Available online at www.sciencedirect.com
ScienceDirect
Procedia Materials Science 11 (2015) 287 – 292
Procedia Materials Science
www.elsevier.com/locate/procedia

5th International Biennial Conference on Ultrafine Grained and Nanostructured Materials, UFGNSM15

Tunneling Carbon Nanotube Field Effect Transistor with Asymmetric Graded Double Halo Doping in Channel: asym-GDH-T-CNTFET

N. Valed Karimi[a], Y. Pourasad[b,]*

[a]Electrical Engineering Department, Islamic Azad University, 6491615111, Rasht Branch, Guilan, Iran
[b]Electrical Engineering Department, Urmia University of Technology, 5715756188, Urmia, Iran

Abstract

A tunneling carbon nanotube field effect transistor with asymmetric graded double halo (asym-GDH-T-CNTFET) is investigated in order to enhance band to band tunneling and evaluate the device characteristics by non-equilibrium Green's function (NEGF) method. The asym-GDH-T-CNTFET structure includes in n-doped halo at the source side and p-doped halo at the drain side which covered through the channel. The source-side halo doping, reduces short-channel effect (SCE) and drain induced barrier lowering (DIBL) and the drain-side halo doping reduces drain energy barrier and increases band to band tunnelling in drain contact, subsequently. The asym-GDH-T-CNTFET has represented a higher tunneling current compared to T-CNTFET. Sub-threshold swing increases and ON/OFF current ratio decreases using of asymmetric graded double halo tunnelling carbon nanotube field effect transistor when compared to that of tunnelling carbon nanotube field effect transistor (T-CNTFET). In this paper, we investigate on-state current, tunneling-current and also characteristics of the asym-GDH-T-CNTFET compares to T-CNTFET.

Peer-review under responsibility of the organizing committee of UFGNSM15

Keywords: Asymmetric graded double halo (asym-GDH); band to band tunnelling (BTBT); non-equilibrium Green's function (NEGF); Tunneling carbon nanotube field effect transistor (T-CNTFET).

* Corresponding author. Tel: +98-912-640-6595; fax: +98-441-355-4180.
E-mail address: Y.Pourasad@uut.ac.ir

Peer-review under responsibility of the organizing committee of UFGNSM15
doi:10.1016/j.mspro.2015.11.064

1. Introduction

Silicon based technology will reveal its limitations by 2020, when the channel length of MOSFET is less than 10nm, Dang et al. (2006). As integrated circuit densities increase, scientists study some devices in order to find appropriate replace for silicon, Adessi et al. (2009). CNT made from one grapheme sheet is a single walled carbon nanotube (SWCNT). Usually the thickness and the length of SWCNTs can vary between 1 nm to 2 nm and 100 nm to 10µm, respectively, Rueckes et al. (2000). The structural and electrostatic features of carbon nanotubes make them attractive for the nano-electronic applications, Adessi et al. (2009). There is charge pile-up in the channel CNTFET which leads to increase the off-current and lower the I_{ON}/I_{OFF} ratio. A gate-controlled tunneling FET (T-CNTFET) is offered to compensate these problems, Koswatta et al. (2005). In this type of device either a p/i/n or n/i/p doping profile can be used. The gate voltage can control band-bending in junctions and also tune the band to band tunneling current. T-CNTFETs have advantages such as a low sub-threshold swing and a lower off-current. CNTFET has been investigated with symmetric graded double halo in the channel and as a result improved characteristics of CNTFET, Naderi and Keshavarzi (2012). But also, in this paper, we evaluate tunneling carbon nanotube field effect transistor with asymmetric graded double-halo in channel. The simulations have been performed by self-consistent solution between the Poisson and the Schrodinger equations with open boundary condition. In the asym-GDH-T-CNTFET, halos are placed next to the junction tips. The source-side n-doped halo reduces short-channel effects and drain induced barrier lowering (DIBL) and the drain-side p-doped halo, decreases drain energy barrier and increases band to band tunneling in drain contact. We investigate and compare on-current, tunneling current and I_{ON}/I_{OFF} for asym-GDH-T-CNTFET and T-CNTFET, then investigate those of asym-GDH-T-CNTFET with variation length and concentration of the halo-doping.

Nomenclature

MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor
SWCNT	Single Wall Carbon Nanotube
T-CNTFET	Tunneling Carbon Nanotube Field Effect Transistor

2. Simulation approach

The investigated devices simulates by self-consistent solution of the Poisson 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, Arefinia and Orouji (2008). A 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 by Yousefi et al. (2010). To decrease the computational cost of simulation is used the mode-space approach. 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 considered fixed as the boundary conditions. The iteration between the atomistic quantum transport equation and the electrostatic equation continues until self-consistency is obtained, Naderi and Keshavarzi (2012).

