Novel dual material gate carbon nano tube field-effect transistor based on stepwise doping profile channel

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Abstract— In this work, a novel type of dual material gate carbon nano tube filed-effect transistor, with stepwise doping profile channel (SDC-DMG-CNTFET) is proposed, and simulated using with self-consistent solution of the two dimensional Poisson–Schrodinger equation, within the non-equilibrium Green's function (NEGF) formalism. The doping concentration of SDC-DMG channel is at maximum level at drain/source side and is reduced stepwise toward zero at the middle of channel. The results show that the new structure decreases significantly the leakage current, Increases On current, so increases On/Off current ratio. In comparison with dual material gate structure, this structure on CNTFET enhances the device performance.

Keywords; CNTFET; NEGF; SDC-DMG-CNTFET; leakage current.

I. INTRODUCTION

Nano scale field effect transistors in the sub-10 nm regime, suffer from short channel effects such as direct tunneling from source to drain, increase in gate-leakage current and sub threshold swing effect [1][3-4]. These effects have posed severe problems for miniaturized transistors and directed the recent research toward better alternative semiconductors than silicon. After discovering the carbon nanotube (CNT) by Aijima [2] Carbon nanotube (CNT) devices have attracted a lot of attention, The most important properties of this structure is quasi-ballistic transport and their excellent electronic properties [3]. Another of properties CNT symmetry of the conduction and valence bands makes CNTs advantageous for complementary applications [4-7].

To alleviate this problem, researchers have proposed a structure DMG-CNTFET "Dual Material Gate- CNTFET" to improve both carrier efficiency and SCEs [9]. Due to the discontinuity work function of the gate, this structure leads to potential step along the channel at the conjunction of different gate metals [6-8][10]. Also, doping profile engineering is an attractive issue that has been studied in the literatures [11-12]. Using halo implantation at channel region reduces the short channel effects and better device performance [12-14].

Therefore, we propose a new structure that has a channel with stepwise doping profile which call stepwise doped channel CNTFET (SDC-DMG–CNTFE). In this structure, impurity is distributed with three steps inside the channel region. The doping concentration of SDC-DMG channel is at maximum level at drain/source side and is reduced stepwise toward zero at the middle of channel.

II. NONA TRANSISTOR STRUCTURE

A schematic view of the proposed SDC-DMG-CNTFET is shown in Fig. 1. As shown in Fig.1, the channel region is made of three doped parts whit concentrations of p_1=0.8, p_2=0.4, p_3=0.2 respectively, also the length of each part is equal to 5nm. In this new structure, we consider a (13,0) CNT that results in a band gap of ~ 1eV and d=1 nm, also that is embedded in cylindrical gate insulator of HfO2 with thickness 2 nm and ε_r =16 [7-9]. Its cylindrical gate with length 30 nm consists of two laterally contacting metals with different work functions (M1,M2) and equal lengths 15nm. The work function difference is selected to make the threshold voltage near the source more positive than near the drain.

The brief expressions of used parameters have been listed in Table I.

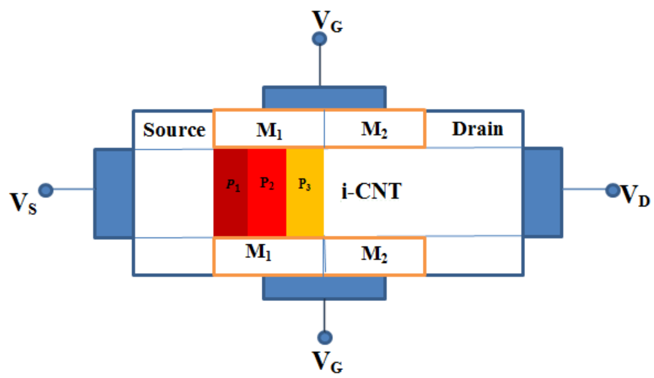

Fig. 1. Schematic view of the SDC-DMG-CNTFET structure.

TABLE I. THE PARAMETERS WHICH HAVE BEEN USED IN SIMULATION

Variable	*Value*
Nanotube type	(13,0)zigzag
Tamperature(K)	300
Gate dielectric constant	16
Dielectric thickness(nm)	2
Source/drain doping density	$1nm^{-1}$
Source/drain overlap with gate	0 nm

III. SIMULATION AND RESULTS

In this work, the simulations have been done by the self-consistent solution of 2-D Poisson–Schrodinger equations, within the non-equilibrium Green's function (NEGF) formalism as those used in [5][9-14].

