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IMPACT OF DIFFERENT CHANNEL MATERIALS ON LOW POWER PERFORMANCE OF TFET

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Abstract: Modeling and Simulation are achieved to plan a P-type Tunnel Field Effect Transistor (PTFET) utilizing various channel materials such as Si, Ge and Graphene Nanoribbon (GNR) for better DC performance. The energy band diagrams and surface potential of the transistor for each channel material are obtained for both on and off states from the solution of one dimensional Poisson equation by using indigenously developed software for simulation of the device properties. The results show that both on-current and on-off current ratio are found better in TFET with GNR as channel material other than Si and Ge as channel material. In this way GNR TFETs are good device for low power digital system.

Keywords: PTFET, GNR, On-Off current ratio

1. INTRODUCTION

Metal oxide field effect transistor can be reduced in size to attain high packing density and on current. In any case the sub-threshold slope of metal oxide field effect transistor cannot be reduced underneath the thermionic constrain of 60mV/decade [1]. Thus, it gets to be troublesome to decrease the off state leakage current underneath a certain restrain. In this regard Tunnel Field Effect Transistors (TFETs) are exceptionally favorable devices where interband tunneling appears. It lowers the sub-threshold swing underneath 60mV/decade with higher on-off current ratio and lower off state leakage current. Since germanium (Ge) has smaller energy band gap (E_G) than Si, Ge can be utilized to extend the ON state current [2] as channel material in TFET. Higher off-state leakage current in Ge TFETs than Si TFETs leads to lower on-off current ratio. The graphene as nano-ribbon (GNR) can be used as one-dimensional channel material in TFETs to increase the on-state current. Therefore GNR makes an improvement in on-off current ratio and sub-threshold swing with width-tunable bandgap and lower supply voltage. Later research works shows that GNR with tunable ribbon width has smaller E_G which improves the on-current (Ion) and significantly decrease the leakage current (I_{off}) [3], [4]. This paper is proposed to discuss comparative analysis of TFET using different channel materials like Si, Ge and GNR with respect to low power performance parameters.

Device Structure

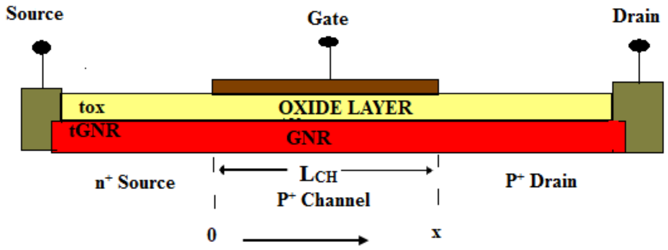

Fig 1. The structure of GNR PTFET

The structure of P –type GNR TFET is appeared in Fig.1. The TFET has exceedingly doped source (n+), channel (p+) and drain (p+) sides. One-dimensional Poisson equation forthe device isnumerically illuminated to get the energy band profile for both on, off condition and surface potential. The channel is completely depleted within the off state at Vgs=0V. Within this work, the oxide thickness is chosen as 2nm. The Y_2O_3 is the gate oxide material.

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The channel length and ribbon width for GNR PTFET are taken to be 20nm and 4 nm respectively following the recent trend of ITRS (International Technology Roadmap for Semiconductors).

The 1-D Poisson's Eqn.[1] for surface potential, $\phi_{surf}(x)$ is given below:

$$\frac{d^2\varphi_{surf}(x)}{dx^2} - \frac{\varphi_{surf}(x) - V_{GS} - V_{bi}}{\lambda^2} = -\frac{q\rho(x)}{\varepsilon_{GNR}} \quad (1)$$

Where V_{bi} is the built-in potential, $\varphi_{surf}(x)$ is the surface potential at position x , Vgs is the gate to source potential, λ is the screening length of the device , $\rho(x)$ is the whole charge density and ε_{GNR} is the permittivity of GNR. Local interband tunneling mechanism occurs in the present study. Graphene nanoribbon is prepared by cutting 2-dimensional graphene sheet in restrain stripes generate sidelong detainment and width tunable bandgap. GNR has high mobility. The dependence of band gap of GNR with ribbon thickness is clarified below [5].

$$E(n, k_x) = s\eta v_F \sqrt{k_x^2 + k_n^2} \quad (2)$$

Where v_F is the Fermi velocity of carrier 10^6m/s, ħ is the reduced Planck's constant, k_n is the wave vector related to nth subband of the device, and the value of s is ±1 of the device.

The k_n is given by

$$k_n = n\pi/3w_{GNR} \quad (3)$$

Where n=±1, ±2, ±3, ±4….. and w_{GNR} is the ribbon width.

The electron momentum is ηk .Therefore the band gap energy of GNR is written as

$$\xi_G = \xi_C - \xi_V = \xi_{S=+1} - \xi_{S=-1} = \frac{2\pi\eta v_F}{3w_{GNR}} \quad (4)$$

The ribbon width w_{GNR} and Fermi velocity (v_F) as appeared in Eqn. (4)

