Modeling and Simulation Graphene based Nano FET : A Review

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Abstract: Graphene-based Field Effect Transistor modelling is described in this article. Utilizing SILVACO TCAD tools, modelling is completed. The structure is built using the virtual ATLAS framework, and the model is used to assess the efficacy of graphene-based FETs. To create the device structure, we first deposit a 5nm thick polysilicon layer rather than a graphene sheet. As the channel material, graphene is used, and it is modelled as a semiconductor with a 10,000 cm 2 /V-s carrier mobility. The output characteristic and transfer curve are plotted as characteristic curves with TONYPLOT. There is no band gap in pure graphene. As a result, it is regarded as a zero bandgap or semi-metal semiconductor. Because GFETs lack a bandgap and have a lower I ON/I OFF ratio than silicon-based transistors, they are still less efficient for use in digital logic circuits than Si transistors. Due to its extreme mobility, it is better suited for RF applications. Thus, in this article, it is possible to get the maximum cutoff frequency (f T) and the maximum oscillation frequency (f max), which are thought to represent the FOMs of RF transistors.

Keywords: *Graphene, grapheme based FET, GFET, Modelling*

1. INTRODUCTION

Planar, two-dimensional, and just one layer thick, graphene is a crystallized form of carbon. It is a key component of fullerenes, carbon nanotubes, charcoal, and one of carbon-graphite's most significant allotropes. In order to generate extended benzene ring configurations, graphene is made up of sp2 hybridized carbon atoms. With a measured electron mobility of up to 250,000 cm2 V 1 s 1 (suspended form), graphene is known to possess exceptional electrical characteristics as a result of its structure. Additionally, graphene has been shown to have remarkable mechanical qualities and to have the greatest breaking strengths ever measured (42 N-m-1). Additionally, graphene has great optical qualities, which allow it to be used in optical devices like light detectors. [1].

The structure's single atom of thickness is formed by a honeycomb lattice of carbon atoms, two-dimensional structure known as graphene. In-depth analyses of each aspect of this unique substance have been sparked by its recent experimental discovery [2].

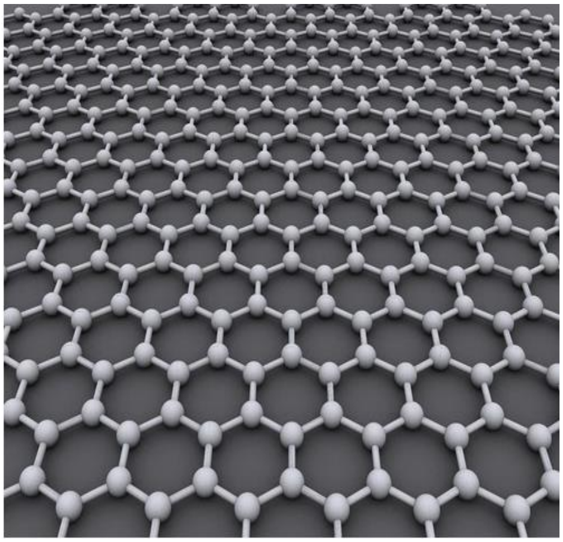

Figure 1: The Composition of a Graphene Layer

Graphene, which has been researched for a very long time and is often referred to as "2D graphite," is used most frequently to illustrate the characteristics of various carbon-based materials. There are many ways in which the fundamental GFET, a three-terminal device, resembles the conventional FET. It consists of a drain, a supply, and a high or back gate. The supply and drain metal electrodes of a GFET are separated from one another by a narrow graphene channel, which is typically tens of microns thick, unlike a silicon-based junction transistor [3].The gate regulates the behaviour of the channel by dictating how electrons react. For the GFET, there are three major gate configurations. As indicated below, typical transistors will either have a high gate, a world back gate, or both.