Fig. 2, shows the I_{DS}-V_{DS} characteristics at V_{GS}=0.5&1V for SDC-DMG and DMG structures. By increasing the doping at channel, the threshold voltage is higher than that of DMG-CNTFET. Therefore, its saturation currents is lower than DMG-CNTFET.

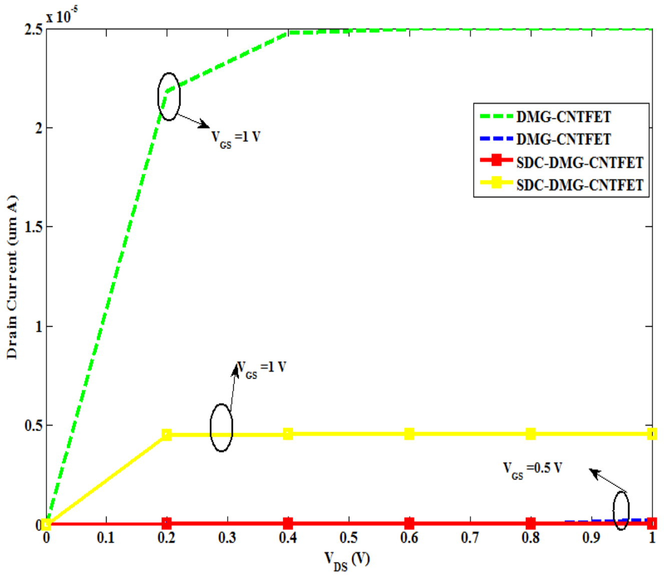

Fig.2. Output characteristics of SDC-DMG-CNTFET and DMG-CNTFET structures at V_{GS} = 0.5 ,1V.

Fig. 3, illustrates I_{DS}–V_{GS} characteristics at V_{DS}=0.5 and 1V. It is observed in the figure that by utilizing stepwise doping profiles in the channel region the leakage current of SDC-CNTFET is less than of DMG-CNTFET.

In Fig.4. shows the threshold voltages of DMG-CNTFET and SDC-DMG-CNTFET structures with various V_{DS}, shift in the threshold voltage of SDC-DMG-CNTFET due to change of V_{DS} is small. Therefore, DIBL in SDC-DMG-CNTFET is less when compared with the DMG-CNTFET.

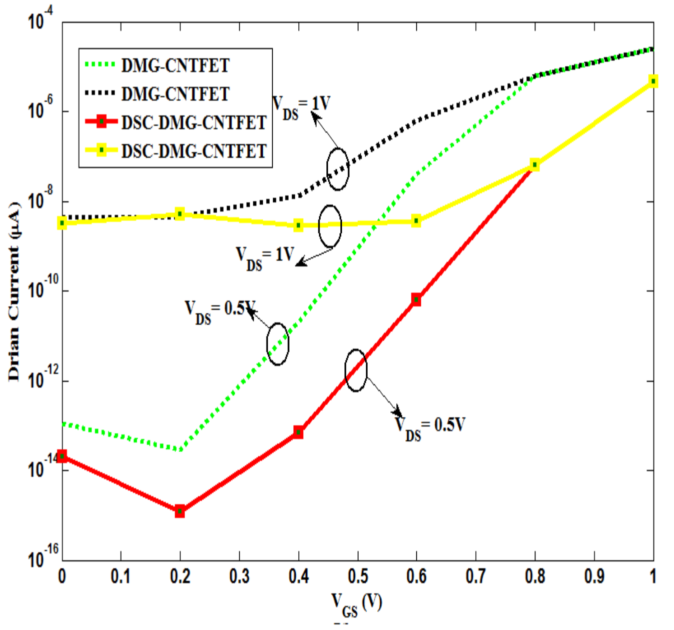

Fig. 3. Output characteristics of SDC-DMG-CNTFET and DMG-CNTFET structures at V_{DS} = 0.5 ,1V.

The subthreshold swing is a key parameter that defined as (DV_{GS}/Dlog (I_{DS})) in subthreshold regime [10-13]. In Fig. 5, subthreshold swing of SDC-DMG-CNTFET and DMG-CNTFET at V_{DS} = 50 mV are compared. It could be seen that the SDC-DMG structure has lower subthreshold swing compare with DMG structure.

