Analytical Modelling of GNRFET on MATLAB

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***Abstract*—In recent years, graphene has shown huge promise as material that can swap silicon-based materials in the future due to its outstanding electrical properties and other characteristics. MOSFETs have disadvantages with shorter channels causing short channel effects but Graphene has many uncommon properties. It is the strongest material ever tested, conducts heat and electricity efficiently, high mobility at room temperature, low atomic thickness, large current density, and is nearly transparent, Graphene shows a large and nonlinear diamagnetism. Graphene is an allotrope form of carbon consisting of a single layer of carbon atoms arranged in a hexagonal lattice. It is a semimetal with small overlap between the valence and the conduction bands and overall with reduced short channel effects. In this project, we propose the analytical modelling and simulation of Graphene Nanoribbon field effect transistor with armchair chirality of GNRs for semiconducting behaviour in which, we model Drain current v/s Drain voltage, Drain current v/s Gate voltage, Current density with varying channel lengths, Transconductance, Ion/Ioff ratio, Channel surface potential and Density of States using self-consistent solution of 2D Poisson equation. This project covers the studies and modelling of Graphene Nanoribbon, which includes current-voltage graphical plots using MATLAB.**

Keywords—Graphene Nanoribbon,MATLAB,Analytical Modelling

I. INTRODUCTION

The need for technological progression in the field of electronics has been persistently escalating. So far silicon has been the most important fabrication material of preference for meeting the current demands. However, silicon itself has few of its own limitations. Silicon based integrated circuits and the scaling of silicon MOSFET design faces complications like tunneling effect, gate oxide thickness effect etc. which has given the extensive perimeter for new materials with improved characteristics to emerge.

The number of transistors on a typical 1 × 1 cm chip has grown exponentially with two fold increase in every 18 months keeping Moore's Law on track. Serious hindrances are in sight as transistor scaling enters the Nano-meter domain. Short-channel effects are significant as devices are scaled below sub-100 nm, providing challenges and opportunities for device and process engineers. Researchers across the globe are exploring new Nano-materials with transformed architecture to circumvent the roadblocks of silicon-based nanotechnology for enhanced circuit performance. Carbon-based allotropes offer a distinct advantage in a variety of applications. Graphene has exceptional properties such as large carrier mobility, high carrier concentration, high thermal conductivity, low subthreshold swing, etc. and patterning it into Nano-ribbon strips induces a band gap in graphene for switching purpose. Graphene Nanoribbons (GNRs) are one-dimensional (1D) nanostructures restricting carrier motion in only one direction, reducing scattering for enhanced mobility. The transistor current is quite high as electrons are injected from the source and transit to the drain terminal. A narrow width semiconducting GNR is utilized as a channel in a top-gated transistor. This pushes the limits of complementary metal-oxide semiconductor (CMOS) type of technology beyond its limits in a GNR.This project focuses on modelling, simulation, and benchmarking of top-gated graphene nanoribbon field effect transistors (GNRFETs).The Simulation modelling is carried out in MATLAB and circuit development and device physics along with comparing the simulation results is performed using TCAD software.

Graphene which is a monolayer of carbon atoms packed into a two-dimensional honeycomb lattice, has emerged as a promising candidate material for Nanoelectronics applications. Graphene based devices offer high mobility for ballistic transport, high carrier velocity for fast switching, monolayer thin body for optimum electrostatic scaling, and excellent thermal conductivity. The potential to produce wafer-scale graphene films with full planar processing for devices promises high integration potential with conventional CMOS fabrication processes, which is a significant advantage over carbon nanotubes (CNTs). Although two-dimensional graphene is a zero band-gap semimetal, a band-gap is achieved by patterning graphene into a graphene nanoribbon (GNR) that is a few nanometers wide. The band-gap of a GNR is in general inversely proportional to its width.

II. SIMULATION AND MODELLING

Fig.1 shows the representation of GNRFET under study.A single layer of armchair Graphene Nano-Ribbon (A-GNR) with index of N=12 is used as the channel material which is taken to be intrinsic.The Index N,defines the number of dimer carbon atom lines transverse to transport direction which is determined by the GNR width,W.The width and length of this GNR channel are assumed to be Wg=33.54nm and L=15nm,respectively.The insulating layers have 0.95nm thickness and consist of the SiO_2 material with the dielectric constant of k=4.The source and drain regions are assumed to be heavily doped GNR with doping concentration value of 1*10^16.

