

## Technical Review on Properties of Graphene and Its Application in Bioelectronics

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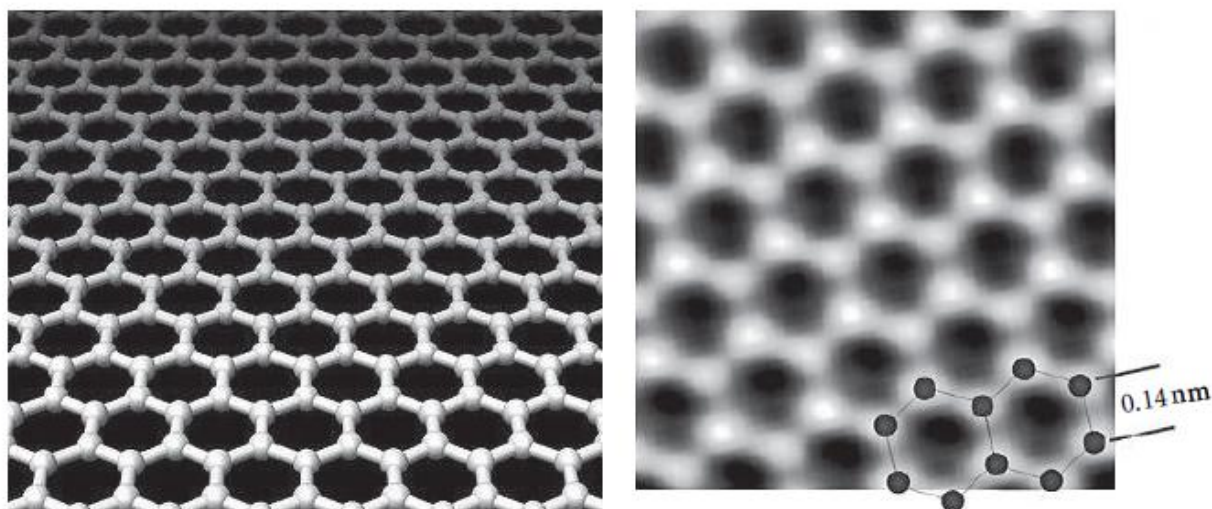
**Abstract:** Graphene, a carbon, displays unique 2-D structures with preternatural physical, chemical and electronics properties that necessitated its applications in different fields of engineering systems. Among these applications, bioelectronics application of graphene has attracted an increasing interest over the last years. The advantages conferred by the physical, optical and electrochemical properties of graphene-based nanomaterial have contributed to the current variety of ultra-sensitive and selective biosensor and sensors devices, Nano electronics, super-capacitors, solar cells, batteries, flexible displays, hydrogen storage in electronics. This paper provides a review on graphene variant properties and their applications especially in bioelectronics

**Keywords:** Graphene, unique 2-D structure, properties, nanomaterial base, bioelectronics.

### INTRODUCTION

Nano science and technology on active materials in micro electromechanical systems (MEMS) and bio medicals have grown wild to the level of innovations and improvement. Graphene, an atomically thin layer of graphitic carbon, has been first isolated twelve years ago and quickly became a material of interest to build microelectronic devices. In particular, graphene is a promising platform for bioelectronics as it gathers in one material many unique properties such as high electrical conductivity, chemical inertness, optical transparency and flexibility with a bending rigidity comparable to the phospholipidic bilayer of cells membrane.

As this material becomes more and more easily available and can now be produced at large scale; its promising integration in bio-sensing and bioelectronics devices is being investigated. The two-dimensional (2D) property of graphene as a nanomaterial played a tremendous role in the microelectronic world for smart systems. Graphene has a definition of, "a single-atom-thick sheet of hexagonally arranged, sp<sup>2</sup>-bonded carbon atoms occurring within a carbon material structure". Graphene film has a thickness of 100 μm of lateral size observed as carbon planes connected together by van der Waals forces acting over a distance of about 0.335 nm. The properties of graphene are those of a semi-metal and are stable under ambient circumstances. This contradicts the general belief that a 2-D material could not exist and be thermodynamically stable. The charge transport and electronic properties of graphene are due to its unique electronic band structure. In particular, among existing nanomaterial graphene has a large surface area (2630 m<sup>2</sup>/g) being available for direct interaction in a wide range of biomolecules. Graphene can be engineered with structural defects using low-cost fabrication methods due to the migration of heteroatoms, oxidation, and reduction by chemical modification. Graphene's honeycomb like hexagonal structure that does not permit the small helium gas atoms can pass through it.