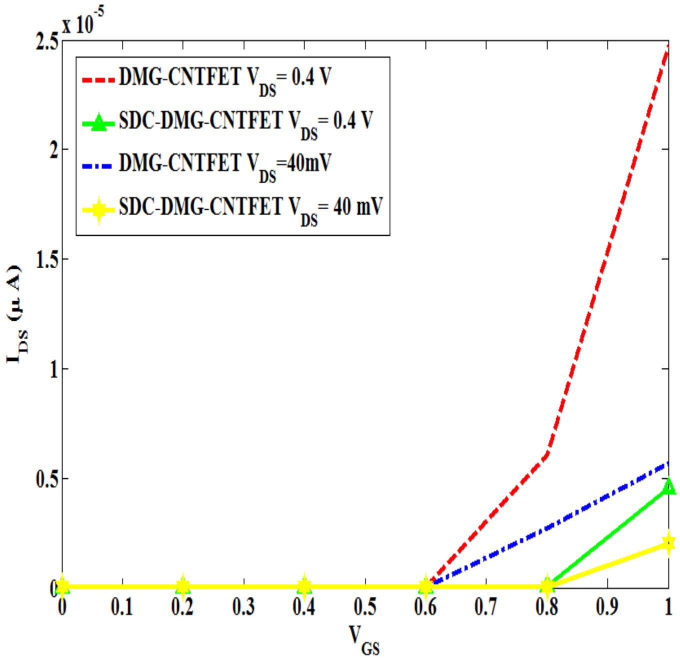

Fig. 4. I-V characteristics of DSC-DMG-CNTFET and DMG-CNTFET structures at V_{DS} = 40mV ,0.4 V.

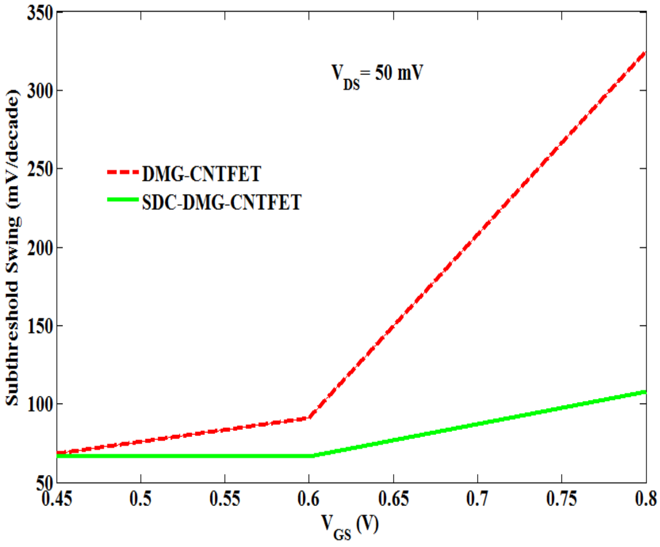

Fig. 5. The subthreshold swing of SDC-DMG-CNTFET and DMG-CNTFET structures biased at V_{DS} = 50 mV versus channel length for various channel doping profiles.

Figs. 6–8 show the on, off, and on/off current ratio respectively at different channel length and doping density for each two structures.

The ON-state current under V_{GS}=V_{DS}=0.8 V and OFF-state current under V_{DS}=0.8 V, V_{GS}=0V are compared. While saturation current of the DMG-CNTFET is larger than of the SDC-DMG-CTFET structure, But off current SDC-DMG structure much less than of the DMG structure and causes to higher on/off current ratio.

The results show that in the structure have proposed, reduced leakage current, Subthreshold swing and increases on–off current ratio thus making it a more reliable device configuration than the DMG-CNTFET for high performance complementary.

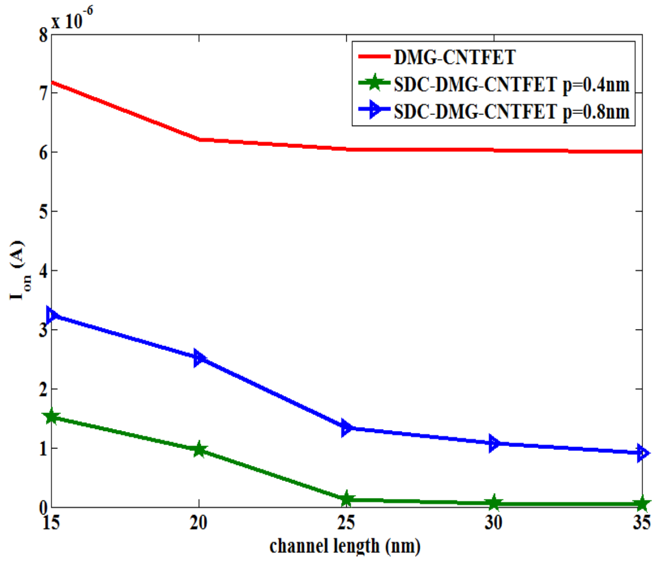

Fig.6. The saturation current of SDC-DMG and DMG–CNTFET, structures biased at V_{GS} = 0.8 V and V_{DS} = 0.8 V versus channel length.