The below mentioned flow chart in Fig.2 is designed using self-consistent solution. Here E is energy level in vector form. Which defines different energy levels. Specify Density of States and Current Density analytically. Initialize Surface Potential as zero. And solve for N and U_{scf} iteratively using Self-Consistent solution. If du converges to certain value as defined in flow chart, then evaluate current Id.

STEPS:
(1)Specify the Semiconductor carrier and Current Density J(E) and Density of states D(E) analytically.

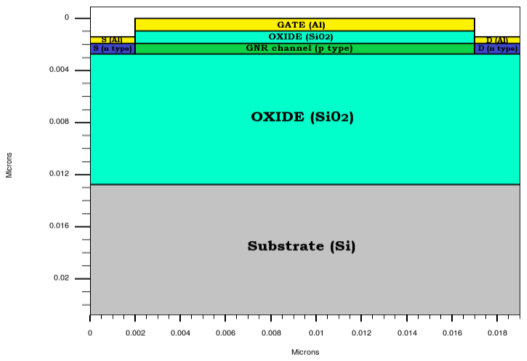

Fig 1:Structure of GNRFET

(2)Specify Vg, Vd,Vs and Ef.
(3)Iteratively solve for $Uscf=U_L+U_P$ and N.
(4)Evaluate the current for the assumed and Vg and Vds

TERMS USED IN THE DERIVATIONS:

(1) DENSITY OF STATES (DOS):

The density of states of a system is described as the number of states per an interval of energy at each energy level available to be occupied. It is mathematically represented by a density distribution and it is generally an average over the space and time domains of the various states occupied by the system.

$$D(E) = \frac{g}{2\pi} \times \frac{1}{E^2+(g/2)^2} \quad (1)$$

(2) FERMI FUNCTION:

If the source and drain regions are coupled to the channel (with VD held at zero), then electrons will flow in and out of the device bringing them all in equilibrium with a common electrochemical potential, μ, just as two materials in equilibrium acquire a common temperature (T). In this equilibrium state, the average (over time) number of electrons in any energy level is typically not an integer, but is given by the Fermi function:

$$f(E_i) = \frac{S_i}{N_i} = \frac{1}{1+e^{(E_i-EF)/kT}} \quad (2)$$

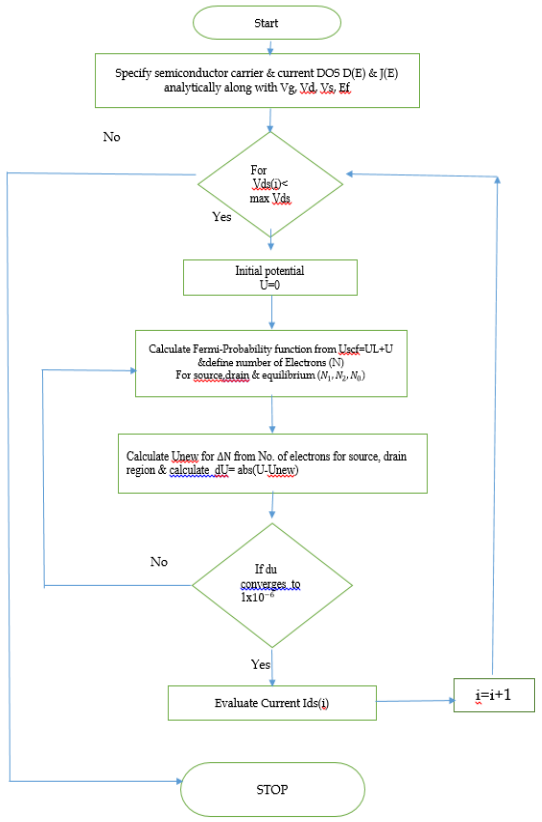

Fig 2:Flowchart of Analytical Modelling

(3) SELF-CONSISTENT POTENTIAL (Uscf)

Surface potential is defined as potential which is determined between source and drain that is along the channel. So it is determined using self consistent solution. This can be determined by iteratively solving Electrostatic and Transport equations.

$$U_{scf} = U_L + U_P \quad (3)$$

(4) ELECTRON DENSITY (N)

Electron density is the measure of the probability of an electron being present at a specific location within an orbital.