**Fig-1: The two-dimensional honeycomb structure of carbon atoms in graphene**

Source: Ujjal Kumar Sur [1]

Figure above shows two-dimensional honeycomb structure of carbon atoms in graphene along with the high resolution transmission electron microscopic (TEM) image showing the hexagonal lattice with carbon-carbon distance 0.14 nm. Graphene is the fundamental building block for graphitic materials of all other dimensions. It can be wrapped up into zero dimensional (0D) fullerenes, rolled into one-dimensional (1D) nanotubes and stacked into three-dimensional (3D) graphite. Graphene unique electrical properties and ultra-low cost guaranteed its immense potential in electronics and a variety of applications. It is found to be an excellent conductor of both heat and electricity with electron mobility 100 times faster than silicon. At very low temperatures, the electrons in graphene do not slow down and act as if they have “no mass”. Graphene never stops conducting besides its transparency and strength it becomes a potential material for composite materials used in many areas ranging from fuel systems, electric batteries, lighter aircraft and automobile parts, cell phones to computers. Many scientists think that due to its high energy storage capacity, graphene will soon be the successor of semiconductor technology. For these reasons, Graphene has been touted as the “miracle material” of the 21<sup>st</sup> century [2]. The extraordinary electronic behavior of graphene makes it a test bed for the foundations of theoretical physics. Its befitting thin-structure and high conductivity makes it a potential candidate to test the Casimir effect. Graphene, being important both from the fundamental and application points of view, is increasingly drawing attention of the scientists from different disciplines and researches are being deepened on this material to make the world a better place. And having earned the fame of “the poor man’s material” is transcending across the economic bounds and barriers where the luxury of astronomically expensive particle accelerators is not possible. According to James Hone, a research scientist at Columbia University, “It would take an elephant, balanced on a pencil, to break through a sheet of graphene the thickness of saran wrap.”

As reported by P. Genapati, the Gadget lab reporter, “Clothing could have been dyed with graphene that could hold an electric charge. Information stored in the graphene might allow people to monitor physical functions or just charge their cell phone by placing it into the pocket.”

All graphitic carbon-based nanomaterials are graphene based essential for bioelectronics applications.

### **Material Descriptions and Properties of Graphene**

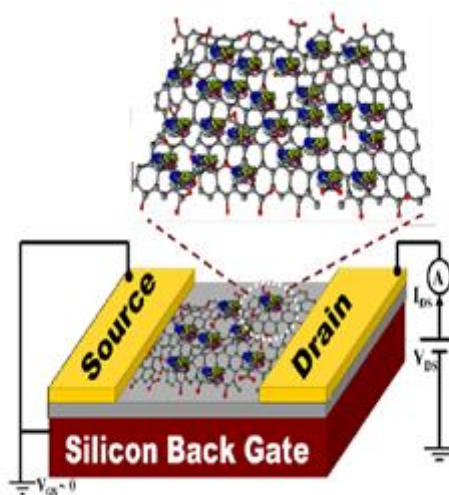
Graphene is a super material due to its unique physical properties. This new kind of 2-D carbon nanostructure has attracted tremendous attention in the science and engineering worlds. Today, graphene is the most attractive nanomaterial not only because it is the thinnest known material in the world and the strongest ever measured but also due to its excellent electrical, thermal, mechanical, electronic, and optical properties it becomes a versatile nanomaterial. It has high specific surface area, high chemical stability, high optical transmittance, high elasticity, high porosity, biocompatibility, tunable band gap, and ease of chemical functionalization which actually helps in tuning its properties. Graphene exhibits many exciting properties such as half-integer room-temperature quantum Hall effect, long-range ballistic transport with almost ten times greater electron mobility than that of silicon (Si), availability of charge carriers that behave as massless relativistic quasi particles (Dirac fermions), and quantum confinement giving rise to finite band gap and Coulomb blockade effect. The below table shows some of the astounding physical properties of graphene. These extraordinary

properties of graphene can be utilized for making many novel electronic devices such as field-effect transistor (FET), sensors/biosensors, bioelectronics components and super-capacitors to name but few. A noteworthy feature of graphene is that the energy of electrons is linearly dependent on the wave vector near the crossing points in the Brillouin zone. The charge carriers which behave as massless relativistic particles can be explained according to Dirac equation rather than the usual Schrodinger equation. Thermal fluctuation effect creates formation of ripples on the graphene surface which is expected to be flat.