3. Device structure

The figures of T-CNTFET and asym-GDH-T-CNTFET structures have been shown in fig 1. Both devices are supposed to be constructed with the similar CNT and gate substance. The CNT is assumed to be made with a zigzag (16, 0) of 0.63-nm radius and length of L=15nm. A coaxial gate is placed around the carbon nanotube. The gate and

CNT have been separated another one by the dielectric layer HfO_2. HfO_2 has 2nm-thick and the relative dielectric constant ε_r=16. Two structures include in p-doped source and n-doped drain region with 30nm length and $2nm^{-1}$ doping. For asym-GDH-T-CNTFET, the length and the concentration of the halo are Lh =5nm and Nh=$1nm^{-1}$, respectively. Concentration of the GDH doping is zero at the middle of channel and rises linearly to source and drain and gets its maximum values at drain and source connection tips.

4. Results and discussion

The position of the energy bands of asym-GDH-T-CNTFET and T-CNTFET can demonstrate in Fig. 2. If the conduction band (E_C) in the channel is above the valence band (E_V) of the source, carriers can't tunnel from the source to the drain. On the other hand, when E_C in the channel is lower than the E_V in the source, a smaller tunneling barrier will observe at the source-channel junction and as a result band to band tunneling current (applied $V_{DS} > 0$). With increasing V_{GS}, the bands at the source side will bend more which causes tunnelling barrier increasingly thinner so, transmission rises. This chip on sub-threshold swing below conventional limited (60mV/Dec), and also increased on-current are obtained. On the other hand, applying negative V_{GS} leads to increase tunnelling current at the drain-end of the channel which results in ambipolar conduction. Fig. 3a shows that when the device is on the drain current saturates at high V_{DS}. But, increasing V_{DS} result in increased band to band tunnelling at the drain-channel side, finally (Fig. 3b). While holes injection at source contact can be decreased through the n-doping region of CNT near the source, p-doping region of CNT near the drain increases holes current at the drain contact. Figure 3a shows that tunneling current for T-CNTFET is lower than that for the asym-GDH-T-CNTFET also the on-current for T-CNTFET is higher than that for the asym-GDH-T-CNTFET. The value of I_{ON} depends on the thickness of the tunneling barrier at the end-source, so n-doped halo of CNT near the source increases tunneling barrier at the source-end and result in a smaller I_{ON}. On the other hand, p-doped halo of CNT near the drain decreases barrier height at the drain contact and increases tunneling current. The considerable increase of off-state leakage current for the asym-GDH-T-CNTFET in compare to that of T-CNTFET can be seen in Fig. 3b. This increasing is due to ambipolar conductance. This figure shows transconductance characteristics of asym-GDH-T-CNTFET and T-CNTFET structures at the different V_{DS}. The any drain voltage applied to the asym-GDH-T-CNTFET leads to decrease the energy barrier near the drain contact which due to the p-doping of the CNT near the drain and also off-current increases. In consequence, the tunneling current of holes is increased at the drain contact. The reduction of the sub-threshold slope and the increase in drain off-current can be observed from Fig. 3 which due to reduction of the control of gate voltage on drain-current and short channel effects (SCE). Reduction of the channel length results in smaller the threshold voltage. It is because the controllability of the gate over the channel region reduces which due to increased charge sharing from source/drain region. DIBL (drain inducted barrier lowering) effect happens as tunneling barrier for channel carriers at the source-end reduces. This is due to the impact of drain electric field. So n-doped halo at the source side causes increase height of the barrier and suppress SCEs and DIBL. This illustrates that asym-GDH-T-CNTFET can suppresses DIBL as can be found from Fig. 3b. Fig. 4 shows and compares the I_{ON}/I_{OFF} ratio as a function of I_{ON} for both structures. As can be observed in Fig. 4 the I_{ON}/I_{OFF} ratio for the T-CNTFET is larger than that for the asym-GDH-T-CNTFET. Reduction of ON/OFF current ratio is due to decrease on-current and off-current of asym-GDH structure. Fig 5 is investigated I_{DS}-V_{GS} of the asym-GDH-T-CNTFET with variation length of the channel, at a constant concentration of the halo doping. As can be seen from Fig. 5, on-current and tunneling current increase with a decrease in channel length. The on-current and tunneling current increase due to the fact that the length of tunneling path is decreased from the source to the drain, so the carriers can tunnel due to reduction of channel length increasingly. Also reduction of the channel length causes increase off-current, unfortunately (Fig. 5b). It is due direct tunneling from source to drain. At a constant channel length L=15nm, the dependency of I_{DS}-V_{GS} characteristics of asym-GDH-T-CNTFET on the different values of the concentration of halo-doping regions is shown in fig 6. It can be observed that with decreasing concentration of the halo doping, on-current increases and tunneling current reduces. The reason of this increasing of on-current is that reduction of the concentration of the halo leads to lower potential barrier at the source side so, more numbers of the carriers can tunnel from source to channel. Also tunneling current decreases due to decrease concentration of the p-doped halo of CNT near the source, it leads to weak potential barrier at the drain side. Reduction of the concentration of the halo-doping results in decreased off-current.

