A STEP TOWARDS REALIZATION OF GRAPHENE FOR DIGITAL ELECTRONICS

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***Abstract—G*raphene has shown high mobility, high saturation velocity, high gain, good thermal and electric properties still it is not found suitable to replace the silicon technology. The reason behind this is the lack of band gap and no current saturation. This paper reviews the different techniques used for inducing band gap in the material so that it can be used for logic purpose as well as its characteristics which makes it suitable for storage purpose**.

***Index Terms*—band gap**

I. INTRODUCTION

Si technology is reaching to its physical limit. The scaling of CMOS results in short channel effect which limits further scaling. Hence researchers are searching for new materials which can be used in place of Si. Many materials available each one has their own limitation. The Graphene is also one of the materials which can replace Si in near future. Graphene has good mobility, temperature stability which can be used as channel material in MOSFET. Graphene is band less material which makes it unsuitable for switching function [2]. But it shows good RF characteristics which makes it suitable for RF application. But still research is going on to make it suitable for digital function.

II. Limitation of graphene for logic function

Due to absence of Band gap graphene transistor cannot be used for switching function. Wide research is going on to make the graphene transistor suitable for switching function some of them mentioned below.

A. By dimension constraining

Different techniques used for inducing the band gap the most popular is constraining one dimension of large-area graphene thus forming narrow graphene nanoribbon (GNRs) [3],[4].The band gap depends on chirality one with chirality (16,0) shows 0.71eV band gap but with chirality (14,0) shows 0.13eV . GNR MOSFETs with on-off ratios exceeding 10^6 have successfully been fabricated [1]. However, ribbons having a width well below 10 nanometers
are needed for a gap ensuring good switch-off [6, 1] and this represents a serious processing challenge.

The two ideal GNR types are armchair (ac) and zigzag (zz) nanoribbons. It has been predicted that these two GNR configurations show a bandgap (EG) that depends on the GNR width roughly according to band gap is inversely proportional to ribbon width [4]. The gap opening has been verified experimentally for ribbons with widths down to about 1 nm [4]. But it has also seen by introducing band gap mobility decreases in large amount. Moreover, the gap opening in GNRs is accompanied by a dramatic mobility reduction and irregular ribbon edges deteriorate transistor performance. A recent experiment [3] demonstrated that all sub-10 nm GNRs are semiconducting due to the edge effects, which make them more attractive for electronic device applications. Both the results indicate that the 3NN (Third Neighbor neighbor)interaction and the edge bond relaxation effects both result in a decrease of the band structure-limited velocity a high energies.3NN interaction and the edge bond relaxation are responsible for opening a band gap with roughly equal contribution from each effect.

For an AGNR(Arm chair GNR) with an index of $m=3p$, the band gap decreases and the ON current increases whereas for an AGNR with an index of $m=3p+1$, the quantum capacitance increases and the ON current decreases[7] [4].

B. By doping

If undoped, a bilayer of graphene sheets is considered a semimetal, a material in which the conduction and valence bands slightly overlap in energy. When the researchers first synthesized their bilayer graphene films onto the silicon carbide substrate, the graphene became a weak n-type semiconductor, having a slight excess of negatively charged electrons; the interface layer acquired an excess of conduction electrons from the substrate, creating a small bandgap. Potassium atoms deposited onto the graphene donated their valence electrons to the graphene's surface layer, initially closing the bandgap. However, as the potassium deposition continued, the bandgap was reopened by the excess of electron charge-carriers on the graphene's surface layer. Progressive potassium deposition further enhanced the *n*-type doping. These results demonstrate that by controlling the carrier density in a bilayer of graphene, the occupation of electronic states near the Fermi level (EF) and the magnitude of the gap between the valence band and conduction band can be manipulated. This control over the band structure suggests the potential application of bilayer graphene to switching functions in electronic devices with a thickness of only two atomic layers [5].

C. By applying electric field to bilayer graphene

As with monolayer graphene, bilayer graphene also has a zero bandgap and thus behaves like a metal. Previously, in 2006, researchers at the ALS observed a bandgap in bilayer graphene in which one of the layers was chemically doped by adsorbed metal atoms. But such chemical doping is uncontrolled and not compatible with device applications but a bandgap can be introduced if a perpendicular electric displacement field is applied to the two layers; the material then behaves like a semiconductor. A team of researchers from Berkeley has engineered a bandgap in bilayer graphene that can be precisely controlled from 0 to 250 meV. With precision control of its bandgap over a wide range, plus independent manipulation of its electronic states through electrical doping, dual-gated bilayer graphene becomes a remarkably flexible tool for Nano scale electronic devices. Researchers then tried to tune[5][12]. But when such a field is applied with a single gate (electrode), the bilayer becomes insulating only at temperatures below 1 K, near absolute zero—suggesting a bandgap value much lower than predicted by theory.