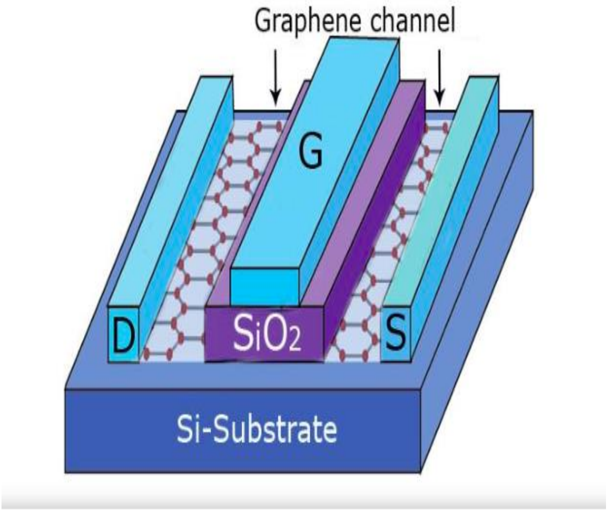

Figure: 2 Proposed Structure of GFET

A GFET's gate regulates the flow of electrons or holes across its channel, much like the gate in vintage semiconductor FETs. The extraordinary sensitivity of the graphene FETs is due to the fact that all of this flows on the surface of the junction transistor channel, which is just one atom thick. In semiconductor devices, current typically moves via electrons or holes. The GFET, however, allows for equal conductivity between electrons and holes. When a hole carrier is conducting in the channel region under a negative bias, GFET devices behave in a usual ambipolar manner. On the other hand, a positive bias causes lepton carrier conductivity[4].

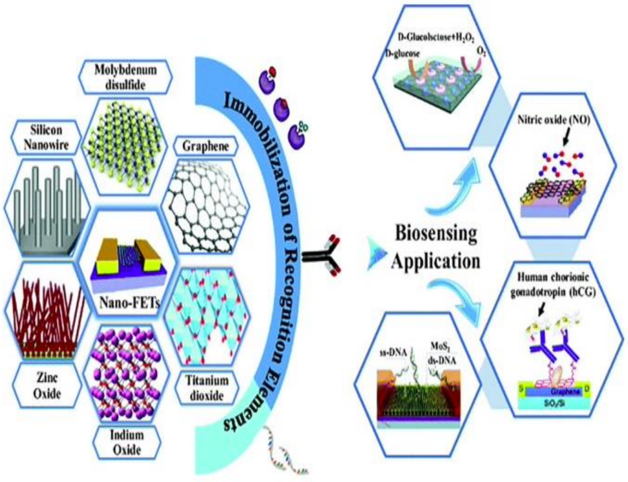

Figure: 3 The various nanomaterial-based FET technologies for the detection of biomarkers are shown schematically in the image above.

One such dual gate G-FET implementation is shown in Fig. 3. Figure 3(a) displays the 2-dimensional read, and Figure 3(b) displays the matching three-dimensional read. The graphene channel is desired in this arrangement between two gate chemical compound layers, namely between the high gate and the rear gate chemical compound (substrate) layers [5]. The SiO2 serves as the rear gate's insulator. The rear gate, or Si wafer, creates a very inexpensive layer. By depositing on a thick SiO2 layer, which was afterwards generated to develop on a heavily doped back gate that is that the Si wafer, the bilayer graphene channel is desired. Channel inversion must often be worn down in order for a G-FET to function as a switch that switches between the ON and OFF states by applying the proper back gate bias voltage. The supply and drain resistance of the GFET are controlled by rear gate.

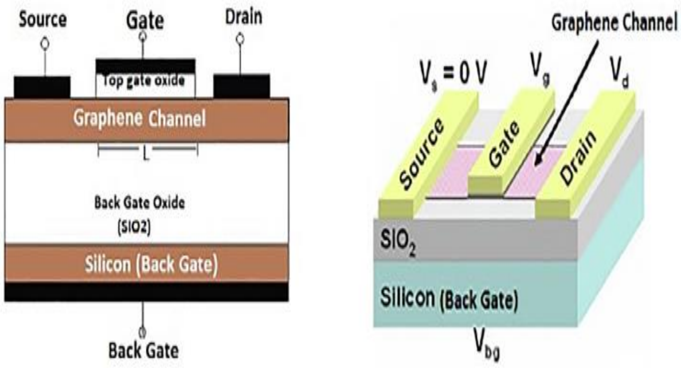

Figure 4: a) 2D view of dual gate GFET b) 3D viewof a twin gate GFET

2. RELATED WORK

2.1 Some of the recent related works are given below

The integrated graphene-based FET (GFET) biosensors at the nanoscale are the main topics of this study. Given how quickly it may spread from one person to another in only minutes, the new kind of coronavirus has clearly emerged as a severe problem in today's dynamic environment. Compared to other coronaviruses like SARS and MERS, COVID-19 may spread more quickly. Due to its resemblance in form under the electron microscope, the term corona is obtain from the Latin word definition "crown." In order to emphasize this roadmap, some of the most current works are examined and examined for this goal. [6].

