A Technical Seminar Report

On

APPLICATIONS OF GRAPHENE IN ELECTRONICS AND COMMUNICATIONS

BACHELOR OF TECHNOLOGY

In

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted By

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CERTIFICATE BY THE SUPERVISOR

This is to certify that the dissertation work entitled "**APPLICATIONS OF GRAPHENE IN ELECTRONICS AND COMMUNICATIONS**" being submitted by **SAI JOSHITHA ANNAREDDY (17011A0423)** in partial fulfillment of the requirements for the award of degree in Bachelors of Technology in Electronics and Communication Engineering at the Jawaharlal Nehru Technological University during the academic year 2020-21 is a bonafide work of technical seminar work carried out during the academic year 2020-21.

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This is to certify that the Seminar report entitled "**APPLICATIONS OF GRAPHENE IN ELECTRONICS AND COMMUNICATIONS**" Submitted by **SAI JOSHITHA ANNAREDDY (17011A0423) i**n partial fulfillment of the requirements for the award of degree in Bachelor of Technology in Electronics and Communication Engineering at the Jawaharlal Nehru Technological University during the academic year 2020-21 is a Bonafide work carried out by her.

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DECLARATION OF THE CANDIDATES

I hereby declare that the Seminar report title "**APPLICATIONS OF GRAPHENE IN ELECTRONICS AND COMMUNICATIONS**" is a bonafide record work done and submitted under the esteemed guidance of **Dr. ASHA RANI**, Professor, Department of ECE, JNTUH CEH, in partial fulfillment of the requirements for Seminar in Electronics and Communication Engineering at the Jawaharlal Nehru Technological University during the academic year 2020-21.

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ABSTRACT

The Moor’s law says that the number of transistors in a dense integrated circuit doubles about every two years. But the speed of cramming is now noticeably decreasing this trend, The main problem is the poor stability of materials if shaped in elements smaller than 10 nano meters in size. At this scale, all semiconductors – including silicon – Oxidise, decompose an uncontrollably migrate Researchers are running into the physical limits of speed and scaling in silicon transistor technology, forcing them to look for next –generation devices. The problem with silicon is its poor stability at 10nm and below when it oxidises, decomposes and uncontrollably migrates. The leading candidate to replace silicon being pursued by is graphene.

Graphene as a new compound can be used in many fields for different applications. This paper discusses about the applications of graphene in Electronics and communication. Mainly this paper focusses on Graphene Transistors, Slot Antenna and Graphene frequency multipliers are discussed in detail.

Graphene is a monolayer of carbon atoms which exhibits remarkable electronic and mechanical properties amenable to photonic and sensor applications. While the plasmonic nature of graphene at terahertz frequency has been widely reported, investigations on the practical utility of graphene in antennas have been very sparse. In particular, losses in graphene significantly limit the radiation performance of microwave antennas fabricated entirely using graphene.

In this paper, a dual-port printed slot antenna is designed with graphene film used as an overlay in the microstrip feed line for broadband impedance matching. Antenna losses are minimized by confining the film to a small area outside the radiator. the ambipolar transport properties of graphene flakes have been used to fabricate full-wave signal rectifiers and frequency-doubling devices. By correctly biasing in ambipolar graphene field-effect transistor in common-source configuration, a sinusoidal voltage applied to the transistor gate is rectified at the drain electrode. This high efficiency, combined with the high electron mobility of graphene, makes graphene-based frequency multipliers a very promising option for signal generation at ultrahigh frequencies.

Also, graphene electrical properties can be controlled, switching it among conducting, semiconducting and electrically insulating forms. In this paper a review is given on graphene and the recent research progress of graphene transistors

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CHAPTER 1

Introduction

Graphene a single- atom- thick honeycomb lattice of carbon atoms, can transport electrons more quickly than other semiconductors, a quality called electron mobility (100 times greater than silicon), making it ideally suited to atomic-scale, high-speed operation. Graphene is a single layer (monolayer) of carbon atoms, tightly bound in a hexagonal honeycomb lattice. It is an allotrope of carbon in the form of a plane of sp2-bonded atoms with a molecular bond length of 0.142 nanometers. Layers of graphene stacked on top of each other form graphite, with an interplanar spacing of 0.335 nanometers.