### Charateristics Properties of Graphene

Some Basic Properties	Units
Young's modulus	~1100 GPa
Fracture strength	125GPa
Thermal Conductivity	~5000Wm <sup>-1</sup> K <sup>-1</sup>
Mobility of charge carrier	2 × 10 <sup>5</sup> cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup>
Specific Surface area	2630m <sup>2</sup> g <sup>-1</sup>

Graphene has sp<sup>2</sup> bonded hexagonal carbon lattice alloyed with the ultimate 2D surface - *two faces of the bulk-less monolayer*. This provides graphene with extraordinary sensing abilities in which the carriers being easily modulated in absence of any dilution from the bulk, and a potentially defect free crystal lattice which leads to low intrinsic noise (low thermal noise and low 1/f noise) thereby showing potential for single quanta detection. Notwithstanding the excellent propensity of pristine graphene for ultra-sensitive detection, the specificity is an issue. Chemically functionalized graphene, which forms a new class of graphene with starkly different properties, offers an excellent route for highly specific chemistries. The most common derivative of graphene is GO - the oxy-functional derivative of graphene. Comprising of an amalgam of sp<sup>2</sup> bonded crystalline islands separated by sp<sup>3</sup> bonded oxy functionalized carbon (typical functional groups being hydroxyl, epoxy, carbonyl, Quinone and others. Structure, GO is a new variety of graphene. The most common synthesis strategy is the Hummer's acid oxidation method involving sulfuric acid and potassium permanganate based oxidation. As expected, owing to the loss of the highly mobile  $\pi$  electrons due to sp<sup>3</sup> bonds, GO is electrically insulating (or semiconducting) depending on the degree of oxidation. However, the most important advantage offered by GO is the easy availability of basal oxy-functional groups, which has been employed for further functionalization to confer high specificity.



**Fig: A schematic diagram of a sample peptide-functionalized GO device**

Source: Nihar Ranjan Mohanty [3]

Here the GO was functionalized with chemical moieties including peptides and DNA for fabricating ultrasensitive bacteria and DNA sensors.

### Mechanical properties of graphene

Graphene has been shown to be one of the strongest materials found in the universe with a Young's modulus of  $E \sim 1$  TPa for a defect free sheet. The table-2 shows the typical values of Young's modulus for various materials.

**Table-2: Young's moduli for various materials**

S/N	Materials	Young's modulus (GPa)
1	RUBBER	0.01-0.1
2	TEFLON	0.5
3	POLYSTYRENE	3-3.5
4	ALUMINUM	69
5	GLASS	50-90
6	KEVLAR	70.5-112.4
7	TITANIUM	105-120
8	SILICON	185
9	STEEL	200
10	SILICON CARBIDE	450
11	CNTs	1000
12	DIAMOND	1220
13	GRAPHENE	1000

Source: Nihar Ranjan Mohanty [3]

Another interesting mechanical property of graphene is its atomic impermeability to standard gases including helium. The closely packed honeycomb lattice of carbon atoms in graphene leaves extremely small interstitial space making it an ultimate membrane (1 atom thick). In addition to experimentally demonstrating the impermeability of graphene, Bunch *et al.*, have shown that graphene membranes can sustain pressure differences of > 1 atm. For a graphene-sealed-micro chamber as shown in the Figure below, in presence of a pressure difference of ~ 0.92 atm, the surface tension of the graphene membrane as determined from the Young – Laplace equation

$$S_{\text{Graphene}} = \frac{\Delta P \times R_x \times R_y}{R_x + R_y}$$

Where, Rx and Ry are the radii of curvature in the x or y direction respectively, was found to be 1 N/m, which is 14 times that of water.