Its potential uses have generated a great deal of attention due to the exceptional electrical characteristics as well as good optical, mechanical, and thermodynamic qualities.

The utility of large area graphene as a channel material in MOSFETs has been constrained by its zero band gap. In addition to outlining a few techniques researchers have used to produce band gaps in graphene, this study also covers the fundamental physics of graphene. Along with a model for the current and charge densities in top gated Large Area Graphene FETs, a few graphene implementations in FETs and their findings are also provided. [7].

Now is the time to seriously consider finding alternatives to silicon for use in transistors. In the modern world, if Gordon Moore's forecast is to come true, the semiconductor industry will soon enter a post-silicon era. Nanomaterials generated from graphene are now being considered as potential post-silicon electronics device materials. Field effect behaviour in graphene and graphite-based devices is the main topic of this work, which also studies and analyzes it. Additionally, it gives a brief overview of graphene's theoretical characteristics before going through its properties as they relate to electrical devices and looking at how they affect the functionality of transistors made of graphene in both logic and radiofrequency applications. It is possible to draw the conclusion that graphene's outstanding mobility may not be its most enticing property from a device standpoint, contrary to what is often believed. Instead, GFFT may be able to overcome the unfavourable short-channel effects that restrict their performance by being scaled to shorter channel lengths and greater speeds if devices with very thin channels are developed.. [8].

In the last ten years, the study of graphene and its use in cutting-edge electronics has grown quickly. Post-silicon technology is increasingly necessary for industry as Moore's law starts to plateau. Additionally, terahertz detectors and receivers cannot be implemented using current technology, which are necessary for a variety of applications, including as security scanning and medical imaging. Due to its exceptional electronic properties, including observed electronic mobilities of up to 2 105 cm2 V1 s1 in suspended graphene samples, graphene is regarded as a key potential candidate for replacing silicon in current CMOS technology as well as realizing field effect transistors for terahertz detection. In relation to the implementation of graphene transistors, this article examines the physics and electrical characteristics of graphene[9]. Mechanical exfoliation, chemical vapour deposition, and epitaxial growth are a few common methods used to create graphene. Since graphene has a zero bandgap and is semi-metallic, this poses a problem for digital electronics applications and is one of the difficulties in fabricating graphene transistors. Consequently, the research also discusses several techniques for opening a bandgap in graphene employing bilayer graphene and graphene nanoribbons. Key merit metrics used in the literature are extracted, and the fundamental workings of a typical field effect transistor are described. The overview of certain cutting-edge graphene field effect transistor examples is offered at the end, with a special emphasis on monolayer, bilayer, and graphene nanoribbons.[10].

This study provides a thorough overview of current advancements in graphene field effect transistors, taking into account a variety of factors including manufacturing, modelling and simulation tools, and applications, particularly in sensors, outlining the directions for the future. Due to silicon's limits in terms of shrinking transistor size, various alternative materials for manufacturing have been tested in order to comply with Moore's law and enhance the transistor density of an integrated circuit due to qualities like increased carrier mobility and very high trans-conductance gain, among others, one such material, graphene, demonstrates its suitability as a silicon substitute. Additionally, high-speed analogue VLSI, RF, and biosensor circuits are finding that G-FET is the best alternative. [11].

3. NEED OF GRAPHENE-BASED FET

GFET Challenges

For silicon-based transistors, graphene FETs are a beautiful substitute. However, there are a number of difficulties that make industrial production difficult, including the following:

1) Bandgap limitations
2) Fabrication prices
3) Saturation

Benefits of Graphene-Based FETs

Low resistance losses and greater cooling than semiconductors are the results of graphene's improved electrical and thermal conductivity. As a result, graphene transistors might provide improved performance and potency[12].