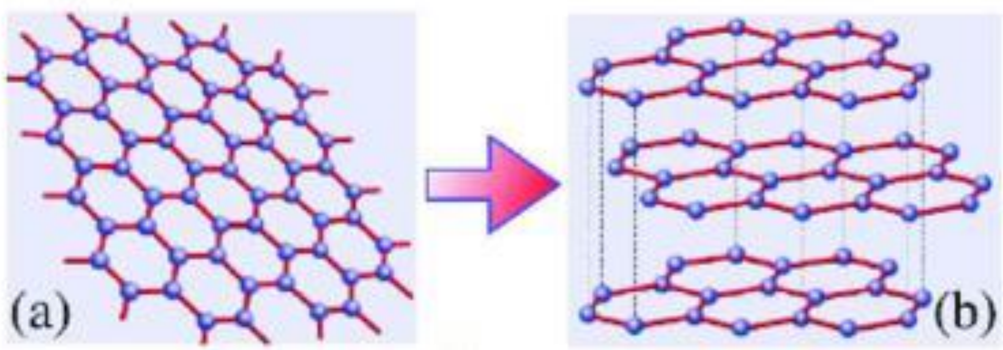


Figure 1

(a) Layer of graphene

(b) Layers of graphene stacked on top of each other form graphite, with an interplanar spacing of 0.335 nanometers.

Graphene possesses many properties like high electron mobility about 100,000 cm2/ Vs at room temperature which is significantly greater than Silicon. Although silicon has its own advantages, but graphene on the other hand has more mechanical strength, flexibility, stiffness that makes it ideal for wearable technologies and also flexible electronics. Graphene is mainly a sheet resistance with a very high transmittance of about 90%. This makes it suitable for the use in foldable touch panels, rollable e-paper and many such devices. Thus combining the properties, potential ability, and relative ease of availability graphene can be used for many electronics and related applications. Graphene has almost negligible band gap that increases its importance in electronics domain. Though synthesis of graphene is tedious job but producing it in large quantities for industrial purposes will reduce the cost and increase the ease of production of graphene.

CHAPTER 2

Properties

2.1 Chemical Properties:

- Graphene is a zero-overlap semimetal.
- In Graphene carbon has sp2 hybridization. Each carbon atom has 3 sigma bonds and 2 pi electrons which travel with speed of light

2.2 Mechanical properties:

- High tensile strength
- High Young's Modulus (about 1TPa)
- High intrinsic strength (about 130GPa)
- High elasticity
- Ultimate tensile strength of 130,000,000,000 Pascals (or 130 gigapascals)

2.3 Electrical Properties:

- The freely available electrons (pi-electrons) that do not get bonded are the reason for electrical conduction to take place.
- Graphene behaves as a semiconductor just like the Silicon, Germanium and GaAs. But since the cause of conduction in graphene is different from that of other semiconductor materials
- The electron mobility of graphene in its pristine form is more than 200,000 cm2 /Vs.
- The sheet resistance of graphene is about 30 ohms. Graphene is mainly a sheet resistance with a very high transmittance of about 90%.
- Graphene atoms are considered as massless, they behave much similar to photons.

2.4 Optical Properties:

- Graphene has very good absorption capacity.
- Even though graphene in pristine form is just 1 atom thick, it has ability to absorb 2.3% of white light.

All these properties make it adequate and appealing for designing of future gadgets and devices that requires being more flexible and at the same time must be strong enough for rugged usage. This paper mainly focusses on Graphene transistors, Graphene frequency multipliers and slot antenna.

CHAPTER 3

Graphene Transistors

Graphene can be carved into tiny electronic circuits with individual transistors having a size not much larger than that of a molecule. "The smaller the size of transistors the better they perform." Manchester broke the transistors size record using graphene. The highest performance graphene transistors are made on graphene flaked form lumps of graphite and stuck to substrates. Transistors made on graphene formed on the surface of substrates have so far been poor performers compared to those on flaked graphene. Here we discuss about two companies that made astounding graphene transistors and some special properties of graphene transistors.