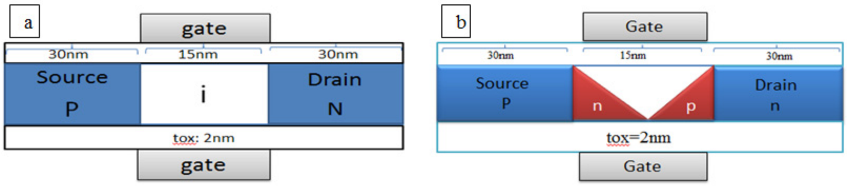

Fig. 1. Schematic cross-sectional views of the (a) T-CNTFET; (b) asym-GDH-T-CNTFET.

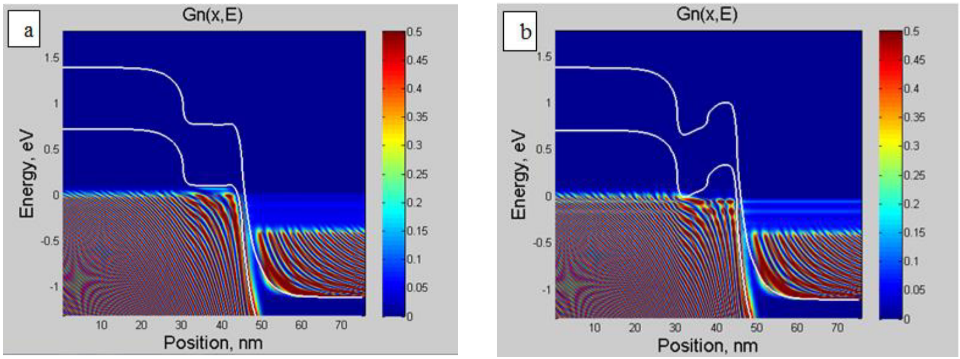

Fig. 2. Color-scaled plot for position energy along the CNT axis for T-CNTFET, the biasing conditions are V_{GS}=-0.6V and V_{DS}=0.4V for (a) T-CNTFET; (b) asym-GDH-T-CNTFET.

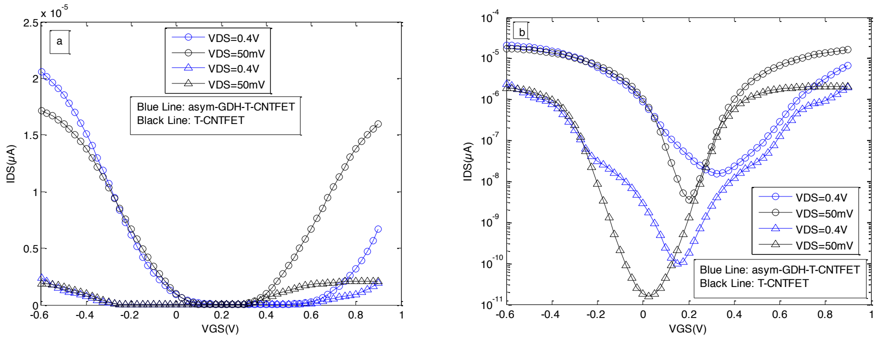

Fig. 3. I_{DS}–V_{GS} characteristic of asym-GDH–T-CNTFET and T–CNTFET at the different V_{DS} for (a) linear mode; (b) logarithmic mode.

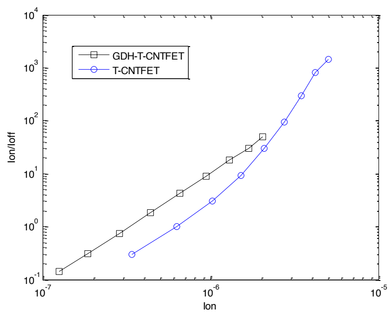

Fig. 4. I_{ON}/I_{OFF} ratio as a function of I_{ON} for asym-GDH-T-CNTFET and T-CNTFET structures, for V_{DS}=0.4V.