(5) CURRENT DENSITY (J)

Current density is defined as the electric current per unit area of cross section. The current density vector is defined as a vector whose magnitude is the electric current per cross-sectional area at a given point in space, its direction being that of the motion of the charges at this point. In SI units, the electric current density is measured in amperes per square metre.

$$J(E) = \frac{1}{2} q\left(\frac{2}{\pi}\sqrt{\frac{2(E)}{m^*}}\right)D(E) \quad (4)$$

$$D(E) = \frac{g}{2\pi} \times \frac{1}{E^2+(g/2)^2} \quad (5)$$

$$J(E) = \frac{1}{2} q\left(\frac{2}{\pi}\sqrt{\frac{2(E)}{m^*}}\right)D(E) \quad (6)$$

$$\Delta N = (N_1 + N_2) - N_0 \quad (7)$$

$$N_0 = \int_{-\infty}^{+\infty} D(E) f_0(E) dE \quad (8)$$

$$N_1 = \frac{1}{2}\int_{-\infty}^{+\infty} D(E) f_1(E) dE \quad (9)$$

$$N_2 = \frac{1}{2}\int_{-\infty}^{+\infty} D(E) f_2(E) dE \quad (10)$$

where,

$$f_1(E) = f(E + U_{scf} - E_{f1}) \quad (11)$$

$$f_2(E) = f(E + U_{scf} - E_{f2}) \quad (12)$$

$$U_{scf} = U_L + U_P \quad (13)$$

where,

$$U_L = -q\left(\frac{C_G}{C_\Sigma}V_G + \frac{C_D}{C_\Sigma}V_D + \frac{C_S}{C_\Sigma}V_S\right) \quad (14)$$

$$U_c = \frac{q^2}{C_\Sigma}\Delta N \quad (15)$$

$$U_P = U_c \Delta N \quad (16)$$

$$I_D = \int_{-\infty}^{+\infty} J(E)[f_1(E) - f_2(E)]dE \quad (17)$$

where,
D(E) is density of states, 'g' is broadening factor, J(E) is current density, U_{scf} is self consistent potential.

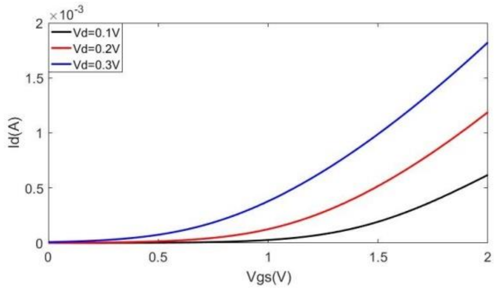

Fig 3:Drain Current v/s Gate Voltage (Linear)

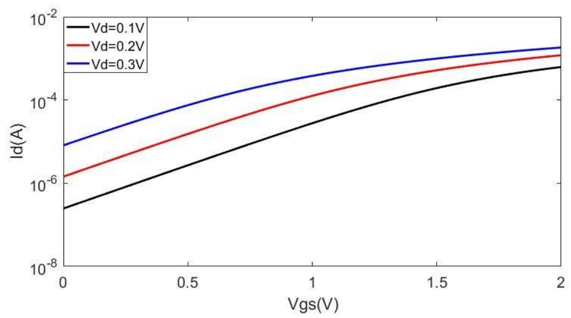

Fig 4:Drain Current v/s Gate Voltage(Logarithmic)

