ISSN : 2278 – 1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 1, Issue 4, June 2012

A Review on Graphene Transistors

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***Abstract*— 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 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. 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, and how to sidestep the obstacles in the way of using graphene as transistor.**

***Keywords*— Graphene ; transistor ; semiconductor ; Graphene generation**

1. I Introduction

The Moor's law says that the number of transistors that can be crammed on an integrated circuit doubles approximately every two years. But the speed of cramming is now noticeably decreasing this trend has continued for more than half a century and is expected to experience its most fundamental challenge in the next 10to 20 years, according to the semiconductor industry roadmap. The main problem is the poor stability of materials if shaped in elements smaller than 10 nanometers in size. At this scale, all semiconductors – including silicon – Oxidise, decompose an uncontrollably migrate along surfaces like water droplets on a hot plate.

Graphene, a sheet of carbon one atom thick, has been studied for its potential use in electronics, and was initially identified as a material that would replace silicon and make devices faster and easier to manufacture. Unlike all other known materials, graphene remains highly stable and conductive even when it is cut into devices one nanometer wide. The main issue with this nanotechnology is that graphene has no "band gap". In semiconductors, electrons can be at two different energy levels known as conduction and valance bands. The energy space that exists between the regions is named the band gap. The energy gap between the two permits transistors to switch on and off which allows the storage of information in the ones and zeroes of binary code. This problem can be solved by making graphene inverters, which is a necessary component of a digital transistor.

Graphene devices have grown by leaps and bounds over the past few years, and they are probably the best bet to eventually replace Silicon. Demonstrations like this are important because they show that wafer-scale production is possible, and the properties, while not ideal, are truly impressive, in that they're already beginning to push the limits of Si technology.

This paper is organized as follow: section I gives the Introduction about Graphene. Section II is helpful to understand the nature of graphene and the background of related work. Section III talks about efforts on making graphene transistors. Section IV shows some special properties that graphene transistors have and at last section V concludes the paper and followed by the references.

2. II Graphene

Graphene is made up entirely of carbon atoms bound together in a network of repeating hexagons within a single plane just one atom thick. It is excellent conductor of electricity and since carbon is common element, it makes it attractive option for synthesizing cheaper CPU's. The mobility of graphene is above 200,000 cm2/vs. at

ISSN : 2278 – 1021

International Journal of Advanced Research in Computer and Communication Engineering
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room temperature. "Greater than 100 times that of Silicon, 30 times GaAs, and larger even than carbon nanotubes, "Said professor Geim, physicist working at the University of Manchester." It is only the material where electrons at room temperature can move thousands of interatomic distances without scattering". Good quality graphene is literally flaked from sample of graphite – the black rock that used in pencils. The flakes are deposited on a substance and then manipulated.

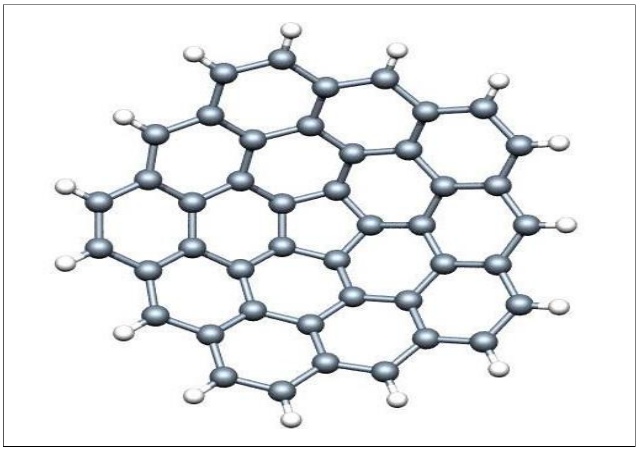

Figure1. Graphene is an atomic-scale honeycomb lattice made of carbon atoms.

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 centimeter 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 – pyrenecarboxylic 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. Electrostatic 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. Electrostatic doping is induced through the electric field between metal gates, which are located 40 nanometers 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.

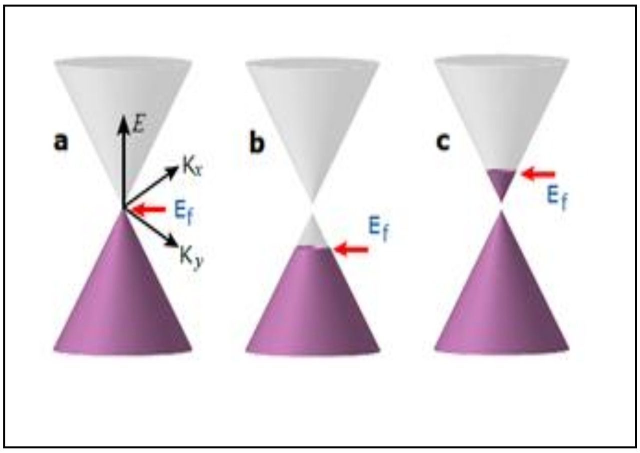

Figure2. Schematic band structures of graphene. (a) Band structure of pristine graphene with zero-bandgap. Ef is at the cross-over point. Band

ISSN : 2278 – 1021

International Journal of Advanced Research in Computer and Communication Engineering
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structures of (b) p-type and (c) n-type graphene with the bandgap. Ef lies in valence and conduction band, respectively.

