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# Design and Analysis of Field Effect Transistor Coated With Graphene Using Finite Element Method

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**Abstract:** A novel graphene coated field effect transistor is designed using finite element method based tool. The various analysis includes drain current and drain voltage is measured by varying the terminal current, electron and hole concentration, signed dopant concentration, electric potential are the factors that are observed. The scaling of semi-conductors transistors has led to decrease of thickness in the layer of silicon dioxide which acts as gate dielectric. This analysis, will give as a replacement of silicon dioxide for the design of semi-conductor using a stimulation tool comsolmultiphysics 5.0 version.

**Keywords:**field effect transistors, graphene, finite element method, semi-conductor.

## I. INTRODUCTION

One of the current priorities in physics, electronics, of grapheme is the study of semiconducting derivative. Right now, the research going into graphene has a great deal in common with the research done in the early days of the transistor. In this paper, we are trying to show how the properties of graphene are suitable to make a semiconductor. Here we are explaining how the material properties, structural properties, electronic properties, favored to design a graphene layered semiconductor.

**1.1 FUNDAMENTAL PROPERTIES OF GRAPHENE:-**graphene, basically a single atomic layer of graphite, which is abundance in nature. The sp2 hybridization, the lattice structure and a very thin atomic thickness are the most unique factors of the graphene. The steps towards bi-layered graphene took place by many scientists which helps in betterment of our research work.

**1.2 HISTORY OF SEMICONDUCTOR:**The semiconductors mainly focused mainly around two important properties i.e, rectification of metal semiconductor junction and sensitivity of semiconductors to light. Whereas before the invention of semiconductor the discovery of semiconductor materials made a tremendous and advancements in the field of electronics. The invention of new semiconducting materials is on process. The term "semiconducting" was used for the first time by Alessandro Volta in 1782. Michael Faraday was the first person to observe a semiconductor effect in 1833. Faraday observed that the electrical resistance of silver sulfide decreased with temperature. In 1874, Karl Braun discovered and documented the first semiconductor diode effect.

**1.3 SEMICONDUCTOR TECHNOLOGY:**Semiconductors have a unique atomic structure that allows their conductivity to be controlled by stimulation with electric currents, electromagnetic fields, or even light. This makes it possible to construct devices from semiconductors that can amplify, switch, convert sunlight to electricity, or produce light from electricity. The doping takes major part in making semiconductor material. The doping involves in changing the structure and properties of a material selected.

## II. LITERATURE SURVEY

The research on graphene started in the starting of the 20th century. Many research papers and scholar written papers are published based upon introducing graphene layer instead of silicon. Which shows better results than the silicon layer. Many materials came into consideration like hafnium dioxide, titanium dioxide, and transition metal dichalcogenide (TMDs) …e.t.c to replace silicon dioxide. But after undergoing many tests by many researches the scientists decided graphene to be the best material to overcome the defects of the silicon dioxide semiconductor.The universities like Harvard university, and Massachusetts institute of technology, Cambridge done many experiments upon this theory of proposal.

**2.1 MOOR'S LAW:**Mooor's law is defined as that the number of transistors on a microprocessor chip would double every two years. This law played a key role in manufacturing chips. As per the material mentioned in this paper.

The best in graphene material is lead to lower heat production, energy production and low cost. In silicon semiconductor the moor's law cannot handle anymore. Because the doubling has already started to flater, where

  

heat is unavoidably generated, electron leakage and other effects. The graphene materials reduce drawbacks of silicon semi-conductor and helps in efficient modeling of chips.

**2.2 Arising of nano materials in the field of semiconductor:**Of many materials as silicon tried to improve its electrical performance. Alternatively semiconductors such as gallium nitride (GaN) and silicon carbide (SiC) cope much better at higher temperatures, which means they can be run faster and have begun to replace silicon in critical high-power applications such as amplifiers.

The first concerns silicon's poor electron hole mobility. A small amount of germanium is already added to improve this, but using large amounts or even a move to all-germanium transistors would be better still. Germanium was the first material used for semiconductor devices, so really this is a "back to the future "move. The materials like gallium nitride, hafnium oxide, zinc oxide, titanium oxide, transition metal dichalcogenides are the considerable materials in the place of silicon oxide

## III. DESIGN OF GRAPHENE BASED FET

The comsol multi physics 5.0 is used to define felid effect transistor coated with graphene. The compact model of the dual gate bilayer –graphene field effect transistors. This model is developed based on the 2-D density of states of bilayer graphene. Furthermore, physical equations describing the behavior of the source and drain access regions under back-gate bias have been proposed. The model is based on the structure shown in Fig. 1.