### Optical Properties of Graphene

The optical ability of graphene is the transmittance for visible light which fall between Single layer graphene displays ~ 97 % transmittance and the bilayer ~ 95 % transmittance. A Very high transmittance for visible light has been observed (~ 97 % for monolayer and 95 % for bilayer graphene). Transmittance decreases linearly upon increase in the number of layers. Hence, the more the layers the lesser the transmittance. This high transparency coupled with the excellent electrical conductivity of graphene, makes it an excellent candidate for transparent electrodes.

The high-frequency conductivity G for Dirac fermions in graphene is a universal constant;

$$G = \frac{e^2}{4h}$$

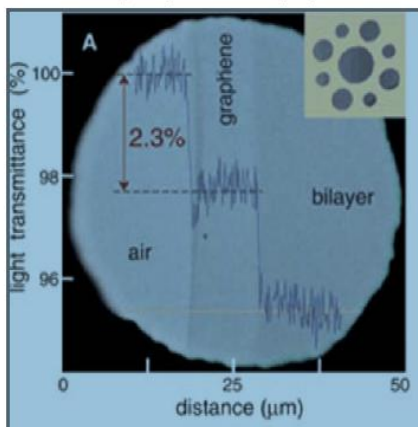
This leads to very interesting optical properties. The optical transmittance and the reflectance of graphene are universal constants for normal incidence,

$$T = \frac{1}{\left(1 + \frac{2\pi G}{c}\right)^2}$$

$$R = \frac{1}{4} \pi^2 \alpha^2 T$$

Where, T= Transmittance, R=Reflectance and  $\alpha = \frac{e^2}{hc}$

Further, the transmittance in graphene can be tuned via the gate potential mediated Fermi level shifts resulting in significant shifts in the charge density. Ultrafast (~ 40 GHz) and highly efficient (6-16 % internal quantum efficiency) photo response times have been observed in graphene FETs, attributed to the ballistic carrier mobilities. This has applications for high speed optoelectronic devices.

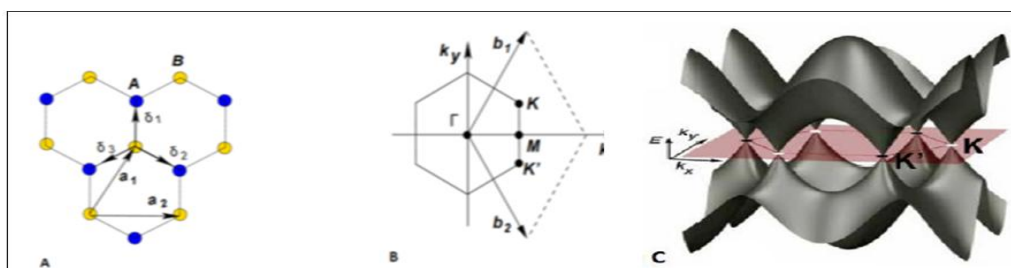


**Fig: transmittance profile on a monolayer and bilayer graphene placed on a 50 micron aperture**  
Source: Nihar Ranjan Mohanty [3]

The optical property of graphene is the quantum confinement and edge effect mediated emergence of photoluminescence. Unlike their 2-D graphene counterpart, 1 dimensional graphene quantum dots (GQDs), nano-sheets of graphene with dimensions less than 100 nm, display strong luminescence owing to the prominent effects of the quantum confinement and the edge terminations. Both theoretical and experimental studies have demonstrated the emergence of unique UV-Vis absorption bands and photoluminescence emission spectra for the GQDs depending on their dimensions and edge crystallographic structure. Several strategies have been proposed for synthesizing GQDs such as sonochemical methods, lithographic methods, chemical bottom-up strategies and the recent opening of fullerene molecules.

### Electronic properties of graphene

The graphene exception in electronic transport owns to the honeycomb lattice structure which is not by itself a Bravais lattice, implying that every atom in the crystal are not equivalent. Indeed, there are two distinct environments for graphene carbon atoms.



