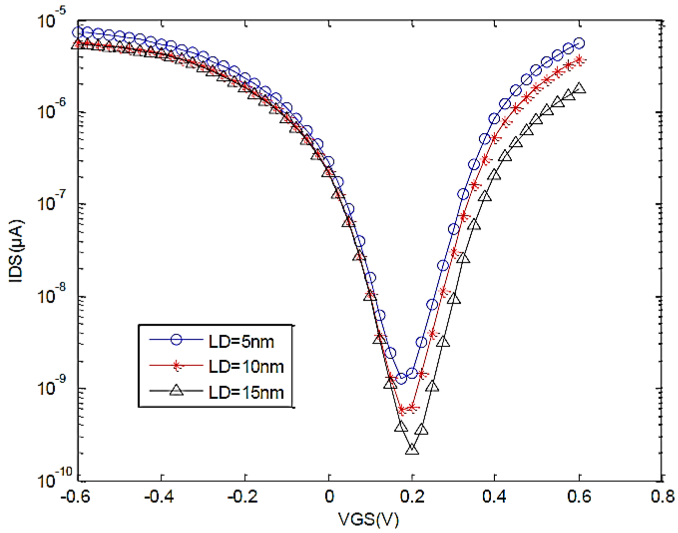

Figure 9: Transconductance characteristics of LD-T-CNTFET with vary length of the LD regions and concentration of the LD regions linearly up 2nm-1 (Logarithmic mode).

Fig.8 and fig.9 demonstrate the IDS–VGS characteristics of the LD-T-CNTFET at the linear and logarithmic modes, respectively. As the doping concentrations in LD regions considered to linearly differ up 2nm-1 and different length of the LD regions. The both figures are obtained from the same bias of VDS= 0.4V. At a constant LD regions concentration linearly differ up 2nm-1 and vary length of LD regions, the dependency of IDS-VGS characteristics of LD-T-CNTFET on the different values of the length of LD regions is shown in fig.8 and fig.9. It can be observed from fig.8 that by decreasing the length of LD region at the source side, on-current increases as well. The reason of this increase is that reduction of the length of the LD regions at the source side leads to lower potential barrier at the source-channel. Also reduction of the length of LD region at the drain side leads to thinner tunneling barrier at drain-channel, which results in increasing tunneling current. Increasing of the length of LD regions source and drain sides cause reduce in number of the carriers at the source and drain sides, it leads to decrease the currents at both drain and source sides.

Conclusion

The performance of linear doped tunneling carbon nanotube FETs was examined by quantum simul ation. The NEGF formalism has been used to simulate the electronic properties of the T-CNTFET str ucture with LD regions, namely, LD-T-CNTFET. The simulated characteristics were compared with those of the T-CNTFET with the same dimensions. Simulations result show that presence of the LD regions reduce the band to band tunneling of electrons existing between the sources and drain regions and the channel, but improves its off-current compared with T-CNTFET. Appropriately designed LD regions have resulted in a lower ION, The effects of length of the LD regions on the LD-T-CNTFET currents were also evaluated. As can be observed from simulations result, the maximum on current and tunneling current for the LD regions are obtained to be length of the LD region 5nm.

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