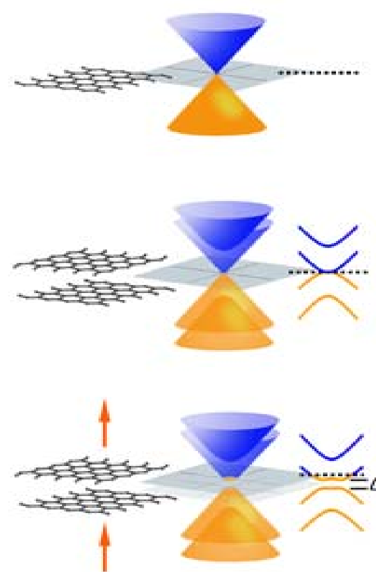

Fig. 1 Schematic depictions of graphene crystal structure (lattices), conduction band (blue cones and curves), valence band (yellow cones and curves), and Fermi level (dotted lines). Top: Monolayer graphene. Center: Bilayer graphene. Bottom: A bandgap (Δ) is induced in bilayer graphene by an external electric field (arrows).

To better understand exactly what was happening electronically, the Berkeley team built a two-gated bilayer device, which allowed them to independently adjust the electronic bandgap and the charge doping. The device was a dual-gated field-effect transistor (FET), a type of transistor that controls the flow of electrons from

a source to a drain with electric fields shaped by the gate electrodes. Their nano-FET used a silicon substrate as the bottom gate, with a thin insulating layer of silicon dioxide between it and the stacked graphene layers. A transparent layer of aluminum oxide (sapphire) lay over the graphene bilayer; on top of that was the top gate, made of platinum.

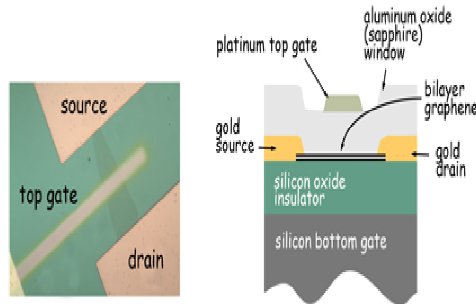

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Fig. 2 double gate graphene transistor

But the theory and experiments the performance improvements achievable use bilayer graphene as channel material in field effect transistors for analog applications as compared to digital applications. Bilayer graphene provides larger output resistance than monolayer graphene, which translates in both higher voltage gain and higher maximum frequency oscillation

D. Substrate-Induced Band-Gap Opening in Epitaxial Graphene

A multi-institutional collaboration under the leadership of researchers with Berkeley Lab and the University of California, Berkeley, have now demonstrated that growing an epitaxial film of graphene on a silicon carbide substrate results in a significant band gap, 0.26 electron volts (eV), an important step toward making graphene useful as semiconductor[8].

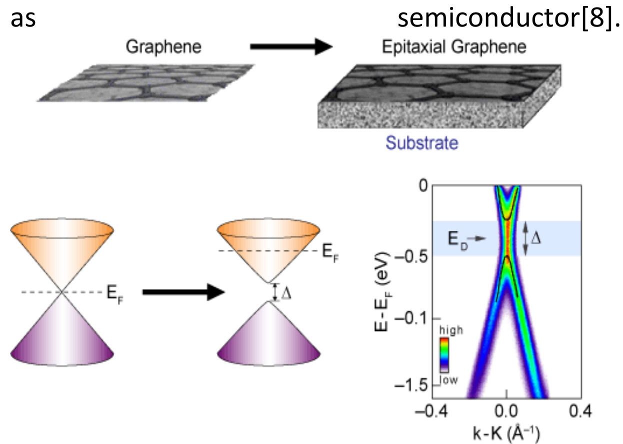

Fig. 3 Left: In graphene's electronic band structure, the conduction (orange) and valence (purple) bands just meet at the Fermi energy (E_F), so there is no band gap. Right: When a graphene layer is grown on a silicon carbide substrate), broken symmetry opens a gap ( ) between the valence and conduction bands around the so-called Dirac energy (E_D), as shown in the ARPES intensity map (lower right), but below the Fermi energy.

The team found that the size of the energy gap decreased with thickness and all but disappeared at four layers. Next on the agenda are finding ways to control the width of the band gap, perhaps by using a different substrate material with a different graphene–substrate interaction strength, and to move the Fermi energy from the conduction band into the band gap to allow transistor action.