An inverter is a critical building block of digital transistors that enables the conversion of direct current to alternating current. First graphene inventers were only able to work at very low temperatures near 77 degrees kelvin, which is minus 196 Celsius (minus 320 Fahrenheit). Now inverters are made that can work at room temperature and have gain larger than one in order for transistors to amplify signals and be capable of switching from 0 to 1.By creating these inverter devices the most difficult hurdles plaguing the adoption of graphene as a potent replacement for silicon is eliminated.

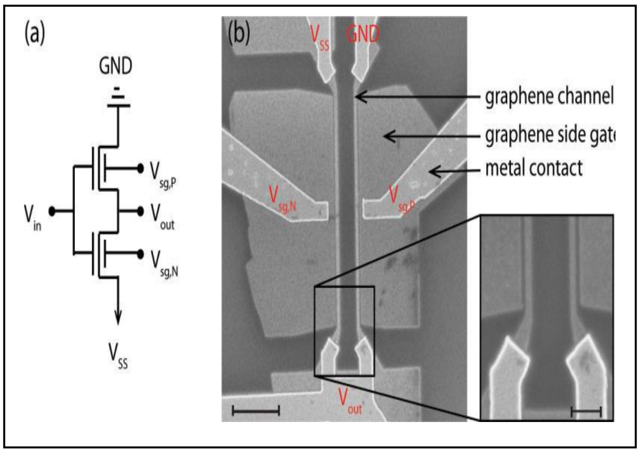

Figure 3. This composite image shows the circuit schematics of a new type of graphene inverter, a critical building block of digital transistors, (a), and scanning electron microscope images of the fabricated device, (b).

3. III 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." Say Manchester researchers. Two years ago 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 talk about two companies that made astounding graphene transistors and some special properties of graphene transistors.

A. IBM

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. However, the team of researchers has found a solution to minimize that. A diamond- like carbon is placed as the top layer of substrate on a silicon wafer. The carbon is non-polar 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.

B. Fujitsu

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.

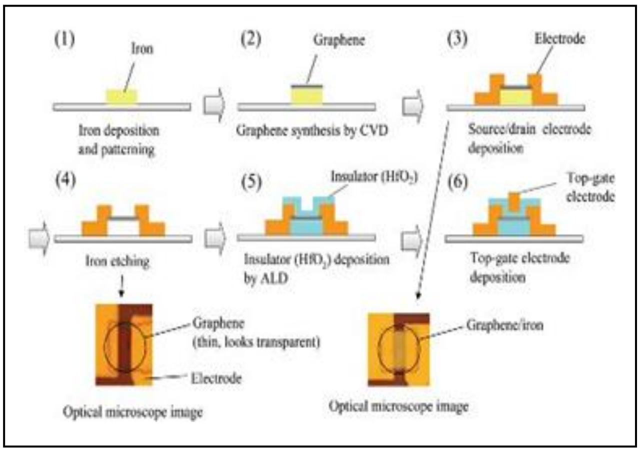

Figure 4. Fujitsu process of making graphene transistor.

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 center, which will eventually become the channel, exposed. The source and drain metal also bonds 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 nanometers 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.

4. IV SOME SPECIAL PROPERTIES OF GRAPHENE

Graphene has lots of interesting properties. Here we point out two of graphene transistors most interesting properties: self –cooling and working without much noise

C. *self cooling graphene transistors*

Heat is a sad fact of life for current generation electronics. And by today's standards, a balmy 85 degrees Celsius, while hot enough to cook an egg, is a pretty "good "operating temperature for a high-powered PC graphics processing unit. But that could all soon change. Examining graphene transistors made a remarkable discovery that graphene appears to self-cool. Because graphene transistor is so extremely thin. It is difficult to test and measure accurately certain properties of the material. To overcome this problem, the University of Illinois used an atomic force microscope tip as a temperature probe (Fig .5) to make the first nanometer-scale temperature measurements of a working graphene transistor.

Resistive heating (waste heat) effect in graphene was weaker than its thermo-electric cooling effect at times. In Silicon and most materials, the electronic heating is much larger than self-cooling. However graphene transistors have regions where the thermoelectric cooling can be larger than the resistive heating. What this mean is that graphene circuits may not get hot like traditional silicon-based ones. This provides even more motivation for semiconductor manufacturing companies to mass-produce circuits based on graphene transistors.