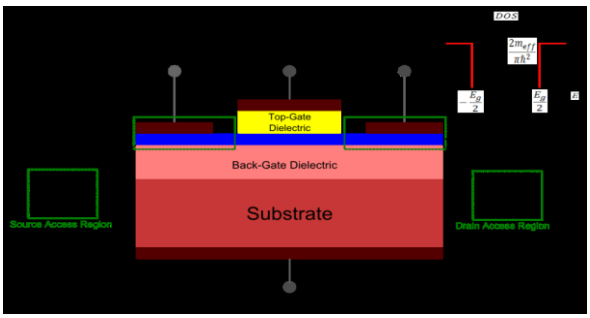


FIG 1- bilayer graphene FET device

**3.1 Electronic properties:**Basically, graphene is not a metal but the due to its zero band gap it is named as semi metal. Electrons present in graphene behave as a massless particles. They possess a very strange properties, for example anomalous quantum Hall effect, absence of localization, high electron mobility at room temperature (250,000 cm2/Vs) , thermal conductivity (5000W/(mK) due to zero bandgap. As we discussed, the zero band gap of graphene makes it a metallic behaving material. Actually more metallic than conventional metal. But this holds true unless the size of the graphene layer is in the range of several microns or even several hundred nanometers. However, a distinct band gap can be generated as the dimension of graphene is reduced into narrow ribbons with a width of 1–2 nm, producing semi conductive graphene with potential applications in transistors. Thats how graphene can also behave as a semiconductor.

## IV. PARAMETER SECTION

| NAME | VALUE | DESCRIPTION |
|---|---|---|
| Vg | 2v | Gate voltage |
| Vd | 0.01v | Drain voltage |

The parameters which we defined gain voltage and drain voltage are used to define parametric sweps.

**4.1 Material properties** Bilayer graphene can be controlled by an applied electric field so that the electronic gap between the valence and conduction bands can be tuned between zero and mid-infrared energies. This makes bilayer graphene the only known semiconductor with a tunable energy gap and may open the way for developing photo detectors and lasers tunable by the electric field effect. The development of a graphene-based tunable semiconductor being reported here, as well as the discovery of anomalous integer quantum Hall effects (QHE) in single layer and unbiased bilayer graphene, which are associated with massless and massive Dirac fermions, respectively, demonstrate the potential of these systems for carbon based electronics.

| **Description** | **Value** |
|---|---|

  

| | |
|---|---|
| Relative permittivity | 100 |
| Band gap | 200 |
| Electron mobility | $25.99e^{-3}$ $m^2/(V*s)$ |
| Hole mobility | $39.64e^{-3m2}/(V*s)$ |
| Temperature | 293.15 [K] |

Using these basic parameters of graphene material the semi conductor material model is being constructed. In this section the model inputs, material properties, mobility of electrons and holes, band gap narrowing, dopant ionization are being defined.These are the basic semiconductor equations:- $\nabla \cdot (\epsilon_r \nabla V) = q(n - p + N_A^- - N_D^+)$

$$\frac{1}{q}\nabla \cdot \mathbf{J}_n = -U_n, \quad \frac{1}{q}\nabla \cdot \mathbf{J}_p = U_p$$

$$\mathbf{J}_n = \left(\mu_n \nabla E_c + \frac{qD_{n,th}}{T_l}\nabla T_l\right) n + \mu_n k_B T_l G(n/N_c)\nabla n \quad \mathbf{J}_p = \left(\mu_p \nabla E_v - \frac{qD_{pth}}{T_l}\nabla T_l\right) p - \mu_p k_B T_l G(p/N_v)\nabla p$$

$$E_c = -q(V + \chi), \quad E_v = -q(V + \chi + E_g)$$

**4.2 Mobility** To obtain mobility by measuring conductivity σ = (L/W)I14/V23 as a function of VG0 at low fields (~2 mV/μm). Mobility vs. carrier density is extracted as μ = σ/q(p+n) at various temperatures and VG0 > 0 (n > p). Hall mobility measurements yield identical results to carrier density. The mobility first increases, peaks at ~4500 cm2 /V·s and n ~ 2×101 cm-2 (at 300 K), then decrease with carrier density. Mobility decreases with rising T > 300 K for all carrier densities. Similarly the mobility for the holes are also determined. By using energy bands the difference in the electron and hole mobility is not found. This is most likely due to the calculated hole density underestimating the actual value in the device, probably due to a spatial inhomogeneity of the "puddle" regime that is not accurately predicted by the simple ±ΔV0 potential model. We note the mobility shape recovers at higher temperatures (350-500 K).