Graphene devices have been made previously by placing the graphene sheet on top of an insulating substrate, such as silicon dioxide. However, this substrate can degrade the electronic properties of graphene. A diamond- like carbon is placed as the top layer of substrate on a silicon wafer. The carbon is nonpolar dielectric and does not trap or scatter charges as much as the silicon dioxide alone. This new graphene transistor, due to the diamond-like carbon, shows excellent stability in temperature changes, including extremely cold temperature like that in space. IBM has announced the development of a new graphene transistor which has a cut-off frequency, a measure of device speed under operating conditions and is typically a fraction of intrinsic speeds often reported, of 155GHz (155 billion cycles per second). These new high-frequency transistors are being targeted to applications primarily in communications such as phones, internet, and radar.

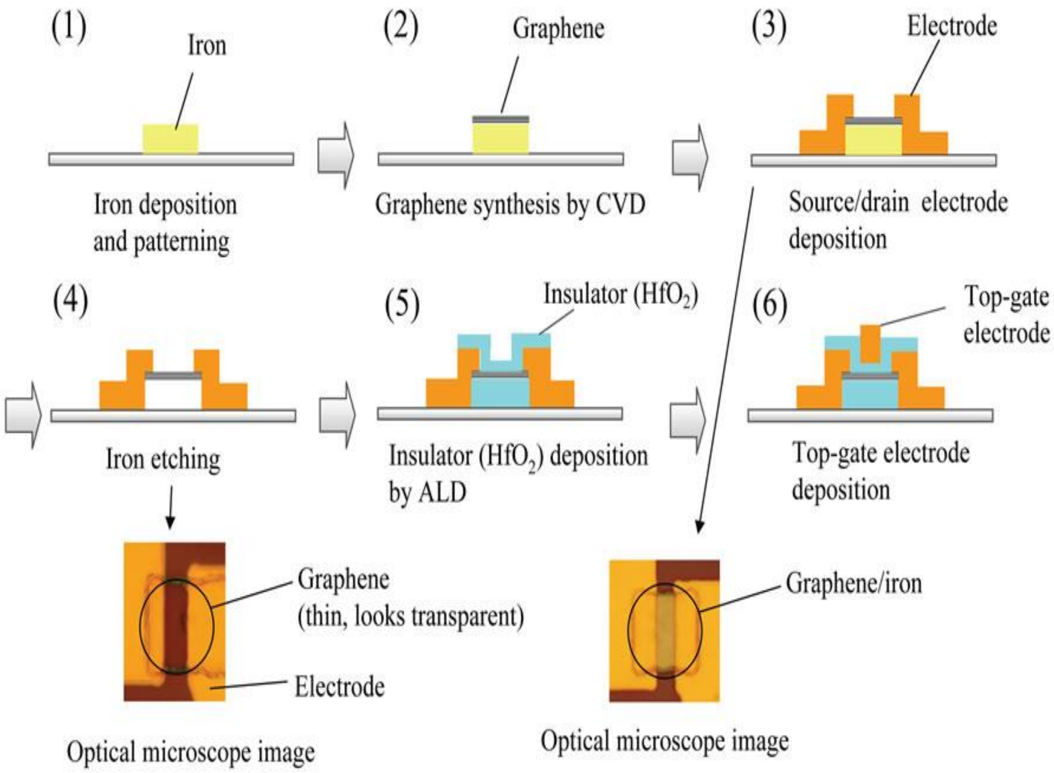
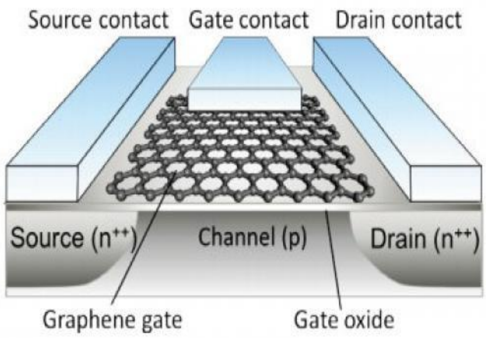