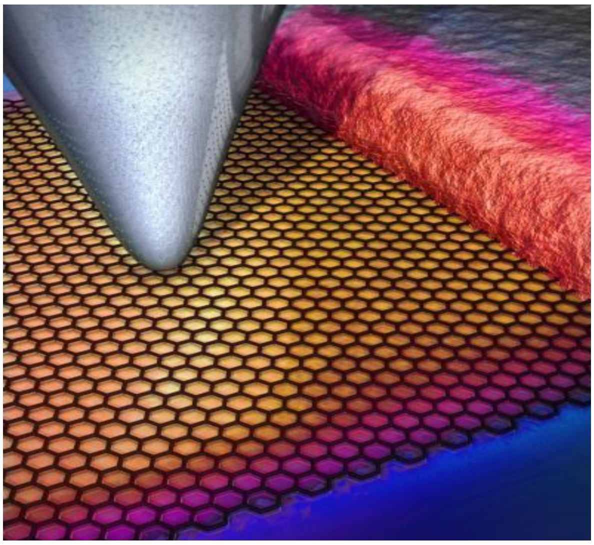

Figure 5. An atomic force microscope tip scans the surface of a graphene-metal contact to measure temperature with spatial resolution of about 10 nm and temperature resolution of about 250 mK. Color represents temperature data.

D. *Working without much noise*

For any transistor to be useful for analog communication or digital applications, the level of the electronic low-frequency noise has to be decreased to an acceptable level. Low frequency electronic noise dominates the noise spectrum to a frequency of about 100 kHz. The Nano-Device Laboratory research group of A. Balandin at the University of California - Riverside (UCR) has designed and built single-layer graphene transistors with two gates: the back gate made of degenerately doped silicon wafer and the metallic top gate separated from the graphene device channel by HfO2.

The specific fabrication procedure for the advanced top-gated graphene transistors (Fig.6) has been developed.

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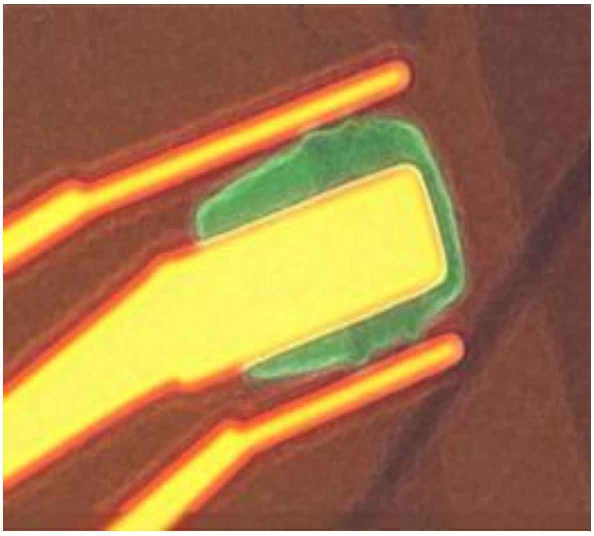

Figure 6. Optical microscopy image of the top-gated graphene transistor. Brown color is SiO2, yellow are metal gates and green is HfO2.

The low-frequency noise in conventional transistors is characterized by a figure-of-merit conventionally known as Hooge parameter. Although there are still a lot of debates about the origin of low-frequency noise and physical limits of applicability of the Hooge parameter, in conventional materials, the Hooge parameter is on the order of 10-5 to 10-3. In graphene transistors the Hooge parameter is rather low; it is on the order of 10-4 to 10-2. From the gate bias dependence and presence of characteristic generation-recombination (GR) peaks in the noise spectra we also found that it is dominated by fluctuations in the charge carrier density due to their trapping and de-trapping by defects. This means that the noise level can be reduced even further with improvements in graphene device fabrication technology.

5. V CONCLUSION

Graphene devices have grown by leaps and bounds over the past few years, and they are probably the best bet to eventually replace Silicon. Demonstrations like this are important because they show that wafer- scale production is possible, and the properties, while not ideal, are truly impressive, in that they're already beginning to push the limits of Si technology. Such Advantages of graphene transistors are, their high motilities for both electrons and holes; having ideal electrostatics that enable aggressive scaling; and straightforward integration with CMOS. But graphene has a low energy bandgap, so graphene continues to conduct a lot of electrons even in it's off state. If there be a billion of graphene transistors on a chip, a large amount of energy would be wasted. This can be improved if graphene ribbons can be made thinner, and by using techniques like doping and making graphene inverters.

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Biography

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His research interests include micro-architectural and circuit techniques for low-power and variability-tolerant digital IC design and distributed power control .