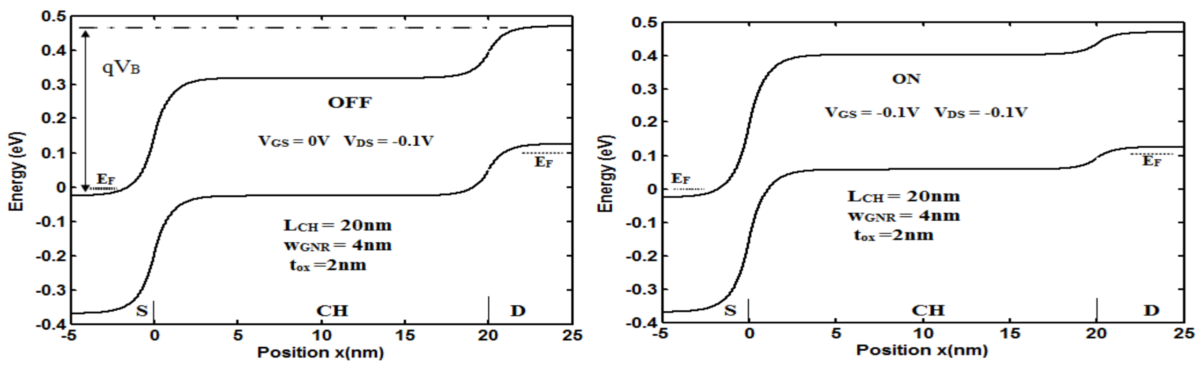
The screening length λ is written as [6]

$$\lambda = \sqrt{\left(\frac{\varepsilon_{GNR}}{\varepsilon_{OX}}\right) t_{GNR} t_{ox}} = \sqrt{t_{GNR} t_{ox}} \quad (5)$$

Where t_{ox} and t_{GNR} are the thickness of gate oxide and GNR separately. The permittivities of gate-oxide and GNR are ε_{OX} and ε_{GNR} . The dielectric constant of high–k dielectric material (Y_2O_3) used as gate oxide of TFET is known to be 16. To shrink the gate leakage current from gate to channel the high-k dielectric material is used as gate oxide of the device. Several framework GNR PTFET like On-Off current ratio, sub-threshold swing, etc. are obtained and optimized for better digital low power application by changing the device channel length, ribbon width and gate oxide thickness.

2. RESULTS AND DISCUSSION

Therefore energy band profile for the designed GNR PTFET within the off state (Vgs = 0V) and on state (Vgs = -0.1 V, Vds= -0.1 V) are appeared in Figs. 2(a) and 2(b) separately comparing to the values of and as 4nm and 20nm separately. The Fermi energy levels (E_F) within the band graphs for both the Off and On states of the device are moreover appeared.



(a) (b)

Fig.2 Energy band diagrams for a GNR PTFET in the (a) Off-state and (b) On-state

The drain current versus Vgs curve of the device for various channel materials is appeared in Fig.3

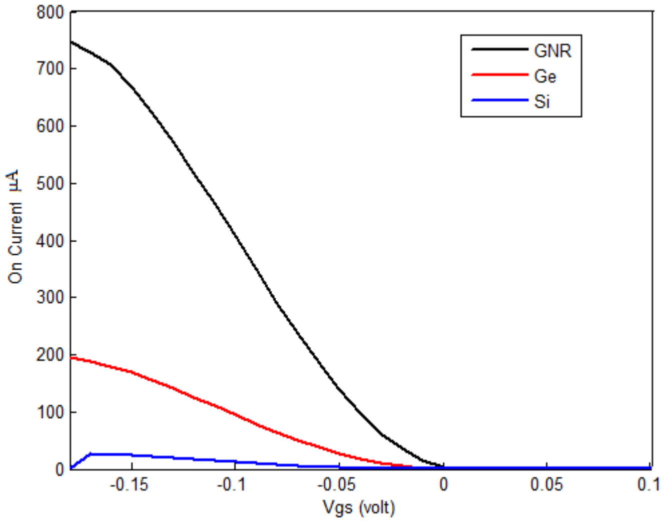


Fig.3 On Current versus Vgs curve of PTFET for various channel materials

Fig. 3 indicates that PTFET with GNR as channel material having 20 nm channel length would provide highest on state current as compared to other TFETs at V_{gs}=-0.1V.

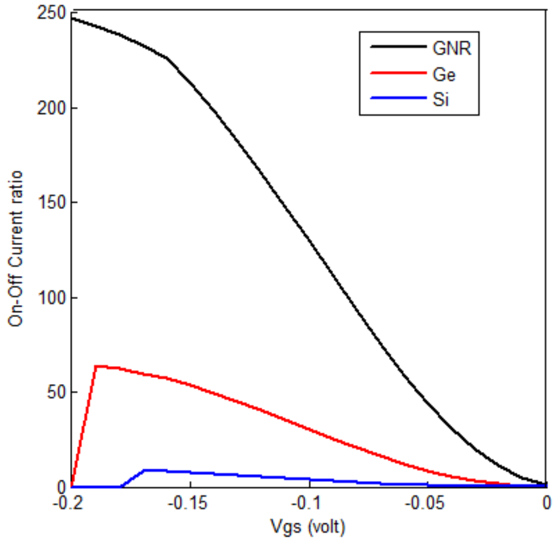


Fig.4 On-OFF current ratio for various channel material

Fig 4 appeared the On-Off current ratio vs (V_{gs}) for various channel materials. On-Off current ratio is found to be highest in GNR TFET with respect to Si and Ge TFETs. The On-Off current ratio is found to be 210 at Vgs=-0.1V in GNR PTFET. The sub-threshold swing (SS) of the optimized GNR PTFET is found to be 8mV/decade at V_{gs} = -0.1V. The On-Off current ratio is much less for Ge and Si TFETs i.e. 49 and 25 at V_{gs}=-0.1V

CONCLUSION

A P-type TFET with Si, Ge and GNR as channel materials is optimized by way of modeling and simulation by employing a MATLAB based design computer program for investigation of their low power device circuit design. It is found that PTFET with one dimensional graphene nanoribbon as channel material gives superior performance as respects on-current and on-off current proportion compared to PTFETS utilizing other channel materials. Hence GNR TFETs are promising following era devices for low power device design.

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