Figure 2

Fujitsu process of making graphene transistor

Fujitsu has made transistors on graphene grown directly on insulating substrates with a novel structure this process involves starting with an iron film catalyst over an oxide film on a silicon substrate. To make transistors, the iron is formed into strips using a conventional photolithography before graphene growth. Once the graphene has been grown, source and drain electrodes of titanium-gold film are formed at the ends of each graphene strip. This leaves the centre, which will eventually become the channel, exposed. The source and drain metal also bond the ends of each graphene strip to the substrate, allowing the iron under it to be etched away with acid to leave a graphene channel suspended as a bridge. To stop this breaking, atomic layer deposition is used to replace the missing iron support with insulating hafnium dioxide. At the same time, HfO2 also grown on top of the channel to form an insulator for the gate which is finally laid down on top. It enables formation of graphene transistors across the entire surface of a large substrate. The relationship between drain current and gate voltage clearly shows am bipolar characteristics that are particular to graphene. As graphene at the thickness of a few nano meters is transparent, it is a candidate for use as the channel and electrode material in thin-film transistors used in video displays. The manufacturing of these new graphene transistors can be accomplished utilizing technologies already in place for standard silicon devices.



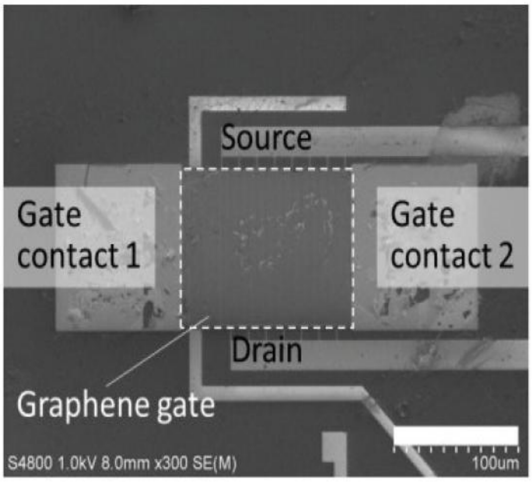


Figure 3

Graphene was first made deliberately in the laboratory by peeling it from graphite using sticky tape. Since then, faster flaking techniques and variety of methods developed for producing graphene. One method is an exfoliation technique that involves stripping individual graphene layers off a layer of graphite. This technique cost as much as $100M USD to produce a single cubic centimetre of material. There is a new way for flaking large quantities of graphene from graphite using simple chemistry. Graphite powder is submerged in a mixture of dilute –pyrene carboxylic acid (PCA), water and methanol; then exposed to ultrasound. Large quantities of undamaged, high-quality graphene are produced, dispersed in water. This process is advantageous for mass production as it is low cost, devoid of any harsh chemicals. Agitation weakens the already frail molecular bonds that old together graphene sheets in graphite. This allows the pyrene part of PCA to work its way between the layers. But the technique that always remains the technique of choice for research and proof-of-concept is isolating graphene by rubbing a lump of graphite to flake it off the sheets. That's because it gives single layer of graphene. Ideally one layer only or two at most, of graphene would be grown on substrate. More than this and the astounding mobility does not appear. It is discovered that graphene has no "band gap," a trait critical to digital transistors storing binary codes which allows the signal to be turned on and off, so its digital applications appeared to be limited. The devices made from the zero-bandgap graphene are difficult to switch off, losing their advantage of low static power consumption of the complementary metal oxide semiconductor (CMOS)technology. Quantitatively, the Ion/Ioff ratios for graphene-based field- effect transistors (GFETs) are less than 100, while any successor to the Si MOSFET should have excellent switching capabilities in the range 104-107.Promising way of opening graphene bandgap-doping, examining the state-of-the-art doping, methods, which are roughly classified into three categories: 1. Hetero atom doping; 2. Chemical modification; and 3. Electro static field tuning. The two first methods can be used to open the bandgap and tune the Fermi level, the energy that pertains to electrons in a semiconductor, of graphene. While the electrostatic field tuning method, the polarity and value of the gate voltage can change the Femi level of graphene, but the bandgap cannot be opened. Electro static doping is induced through the electric field between metal gates, which are located 40 nano meters away from graphene channels. The doping can be altered by varying the voltage, enabling researchers to test specific doping levels. This makes it possible for graphene inverters to mimic the characteristics of silicon inverters.