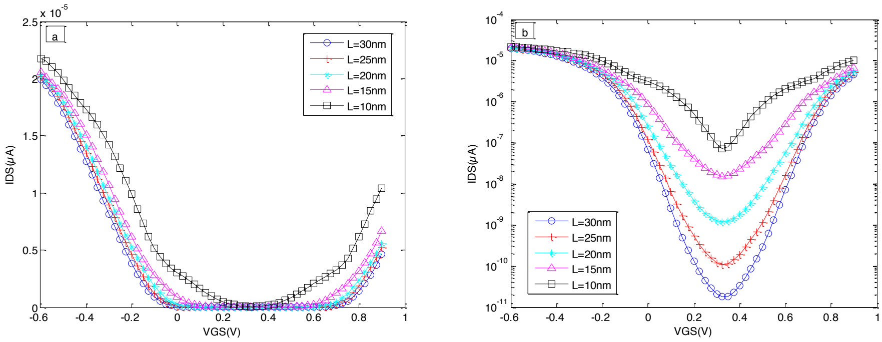

Fig. 5. I_{DS}–V_{GS} characteristic of asym-GDH–T-CNTFET and T–CNTFET with concentration of the halo 1nm^{-1} and different lengths of the channel for (a) linear mode; (b) logarithmic mode.

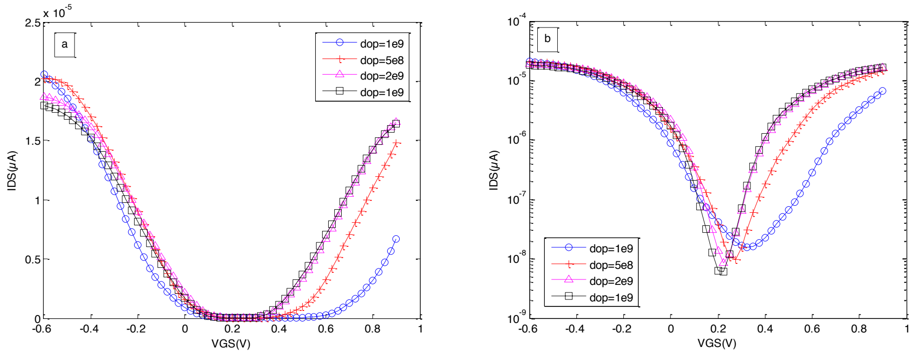

Fig. 6. I_{DS}–V_{GS} characteristic of asym-GDH–T-CNTFET and T–CNTFET with length of the halo 15nm and different concentrations of the channelfor: (a) linear mode; (b) logarithmic mode.

5. Conclusion

We investigated the effect of asymmetric double-halo doping on the performance and characteristics of T-CNTFET. Simulations performed by self consistently solving the Poisson and the Schrodinger equations using the NEGF formalism. The simulations have demonstrated that asymmetric GDH-T-CNTFET has reduced on-current when compared to that of a T-CNTFET which leads to I_{ON}/I_{OFF} ratio. Also, as discussed if length of the halo is constant, a decrease in concentration of the halo-doping increases the on-current and also leads to decrease tunneling current. In constant concentration of the halo doping, due to reduce the length of the halo-doping, on-current and tunneling current increase, subsequently.

References

Adessi, C., Avriller, R., Blasé, X., Boarnel, A., Cazin, H., Doiifus, P., 2009. Multiscaled Simulation of carbon nanotube devices. C.R. Physiqu E 10, 37-70.

Arefinia, Z., 2009.Investigation of the performance and band-to-band tunneling effect of a new double-halo doping carbon nanotube field-effect transistor. Physica E. 4, 1767-1771.

Arefinia, Z., Orouji, A. A., 2008. Impact of single halo implantation on the carbon nanotube Field effect transistor: Aquantum simulation study. Physica E. 41, 196-201.

Dang, T., Anghel, L.,Leveugle, R., 2006. CNTFET Basics and Simulation, International conference Design and Test of Integrated Systems in Nanoscale Technology. Tunis, 28-33.

Koswatta, S. O., Nikonov, O., Lundstrom, M. S., 2005. Computational study of carbon nanotube p-i-n Tunnel FET. IEEE IEDM Technical Digest, 518-521.

Naderi, A., Keshavarzi, P., 2012.Novel carbon nanotube field effect transistor with graded double halo channel. superlattices and Microstructures 51, 668-679.

Rueckes, T., Kim, K., Joselevich, E., Tseng, G. Y., Cheung, C. L., Lieber, C. M., 2000. Carbon nanotube-based nonvolatile random access memory for molecular computing 289, 94-97.

Yousefi, R., Saghafi, K., Moravvej-Farshi, M. K., 2010. Numerical Study of Lightly Doped Drain and Source Carbon Nanotube Field Effect Transistors. IEEE Transactions Electron Device 57, 765-771.