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# Investigation on High Switching Performances Graphene Transistors Using Band-gap Engineering

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*Graphene transistors are considered to be the successor's basic element for the next generation of advanced integrated circuits. The graphene suffers from the absence of energy band gap to experience a semiconductor like characteristics. In order to instigate a bandgap, several techniques are used to beak symmetry. The most useful graphene sheet is the Graphene Nanoribbon (GNR). The present paper deals with the investigation on the bandgap engineering approach aiming an increase of the switching characteristics of the graphene transistors. The GNR sheets are synthesized using different techniques yielding controlled electronics and physical characteristics.*

## INTRODUCTION

Graphene nanotransistor (GFET) is seen to be the successor of the MOS transistor as basic unit in Integrated circuits[1,2]. These promising devices can find their application in RF circuits and amplifiers as their temperature and power sustain ability are very appreciable[3,4]. Graphene transistors can be used in flexible and stretchable electronics as well as advanced nanosensors[5,6]. However, their switching characteristics are strongly dependent on the graphene bandgap, which is assumed null for intrinsic graphene materials. In order to build high performance transistors, opening a bandgap for the graphene material is necessary. This is known as bandgap engineering.

Several techniques have been used to create an energy gap in the graphene material. The better form of graphene capable of handling a bandgap is found to be the graphene sheets under the form of bilayer nanoribbon or GNR. However, a major obstacle in exploiting GNR properties is the difficulty of producing high quality GNRs having specific dimensions, i.e., widths, lengths and edges. The widely used method for GNRs synthesis is the lithographic patterning on larger 2D graphene sheets. This is known as top-down approach. This method seems to lack precision and yields to GNRs with unexpected shapes, rough edges and poor electronic properties. A research group at the UC Berkeley has evidenced a better technique for high quality GNRs synthesis with controlled characteristics using, rather, a bottom-up molecular engineering.

## BANDGAP ENGINEERING METHODES

The main obstacle for graphene transistor is the material zero bandgap that worsens the switching characteristics of the GFETs. Opening a bandgap in the graphene is equivalent to create a semiconductor like behavior as shown in Fif.1.

Several techniques have been proposed to open a bandgap in graphene, among these engineering techniques, we can cite the Substrate induced bandgap, Bandgap engineering using h-BN/Ni (111). This method which uses substitutional doping with extra atoms is found to be a good approach to alter the GNR intrinsic electronic properties. Generally, graphene is doped with B and N atoms as these atoms have radii compatible with that of carbon which is the main graphene constituent. For illustration, radius of B is 87, that N is 56 and that of C is 67, the planar geometry is then not altered. Inserting of B or N atoms into a stacked BLG has been studied by several authors for different sites positions (top and hollow sites) in the thickness of the BLG layer. It has been found that the band structures are similar for the two sites in each case.

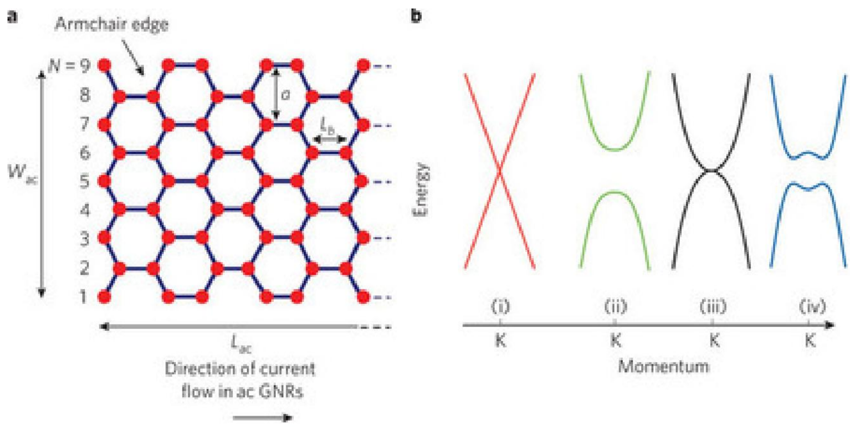


*Figure 1. Atomic Structure of Graphene Nanoribbon Armchair (left) and bandgap Structure (right)*

For BLG bilayer graphene with one N atom in each layer, the total energy varies with the interdopant distances, i.e., increases for decreasing distances and decreasing for increasing distances. Authors have concluded that combination of B-N pairs in vertical position can lead to larger energy gaps and hence serves a better way to control the energy bandgap.