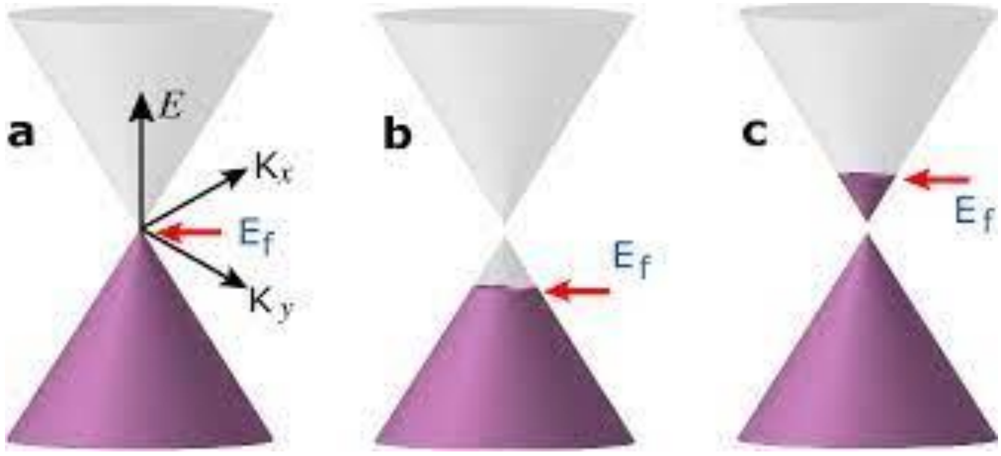


Figure 4 Schematic band structures of graphene.

(a) Band structure of pristine graphene with zero-bandgap. Ef is at the cross-over point.

(b) (b) p-type, Ef lies in valence

(c) (c) n-type graphene with the bandgap. Ef lies in conduction band

CHAPTER 4

Graphene Frequency Multipliers

Frequency multiplication has always been an indispensable part of radio communication and broadcasting technology. It was recognized early on as a crucial signal generation technique, where a signal of frequency $f0$ is introduced to a nonlinear element to generate harmonics, and therefore power, at higher frequencies. For the last 60 years, diode and field-effect-transistor (FET)-based frequency multipliers have seen rapid progress.

Diode-based multipliers offer relatively high efficiencies (~30%) but lack signal amplification. FET-based multipliers offer signal gain at the cost of a very low efficiency (< 15%). In both cases, the spectral purity of the generated signal is very poor, and additional components are often needed to filter the useful frequencies.

A new frequency-multiplier device based on the unique properties of graphene with the potential to overcome the main problems of conventional frequency multipliers. For the first time, frequency doubling is realized with just a single transistor device that can give very high spectral purity at the output without any additional filtering.

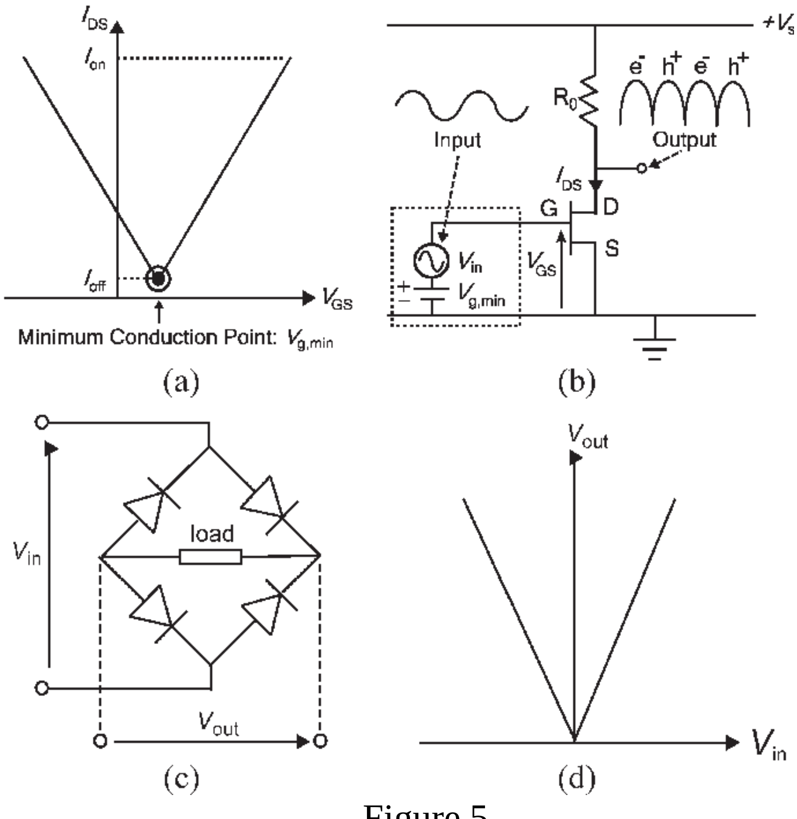


Figure 5

a) Piecewise linear approximation of the transfer characteristic of ambipolar G-FETs.