Ion/Ioff ratio=$(1*10^{-3})/(1*10^{-7})=1*10^{4}$

Sub-threshold Swing(SS)=d(Vgs)/d(log(I_2/I_1))=76.8mV/dec

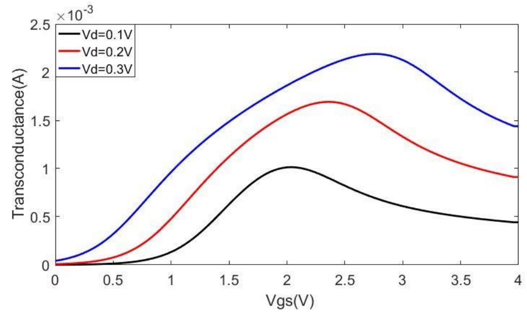

Fig 5:Transconductance v/s Gate Voltage

Transconductance, Gm=d(Ids)/d(Vgs)=((9*10^-6 - 3*10^-6)/(0.4-0.2)=3*10^-5 ohm^{-1}

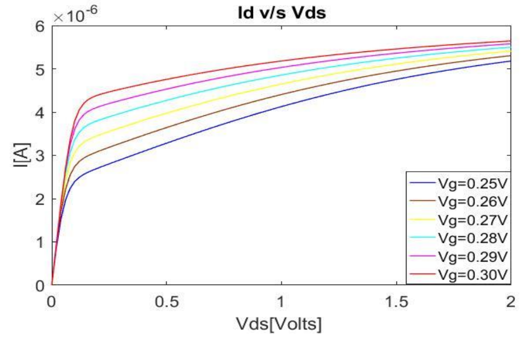

Fig 6:Drain Current v/s Drain Voltage

Drain Resistance, Rd=d(Vds)/d(Id)=(0.1)/(2*10^-6 – 9.49*10^-10)=50k-ohms

Amplification factor,u= Rd * Gm=50k-ohms * 3*10^-5 ohm^{-1}
u =1.5

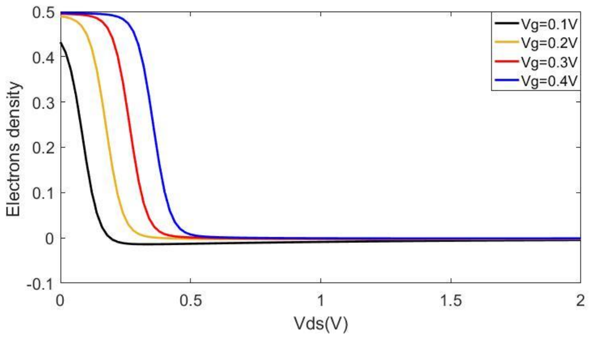

Fig 7:Electron Density v/s Drain Voltage

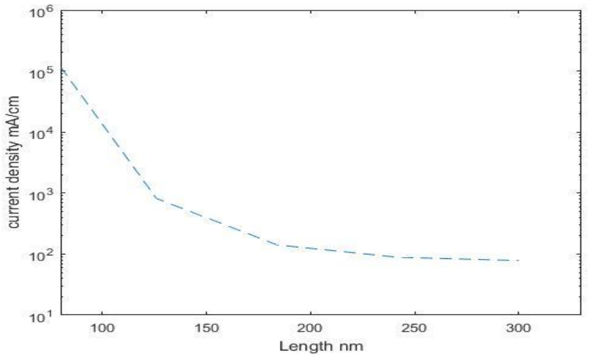

Fig 8:Ion Current Density v/s Length

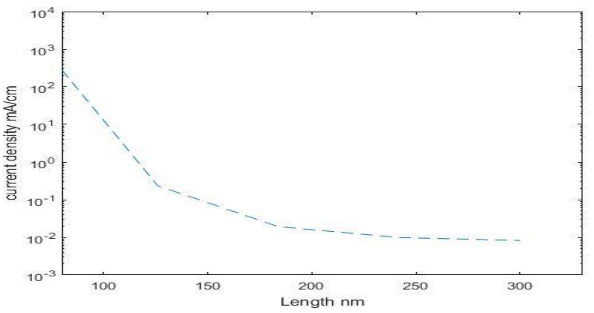

Fig 9:Ioff Current Density v/s Length

III. CONCLUSION

A model for the Graphene Nanoribbon FET using Self Consistent Solution is analysed on MATLAB.The various characteristics have been plotted and they match with the experimental data.It shows that GNRFET have better mobility,high Ion/Ioff ratio,High Amplification factor and thin channel thickness which can lead to better performance than MOSFETs.

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