E. Large Bandgap Opening Between Graphene Dirac Cones Induced by Na Adsorption onto an Ir Superlattice.

Marco Papagno,1 Stefano Rusponi,2 Polina Makarovna Sheverdyaev investigate the effects of Na adsorption on the electronic structure of bare and Ir cluster superlattice covered epitaxial graphene on Ir(111) using angle-resolved photoemission spectroscopy and scanning tunneling microscopy. At Na saturation coverage a massive charge migration from sodium atoms to graphene raises the graphene Fermi level by about 1.4 eV relative to its neutrality point. They find that Na is adsorbed on top of the graphene

layer and when coadsorbed onto an Ir cluster superlattice it results in the opening of a large bandgap of Na/Ir/G =740 meV comparable to the one of Ge and with preserved high group velocity of the charge carriers[9].

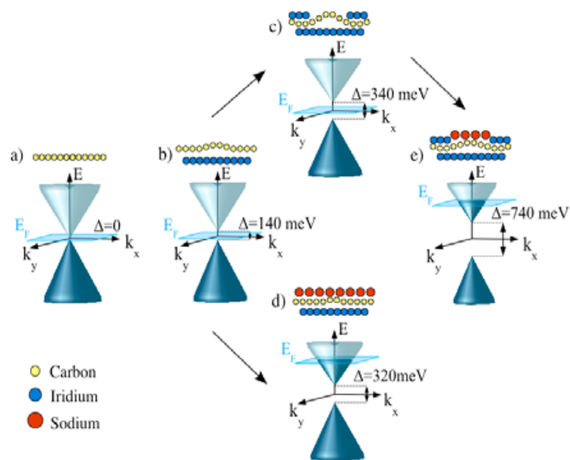

Fig. 4 Figure 1 Side view sketch of the atomic structure and of the π and π* bands dispersion close to the*K*-point of graphene Brillouin zone and to the Fermi level *EF* for (a) freestanding graphene (b) G (c)Ir/G (d) Na/G and (e)Na/Ir/G.

F. Opening of a band gap in graphene by physisorption of porphyrin molecules.

Arramel1*, Andres Castellanos-Gomez1,2, Bart Jan van Wees1 report a robust method to open a gap in graphene via noncovalent functionalization with porphyrin molecules. Two type of porphyrins, namely, iron protoporphyrin (FePP) and zinc protoporphryin (ZnPP) were independent physisorbed on graphene grown on nickel by chemical vapour de- position (CVD) resulting in a bandgap opening in graphene. Using a statistical analysis of scanning tunneling spectros- copy (STS) measurements, they demonstrated that the magnitude of the band gap depends on the type of deposited porphyrin molecule. The π-π stacking of FePP on graphene yielded a considerably larger band gap value (0.45 eV) than physisorbed ZnPP (0.23 eV). They proposed that the origin of different band gap value is governed due to the metallic character of the respective porphyrin[10]. The presence of porphyrin molecules physisorbed on the graphene substrate induces a semiconducting behavior in the surrounding graphene layer up to 10 - 20 nm far from the molecules. Interestingly, the magnitude of the bandgap opened in graphene can be controlled via the selection of the metal core of the porphyrin molecules that determines the graphene-molecule interaction. They believe that this work will open more opportunities to build other hybrid systems based on the noncovalent π-π stacking of aromatic molecules on graphene.

G. Placing Graphene sheet with boron nitride sheet

This technique involves placing a sheet of graphene a carbon-based material whose structure is just one atom thick on top of hexagonal boron nitride, another one-atom-thick material with similar properties[11]. The resulting material adds the band gap while shares graphene's amazing ability to conduct electrons. Graphene is an extremely good conductor of electrons, while boron nitride is a good insulator, blocking the passage of electrons. A high quality semiconductor can be made suggested by MIT team. To make the hybrid material work, the researchers had to align, with near perfection, the atomic lattices of the two materials, which both consist of a series of hexagons. The size of the hexagons (known as the lattice constant) in the two materials is almost the same, but not quite: Those in boron nitride are 1.8 percent larger. So while it is possible to line the hexagons up almost perfectly in one place, over a larger area the pattern goes in and out of register. At this point, the researchers say they must rely on chance to get the angular alignment for the desired electronic properties in the resulting stack. However, the alignment turns out to be correct about one time out of 15, they say. But by this technique the band gap obtained is not sufficient graphene device to use in digital electronics. Graphene and boron nitride hexagons almost perfectly align, merging their properties .The qualities of the boron nitride bleed over into the graphene," Ashoori says. But what's most "spectacular," he adds, is that the properties of the resulting semiconductor can be

"tuned" by just slightly rotating one sheet relative to the other, allowing for a spectrum of materials with varied electronic characteristics. Others have made graphene into a semiconductor by etching the sheets into narrow ribbons, Ashoori says, but such an approach substantially degrades graphene's electrical properties. By contrast, the method appears to produce no such degradation but the band gap is not sufficient to use graphene for digital electronics.