Vg(min), the minimum conduction point, is equal to the quiescent bias point for full-wave rectification and frequency doubling.

b) Graphene-based circuit for frequency multiplication of the input signal Vin. With the device being biased at the minimum conduction point, electrons (e−) and holes (h+) conduct alternatively in neighboring half-cycles of the output signal.

c) Typical full-wave rectifier circuit.

d) Ideal input–output characteristics of a full-wave rectifier.

To demonstrate these new applications, G-FET devices is fabricated from exfoliated graphene flakes. The high RF conversion efficiency shown by the graphene frequency multiplier is due to the slightly sublinear *I–V* characteristics of the fabricated device near the minimum conduction point, which shapes the output-signal waveforms to significantly reduce the power coupled to higher order harmonics. The sublinear characteristics of the graphene device near the minimum conduction point results from a combination of charged-impurity, ripple, and short-range scattering in graphene

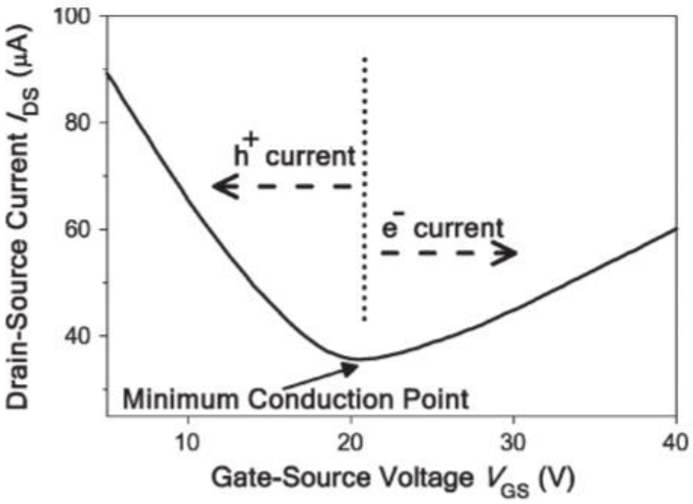


Figure 6

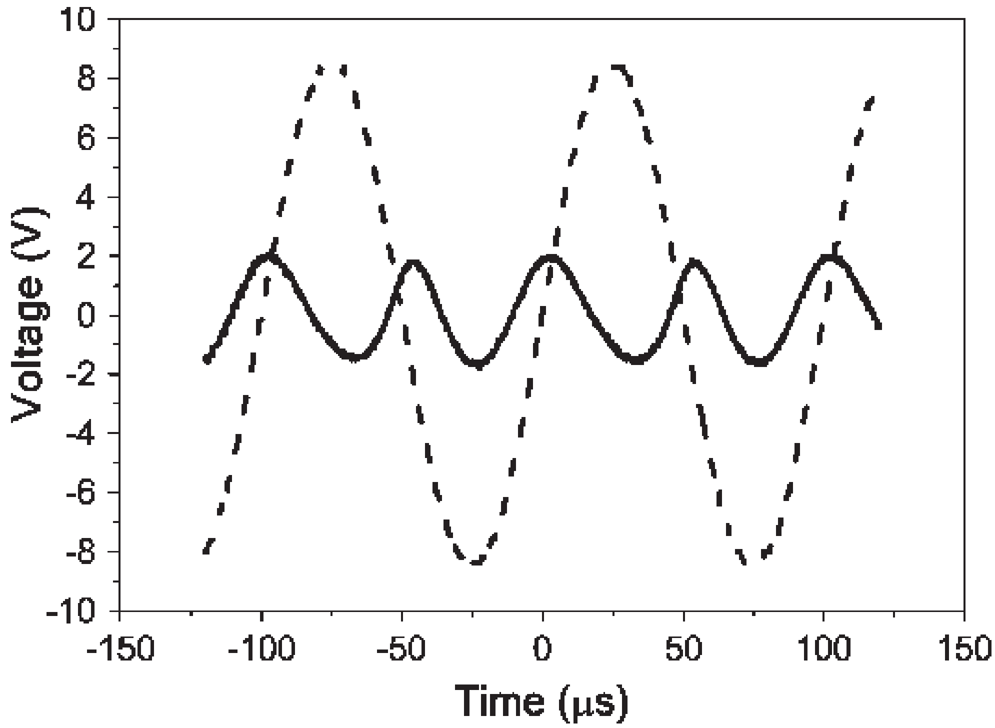


Figure 7

The shape of the sublinear characteristics and the location of the minimum conduction point by controlled impurity (potassium) doping on graphene surface. Graphene is the most suitable for high-frequency applications due to its very high mobility. CNTs have mobility that is comparable to that of graphene. However, the ambipolar