It is known that in theory a maximum of 0.50 to 0.53 eV can be obtained. Such bandgaps are observed on Graphene Bi-Layer (GBL) sheets grown on silicon carbide (SiC).

Other methods are the substitutional doping (SD), Nitrogen doping (NB). In any case graphene engineering should be considered in chemistry and physics view points. A high selective hydrogenation of graphene grown by lithography under the form of nanoribbon showed a very interesting result of 0.7 eV. This process is part of selective chemical graphene functionalization techniques (SCGF).

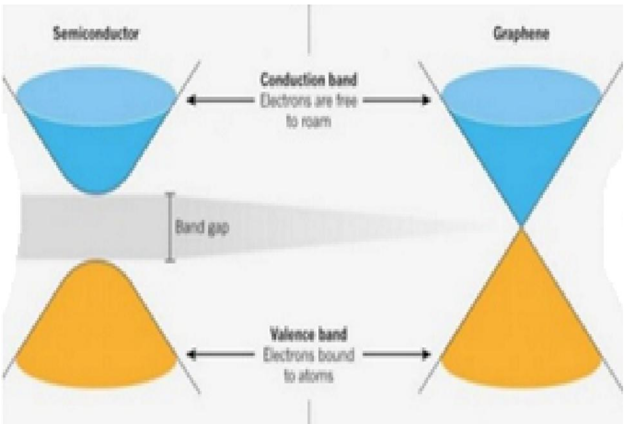


***Figure 2. Graphene bandgap opening and bandgap energy.***

For the case of a BLG graphene, there are different techniques used in creating a bandgap, these techniques may be extended to single layer graphene. Among them, we can distinguish the uniaxial strain, graphene-substrate interaction, lateral confinement, and breaking the inversion of symmetry in bi-layer graphene. Figure 2 summarizes few common results obtained in Bandgap opening techniques.

In this paper we will deal with the graphene nanoruban and the opening of a bandgap capable of inducing an appreciable switching current ratio of at least $I_{ON}/I_{OFF}>10^6$.

## GRAPHENE FET PERFORMANCES

The Graphene Nano Ribbon (GNR) structure used in the form of GNRFET for logic circuits and RF devices combines the high field, high mobility and the possibility of opening a bandgap. The higher carrier mobility of graphene is the basis of all electrical characteristics of graphene transistors. Graphene Metal (GM) and Metal Semiconductor (MS) interfaces as well as carrier mobility are the main critical issues to improve the higher device performances. In our earlier work, we have described the Graphene Metal and Graphene Semiconductor Interfaces and their impact on resistive and schottky contacts[7].The drain/source contact resistances introduce leakage currents that worsen the OFF state current in switching GFETs.

Figure 3 shows a comparative approach on different FETs. We can see that G-FET suffers from low cut-off frequency. This is due partly to mobility reduction due to interface quality and volume of the graphene layer and the difficulty in opening a gap.

Moreover, the graphene sheet length is important in the higher cut-off frequency as the drain/source distance contributes to the lowering the maximum drain current.

If the cutoff frequency is theoretically higher than few tera values, practically it goes down as there is an absence of bandgap and drop of surface mobility in graphene. This maximum frequency is defined as:

$$f_m = \frac{1}{2} f_T \left(g_d\left(R_g + R_{ds}\right) + 2\pi f_T R_g C_g\right)^{-1/2} \qquad (1)$$

$f_T$ is known as unity gain frequency, $g_d$, $R_g$, $R_{ds}$, $C_g$ are the known transistor parameters. Bandgap will affect the transconductance and capacitance of the transistor. The zero bandgap will increase the resistance between drain and source and there will be no current saturation.