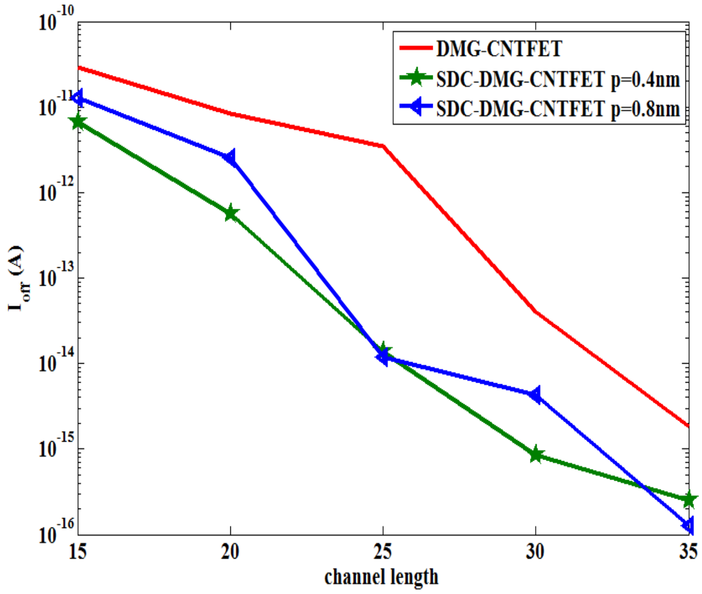

Fig.7. The off current of SDC-DMG and DMG–CNTFET, structures biased at V_{GS} = 0V and V_{DS} = 0.8 V versus channel length.

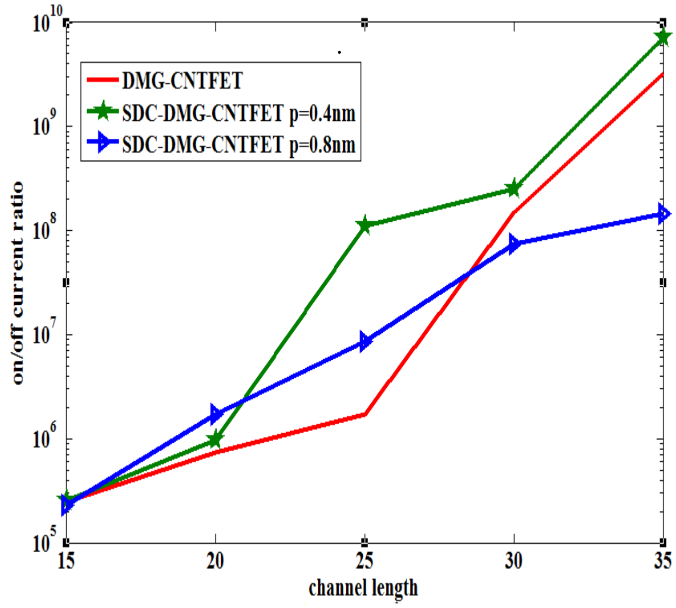

Fig.8. The on/off current ration of SDC-DMG and DMG-CNTFET versus channel length.

IV. Conclusion

A novel carbon nano tube field effect transistor with stepwise doping profile channel (SDC-DMG-CNTFET) structure has been proposed and simulated in this paper using self-consistent solution of the two dimensional Poisson–Schrodinger equation,within the nonequilibrium Green’s function (NEGF) formalism. The proposed structure has superior performance compare with DMG–CNTFET structures in terms of on-off current ratio, leakage current, sub threshold swing, DIBL. Also, the proposed structure has lower leakage current, higher on-off current ratio, lower sub threshold swing. In other words, our proposed DSC-DMG-CNTFET structure improves the device performance and has lower effects on saturation current. So, it can be used as a more reliable CNTFET structure for future experimental works.

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