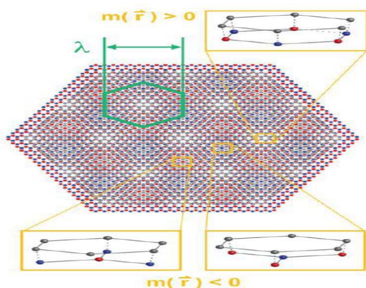

Fig. 5 Insulating states and superlattice minibands in a graphene/hBN heterostructure. Schematic of the moiré pattern for graphene (gray) on hBN (red and blue), for zero misalignment angle and an exaggerated lattice mismatch of ~10%. The moiré unit cell is outlined in green. Regions of local quasi-epitaxial alignment lead to opposite signs of the sublattice asymmetry, m(r), in different regions. (Credit: B. Hunt et al./Science.

III. NEGATIVE RESISTANCE

Guanxiong Liu, Sonia Ahsan, Alexander G. Khitun, Roger K. Lake and Alexander A. Balandin propose complimentary designs for 2-port GNR based negative resistance devices. They proposed negative resistance devices exhibit very high peak to valley current ratios (10^{14}), which is essential in digital applications. Graphene logic circuitry is based entirely on the intrinsic NDR effect in graphene and benefits from graphene's high electron mobility and thermal conductivity. The devices are highly configurable, and their properties can be adjusted and optimized by the selection of voltages applied and the gate WF values. The fabrication and integration of n- and p-type devices are simple and cost effective due to the similarities between their structures[4][13] This approach overcomes the absence of the energy band gap in graphene. The negative differential resistance appears not only in the large scale graphene transistors but also in the downscaled devices operating in the ballistic transport regime. The results may lead to a conceptual change in graphene research proving an alternative route for graphene's applications in information processing[13].

Santosh Khasanvisand , Pritish Narayanan propose a novel Graphene NanoRibbon crossbar (xGNR)exhibiting negative differential resistance (NDR) showed considerable advantages in terms of power dissipation, area and write performance[14].

IV: High density of states and work function

There has been strong demand for novel nonvolatile memory technology for low-cost, large-area, and low-power flexible electronics applications .Graphene flash memory (GFM) has the potential to exceed the performance of current flash memory technology by utilizing the intrinsic properties of graphene, such as high density of states, high work function, and low dimensionality. GFM can fabricate by growing the graphene sheets by chemical vapor deposition and integrated them into a floating gate structure. GFM displays a wide memory window of∼6 V at significantly low program/erase voltages of 7 V. GFM also shows a long retention time of more than 10 years at room temperature [15]. Multi-layer graphene sheets have higher work function and higher density of states compared to single layer graphene (SLG) and lower conductivity along c-axis. A memory window of 6.8V for 1 second programming is obtained at ±18program/erase voltage. Number of electrons stored in MLG sheets after 18V programming voltage is calculated as 9.1 x 1012 cm-2 which is higher than the density of states in SLG, suggesting the suitability of MLG for multi level data storage flash memory devices.

Graphene quantum dot memory has many advantages over the polysilicon trapped memory. Polysilicon trapped memory are affected by the local defects which can be reduced in the quantum dot memory. But it has seen increasing the size improves the erase speed and stability

(27nm) but decreasing the size increases the program speed (12nm). Even other advantage on using the graphene material as trapped layer is the flexibility. It can be deposited over the flexible substrate material and flexible memory is possible to use with flexible device [17].

Resistive memories based on metal oxide thin films have been extensively studied for application as next generation

Nonvolatile memory devices. However, although the metal oxide based resistive memories have several advantages, such as good scalability, low-power consumption, and fast switching speed, their application to large-area flexible substrates has been limited due to their material characteristics and necessity of a high-temperature fabrication process. Graphene oxide is also useful for fabricating a flexible resistive switching memory device .The switching operation of graphene oxide resistive switching memory (RRAM) is governed by dual mechanism of oxygen migration and Al diffusion. However, the Al diffusion into the graphene oxide is the main factor to determine the switching endurance property which limits the long term lifetime of the device [16].