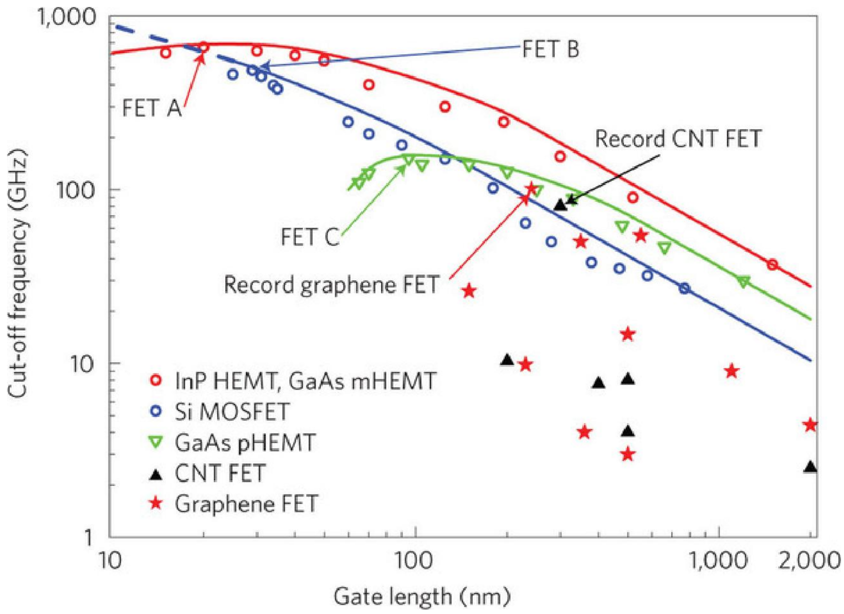


***Figure 3. Comparative study of cut-off frequency for different FETs.***

GNR field-effect transistors (GNRFETs) can exhibit an electrical bandgap up to a few hundred meV as shown in Fig.2 and show very large current on/off ratio even at room-temperature. However, for the case of GNR, the carrier mobility is highly reduced and the material growing techniques are not so reliable for nanoribbons meant for large area applications (Integrated circuits).

This induce (in logic circuits) low $I_{ON}/I_{OFF}$ ration. Lower ratio leads also to higher static power dissipation.

## RESULTS AND DISCUSSION

In this paper we have studied the different methods used in bandgap engineering and opening for possible creation of a semiconductor like graphene material. The most useful method is the lithography and the BN doping method. However it is only applicable for GNR structures in the bilayer form. For the simulation is achieved using different models mainly, the semi-classical device model including the band to band tunneling that is described in Ref[8-9] to emphasize on the bandgap engineering. Device performances are studied based on the current-voltage characteristics with respective bandgap width variations. $I_{OFF}$ current estimated and the performance ratio deduced.

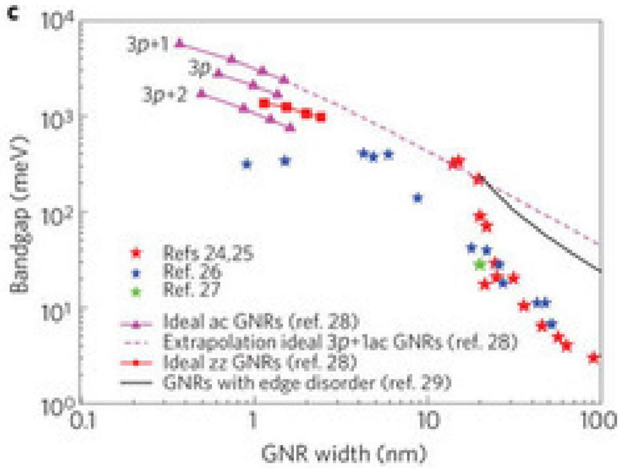


***Figure 4 Few results obtained by different Techniques on different GNRs***

Figure 4 shows that higher bandgap values are obtained for lower values of GNR width and lengths. The GNR structure is affecting the bandgap opening but with smaller values. For all cases, the GNR widths seem to be the most relevant parameter.

As given by Eq.1, the cut-off frequency can be made improved if we combine the length and the bandgap created in the graphene. Reduction of drain/source resistance and capacitance maximizes the cut-off frequency and bandgap opening increases mobility and decreases the resistance and capacitances. However, this is valid for a typical value of GNR length that should be chosen to maximize all performances. According to Figs. 3 and 4, a value of 100 nm can give optimized results, i.e., bandgap opening of 60 mV and cut-off frequency of 100 GHz or even more.

## CONCLUSION

In this work the bandgap engineering using a typical technique is described. It has been found that the graphene lithography with B-N doping can give graphene with bandgap in the form of Ribbons (Graphene Nanoribbons, GNR). Device performances for different bandgap width are simulated and performance parameters are deduced. The most relevant parameter, i.e., cut-off frequency is strongly dependent on GNR width and bandgap. Higher bandgap values and lower GNR widths contribute to better cut-off frequencies.

It has been found that GNRFETs are the better candidate for this gap engineering. Effort should be made to overcome the surface defects and set up optimal gap widths that allow maximum device performances. Interfacial defects reduce drastically the carrier mobility, which will severely affect the cut-off frequency and decrease the $I_{ON}/I_{OFF}$ ratio.

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