Ids–Vgs characteristics of GFETs are often more linear than CNT FETs', leading to a higher spectral purity and efficiency. With the rapid developments in the design and fabrication of G-FET and other ambipolar devices, we may soon see ambipolar FETs leading the next revolution in communications technology.

CHAPTER 5

Slot antenna

The basic topology considered is a slot loop antenna etched on the ground plane of a microstrip substrate, with a two-port microstrip line electromagnetically coupling the excitation signal to the antenna. Dual-port design is used for symmetry as well as potential deployment in MIMO-based sensor arrays. Fig. 8 shows the top view of the slot antenna model, with the slot in the bottom ground plane and the microstrip line on the top side of the dielectric substrate (lossy FR-4, 0.79 mm thick). An IDC connects the two ports at the centre of the line and a thin graphene film is superposed on the IDC. The combination of IDC and the surface impedance of the graphene film provides impedance match over a broadband. The antenna is designed for nominal operation at 3.5 GHz with a broad bandwidth. The dimensions of the IDC and the film are shown in Fig. 9. The annular slot has outer radius of 12 mm and width of 0.5 mm.

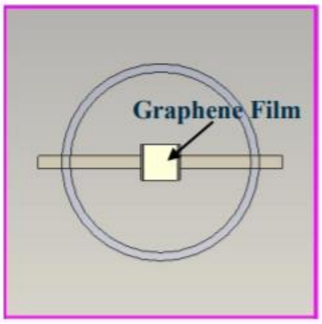


Figure 8. Slot Antenna with Graphene loading

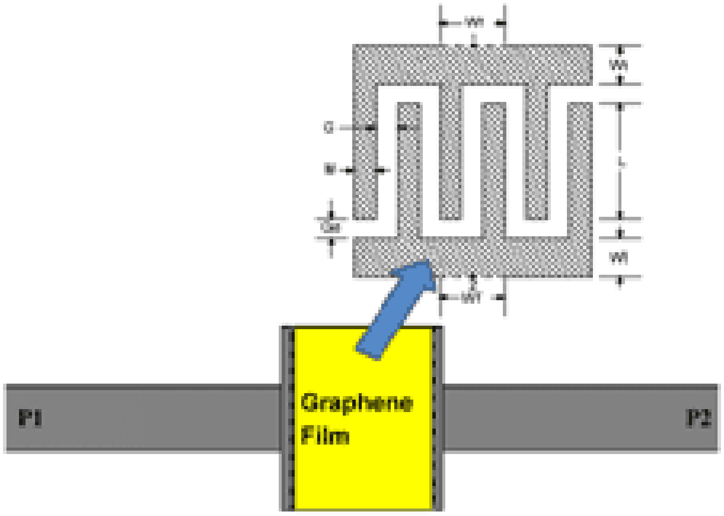


Figure 9. Geometry of an interdigitated capacitor (IDC) with a graphene film overlaid on the fingers.