In terms of performance, a very high on-off power ratio makes graphene-based memory very attractive in terms of performance; a very high on-off power ratio makes graphene-based memory very attractive. While phase-change memories, which are currently, considered the most promising technology for data storage, have an on-off power ratio of 10 to 1. Graphene-based memory is believed to have an on-to-off power ratio of one million to one. Further, their heat generation is extremely low, eliminating the need to use heat sinks, which are usually a part of any storage system used for high-density storage [17].

III Conclusion

Graphene material has tremendous potential to use next generation semiconductor material but lack of band gap was one of the biggest hindrances. Lot of the research is going on in this direction but still no fruitful solution is found. Intensive research needed to increase band gap by optimizing the process and technique. Graphene has potential to be used as next generation storage element.

REFERENCES

[1] X. Li, X. Wang, L. Zhang, S. Lee, and H. Dai, Science, vol. 319, 1229 (2008).

[2] Majumdar, K, Murali, K.V.R.M., Bhat, N., Fengnian Xia and Yu-Ming Lin. “High On-Off Ratio Bilayer Graphene Complementary Field Effect Transistors.” : *Electron Devices Meeting (IEDM) 2010 IEEE International,* December2010

[3] Li, X.; Wang, X.; Zhang, L.; Lee, S.; Dai, H. Chemicallyderived, ultrasmooth graphene nanoribbon semiconductors.Science **2008**, 319, 1229 1232.

[4] Computational Model of Edge Effects in Graphen Nanoribbon Transistors R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[5] T. Ohta, A. Bostwick, T. Seyller, K. Horn, and E. Rotenberg, “Controlling the electronic structure of bilayer graphene,”Science **313**, 5789 (2006).

[6] F. Schwierz, Nature Nanotechnology., vol. 5, 487 (2010).

[7]SPei Zhao1, Mihir Choudhury2, Kartik Mohanram2, and Jing Guo, “ Computational Model of Edge Effects in Graphene NanoribbonTransistor,” Accepted: 14 September 2008©Tsinghua Press and Springer-Verlag 2008.

[8] S.Y. Zhou, G.-H. Gweon, A.V. Fedorov, P.N. First, W.A.De Heer, D.-H. Lee, F. Guinea, A.H. Castro Neto, and A. Lanzara, "Substrate-induced bandgap opening in epitaxial graphene," Nature Materials **6**, 770 (2007).

[9] Marco Papagno, Stefano Rusponi,Polina Makarovna Sheverdyaeva,Sergio Vlaic,MarkusEtzkor,“Large Bandgap Opening Between Graphene Dirac Cones Induced by Na Adsorption onto an Ir Superlattice”.

[10] Arramel, Andres Castellanos-Gomez,Bart Jan van Wees,“Band Gap Opening of Graphene by Noncovalent π-π Interaction with Porphyrins”, Graphene, 2013, 2, 102-108

http://dx.doi.org/10.4236/graphene.2013.23015 Published Online July 2013 (http://www.scirp.org/journal/graphene) scientific research.

[11] B. Hunt et al., Massive Dirac Fermions and Hofstadter Butterfly in a van der Waals Heterostructure, Science, 2013, DOI: 10.1126/science.1237240.

[12] Y. Zhang, T.-T. Tang, C. Girit, Z. Hao, M.C. Martin, A. Zettl, M.F. Crommie, Y.R. Shen, and F. Wang, "Direct observation of a widely tunable bandgap in bilayer graphene," *Nature* **459**, 820 (2009).

[13] Guanxiong Liu, Sonia Ahsan, Alexander G. Khitun, Roger K. Lake and Alexander A. Balandin,“ Graphene-Based Non-Boolean Logic Circuits,” G. Liu et al., UC Riverside (2013)

[14] Santosh Khasanvis, K. M. Masum Habib, Mostafizur Rahman, Pritish Narayanan,Roger K. Lake and Csaba Andras Moritz,“Hybrid Graphene Nanoribbon-CMOS Tunneling Volatile Memory Fabric,”khasanvis@ecs.umass.edu, andras@ecs.umass.edu
978-1-4577-0995-1/11/$26.00_c 2011 IEEE.

[15] Augustin J. Hong ,Hyung Suk Yu, Jesse D. Fowler “Graphene Flash Memory,”VOL. 5 ’ NO. 10 ’ 7812–7817 2011,www.acsnano.org

[16] Seul Ki Hong,1 Ji Eun Kim,2 Sang Ouk Kim,2 and Byung Jin Cho1,”a Analysis on switching mechanism of graphene oxide resistive memory device
; published online 22 August 2011) JOURNAL OF APPLIED PHYSICS 110, 044506 (2011)

[17] Md. Nahid Hossain and Masud H Chowdhury, “Graphene Nanotechnology for the Next Generation Nonvolatile Memory”.