The entire channel is on the surface because the structure is only one atom thick. Thus, in detector applications, the channel is wide open to the material or surroundings underneath the look at. This makes some GFETs sensitive and appropriate for a variety of bio- and chemical-sensing applications[13]. For instance, it might pick up on a molecule sticking to or detaching from a surface. Not to mention, research has indicated that employing a thin, top-gate dielectric material improves GFET properties like open-circuit gain, forward transmission constant, and cutoff frequency. This opens up the possibility of using GFETs in a variety of applications and for very high-frequency operations [14]. Theoretically, the junction transistor can change far more quickly than silicon-based FETs, approaching the rate of change at very high rates. Standard semiconductor materials' lattice structure has various restrictions that make it heat-dissipate rapidly at higher frequencies. On the other hand, the high lepton quality, polygonal form lattice structure, and other features change it to operate at the rate frequencies much better.

4. MODELING & SIMULATION

Programme for G-FET modelling and simulation. This section compares a few of the widely available modelling and analytical tools for G-FET. GFET tool, which simulates conducting behavioural research on the electrical and thermal properties of a GFET. The G-FET's voltage and current can be calculated using this device while the G-FET's temperature is kept constant[16]. The tools for this inquiry employ a drifting technique and a prolixity system. The following research projects on GFETs may also be estimated and started using this method, i.e.

a) Carrier viscosity
b) Temperature profile studies
c) Drift haste and
d) Electric field studies

When creating the models for ATLAS simulator (a device simulator for 2D and 3D structures), Silvaco, a CAD programme, is utilised. This simulator aids in simulating the study of the electronic circuits' electric, optical, and thermal properties. It is simple to understand how the gadget operates thanks to these simulation studies. Theses, which are created using emulsion accessories such as double, ternary, and quaternary, assist in creating an accurate calculation of the bias[17].

Meter The enormous signal GFET for ambi-polar graphene high frequency electronic circuits is modelled using the virtuoso spectre circuit simulator tool. In processes like the multiplier phase sensor, radio frequency sub harmonious mixer, and frequency doppelgänger, this large signal model is frequently used. For RF operations, there is a particular Virtuso spectre interpretation. The tool, called Virtuoso Spectre RF, can be used to assess the DC and AC characteristics, the RC birth for detention estimate, and the electromagnetic (EM) analysis of GFET grounded circuits[18].

Sentaurus is a well-known EDA tool for simulating the Graphene FET grounded detectors used in the detection of single beachfront DNA (also known as ssDNA) and reciprocal DNA (also known as cDNA) (10). It is a cutting-edge design and optimisation tool for GFET grounded circuits. This may aid in creating device simulations in several dimensions. The simulation may include a study of the physical properties of electric, optical, or thermal systems. Electronic biases of the semiconductor grounded or combinational kind are also possible[19].

5. APPLICATIONS OF GRAPHENE

⇒ Due to its remarkable properties, graphene may be employed in a broad variety of applications. Here are a few potential uses for graphene:

⇒ RF circuits (because to the high mobility values reported in it) and significant cutoff frequencies in graphene field-effect transistors (for instance, Lin et al.'s study showed that graphene nanoribbon-based FETs had cutoff frequencies of 100 GHz). Any of the aforementioned techniques may be used to customize a band gap in logic circuits.

⇒ Since graphene is more transparent and flexible than the less transparent and more brittle indium tin oxide that is currently employed in the industry, it may be used to build transparent electrodes for solar technology.

⇒ Due to its semi-metallic behaviour with high mobility and strong flexibility[20], interconnect applications.

⇒ Graphene may one day be utilized to make supercapacitors because of its high surface area to volume ratio.

6. CONCLUSION

The operate of graphene in logic circuits is presently not practical due to low on/off current levels. Due to its high mobility and high cutoff frequency, it may be employed in RC circuits, but the issue of large off currents still exists and resulting in much greater power dissipation than the existing, highly low powered CMOS technology. Further study may enable the creation of bandgaps in graphene without significantly reducing mobility, resulting in the creation of graphene FETs with a favourable on/off current ratio and great mobility. So, in the next years, graphene may replace other materials as the primary component of electrical gadgets.

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