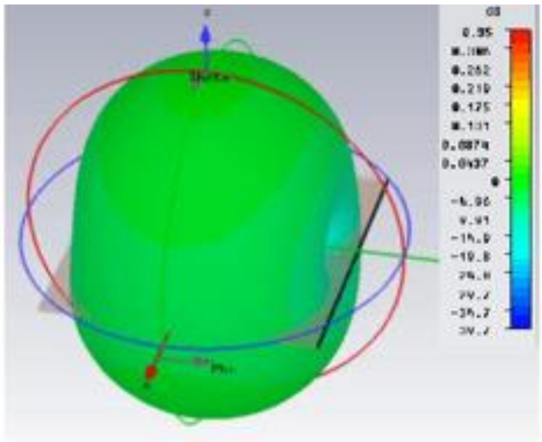


Figure 10. Radiation pattern at 3.46 GHz showing gain of 0.35 dB simulated in CST Microwave Studio.

The plot in Fig. 10 shows a well-matched centre frequency of 3.46 GHz with a 10 dB (or VSWR = 2) bandwidth of ~100%. The S21 plot shows that the insertion loss of the device is about 2.5 db. Therefore, the antenna loss has been minimized to some extent by decoupling the antenna and the graphene film. This is confirmed by the radiation pattern plotted in Fig. 3. The realized gain of the antenna is 0.35 dB with radiation efficiency of 44%. Slot antenna radiates bidirectionally. Hence, the antenna gain can be improved by 3 dB using a reflector below the slot plane at the expense of increasing antenna thickness.

More applications of Graphene are in the table below.

Application	**General Lead**	**Requirements**
Slot Antenna	**To avoid radiation losses but need to be compromised in terms of radiation efficiency**	**Its one-layer atom and small structure**
Transistors (GFETs)	**To achieve high mobility of electrons**	**Due to zero band gap property and free, fast pi electrons**
Organic Light Emitting Diode (OLEDs)Graphene	Can be used in wearable technologies and can be folded to a radius of <5mm	A better control over sheet resistance is required

Touch screens	Easy to implement compared to ITO (Indium Titanium Oxide) and nano ribbons	Requires Flexibility and control over contact resistance
Frequency multiplier	**Output signal has harmonics of Fundamental frequency of input signal**	**Difficulty in designing**
Batteries	Graphene electrodes are useful due to their ultra-thin size and flexibility.	High Thermal Conductivity. It shouldn't susceptible to oxidation
Supercapacitors	Holds large amount of charge for long time and charging time is also less	Due to high electron mobility
Biosensors (In Medical)	Drug delivery and precise targeting of cancer cells.	This is done by simply keeping the graphene oxide layer in a solution of appropriate pH and then applying electric field. These droplets reach the active affected site and then open up.

Table 1

CHAPTER 6

6.1 Limitations of Graphene:

- Graphene acts as a catalyst gets prone to oxidative environments.
- Also, it has been found that graphene inhibits some toxicity too.
- Till now we saw many applications of Graphene but the major drawback of graphene is ‘it could not be produced easily in large scales.
- Graphene was properly isolated and characterized in 2004 by Andre Geim and Konstantin Novoselov at the University of Manchester. For this work they were awarded with Nobel Prize. Later Graphene CVD was first reported in 2008 and 2009, using Ni and Cu substrates.

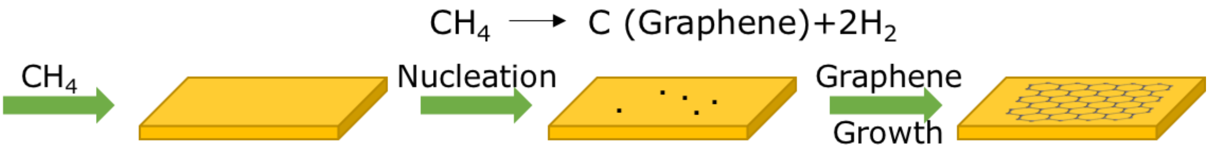


Figure 11

A single layer of graphene is deposited onto a copper substrate and then etched.

6.2 Conclusion:

- Graphene is the trending material on which lots of research are taking place.
- Due to its exotic properties, it can used in various fields and helps in revolutionising the world

6.3 Future scope:

If Graphene could be produced on large scales they can be used abundantly in many applications.
Graphene can be used as flexible screen for smartphones.
Graphene in aviation, Satellites.
Graphene can be used in ultrafiltering of sea water, Any toxic materials in sea water.
Double Graphene sheet as an Armour shield…etc

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