**4.3 Band gap narrowing** graphene is a new material which is a monolayer of carbon atoms and it has many one formative properties. Recently people have more interests in making nano electronic devices. But one challenge in graphene is to create a band gap. But graphene intrinsically have band gap zero. Many researches has tried to create a band gap. As it was predicted theories that if you apply electric field across a bilayer graphene. It can actually generate a tunable band gap so it makes a unique property in graphene. Now you can have a material whispernet band gap and you can also adjust the band gap in order to optimize poses performance for band gap for electronics. Band gap will be of 0-230 milli-electron volts.

**4.4 Meshing** A normal type of triangular mesh is used . The mesh is based on triangular elements in two dimensions or tetrahedral elements in three dimensions. These meshes are often based on structured meshes with refinements in areas of special interest. However, generation of unstructured meshes suitable for device simulation is a cumbersome task, especially in three-dimensional devices. A typical refinement strategy is performed in the dependence of the gradient of the net dopant concentration which is equivalent to the built-in potential. This provides a fine mesh at the metallurgic pn-junctions. One has to consider that depending on the bias of the device in operation, the carrier concentrations can change so that the effective junctions and therefore the positions of the highest gradients of the electrostatic potential and carrier concentrations move. Also the current flow depends on the bias of the system and the direction of currents and fields can change. Special refinement in the channel areas in MOS transistors can be specified using rules which depend on the distance to the gate oxide segment. Depending on the simulations to be performed, a refinement in the gate oxide segments is required. Since fully automatic mesh generation would clearly simplify the work-flow.

## V. RESULTS

The drain current vs gate voltage is calculated keeping drain voltage of 10mV.

VT =VFB+ 2ψB+ dox(dox4εrs,ε0qNaψB)^1/2/εrox,ε0

wheredox is the thickness of the oxide and εr,ox is its relative permittivity, ε0 is the permittivity of free space, εr,s is the relative permittivity of the semiconductor, q is the electron charge, and Na is the acceptor

  

concentration under the gate. The flat band voltage VFB and the potential difference between

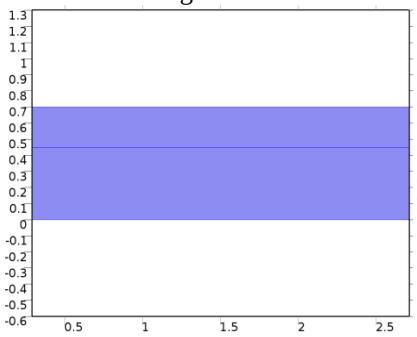


FIG 2: Semiconductor stimulation outline

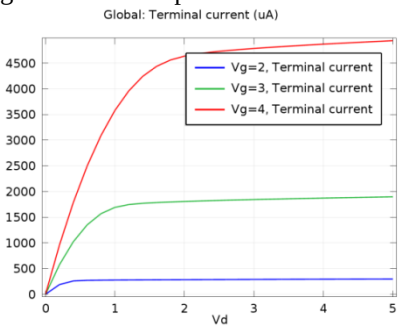


FIG3: Output for drain vs drain voltagethe intrinsic level and the Fermi level (ub)

## VI. CONCLUSION

Recent days the scientists kept a break down to the barriers i.e the manufacturing of graphene. Now this can be achieved by nitrogen doping in the graphene. Where the dopants are placed exactly in the lattice. This precise localizing of dopants reduces the defects and provides greater stability. As we said before this material is having awesome electronic, optical and material characteristics. We can manufacture flexible, transparent transistors and can build some of the basic blocks on logic chips. The moors law can also be satisfied perfectly. These are small and less power hungry transistors which can be used for future logic chips and electronics. Helps in constructing speedy RF transistors. Coming to band gap there are many ways to reduce the band gap. They are by stacking one layer upon the other which is called as bilayer graphene, or by cutting materials into nanoribbions. This is going to change the phase of the future electronics world. Where the new techniques are to be introduced and new manufacturing methods must be put forth.

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