**Fig: Graphene carbon atoms in Bravais lattices**  
Source: Antoine Bourrier [4]

Fig is the two Bravais lattices respectively composed of the intertwined networks of respectively A and B atoms which create their own triangular Bravais lattice shifted to one another. These two distinct lattices are responsible for the very unique graphene's wave propagation properties: A and B sub-lattices energy bands for charge carrier intersect at zero energy near the edges of the Brillouin zone. The  $\pi$  electrons in graphene form an ideal 2-D system: a single atom thickness with  $\pi$  and  $\pi^*$  non-interacting states. The  $\pi^*$  form the positive energy conduction band whereas  $\pi$  states form the negative energy valence band, and those two bands intersect at six points called Dirac or neutrality points that can be reduced to a pair of independent points K and K'. Graphene can thus be called a zero gap semiconductor, thanks to the orthogonal  $\pi$  and  $\pi^*$  non-interacting states allowing the conduction and valence bands to touch. The dispersion relation of charge carriers is analogous to the dispersion of photons:

$$E = C\hbar K$$

With  $C$ = the light velocity and  $K$ = the carrier wave vector.

In graphene, electrons interact with the periodic potential of the two Bravais sub-lattices A and B, allowing the Hamiltonian description of the structure to be written as a relativistic Dirac



Hamiltonian as:

$$H = V_F \cdot \hbar \sigma \cdot K$$

$v_F$  = the graphene Fermi velocity and  $\sigma$  = the spinor-like wave function arising from the fact that there are two atoms in a unit cell. Defining a pseudospin that corresponds to the hopping of the electron between A and B leads to the description of electrons in graphene as relativistic particles of energy  $E$  with a mass  $m$ , velocity  $c$  and momentum  $p$ :

$$E = \sqrt{m^2 \cdot c^4 + p^2 \cdot c^2}$$

Electrons in graphene have a linear dispersion, giving birth to new low energies quasi-particles called massless relativistic Dirac fermions of energy. Graphene density of states increases linearly with energy. Electrons in graphene behave as massless Dirac particles. For all those reasons, graphene exhibits unique transport properties, the non-scattering nature of its surface allowing a very high carrier mobility, with carrier's velocity of  $v_F = 10^6 \text{ m} \cdot \text{s}^{-1}$  providing ballistic transport on tens of micron scale.

Graphene is defined as one or two layers of carbon atoms organized in a honeycomb crystal lattice that has the electronic spectra of a zero gap semiconductor, with the valence band touching the conduction band. Compared to commonly used materials in bioelectronics/electronics, graphene can be classified as a semimetal when pile up several graphene foils to delocalize conduction electrons, or a zero gap semiconductor when in its 2-D crystal form.

### Graphene Transistor A Bio-Sensing Device

Graphene transistors can have surface-exposed channels that lead to very promising biosensors. Indeed, charge carriers are readily on the surface and therefore can be directly influenced by charged elements without any screening. This is in stark contrast compared to the previous generation of biochemical biosensors based on silicon nanowires that do have a "charged crust" of oxide that do impact their detection performance by partially screening the charge elements to be detected. Three types of devices can be made for biosensing are MEA, G-FET for direct charge detection and G-FET coated with redox functionalized layers to make the transduction between a biochemical reaction and the associated charge modification. Ultrasensitive electrochemical affinity can be tuned for that purpose.

Graphene FETs (G-FETs) have been previously used to detect cellular (cardiomyocyte cells) activity. Several recent advances demonstrate graphene transferability on flexible materials like polyimide to perform reading of neuronal activity using Solution-gated Graphene Field-Effect transistors (SGFETs). Such biosensors showed robustness when bending thanks to graphene flexibility with a bending stiffness close to that of phospholipidic bilayer forming the membrane of a cell. Graphene very high electron mobility compared to conventional semiconductors leads to SGFETs with a high trans-conductance and consequently a high sensitivity.

In a SGFET, the drain-source current will be modulated by the gate potential through an interfacial capacitance. The gate potential refers to the global charge on the device. This charge can be associated to a biologic element on the channel surface or to a biochemical redox reaction that will tune the transistor sensitivity to specifically react to a given compound in the solution. The trans-conductance of the transistor has to be known to deduce cell activity values with accuracy. Whereas previously described silicon based transistors use a gate oxide to create the interfacial capacitance, graphene transistors are either back gated through the insulation oxide or front gated by liquid gating in solution gated FETs.

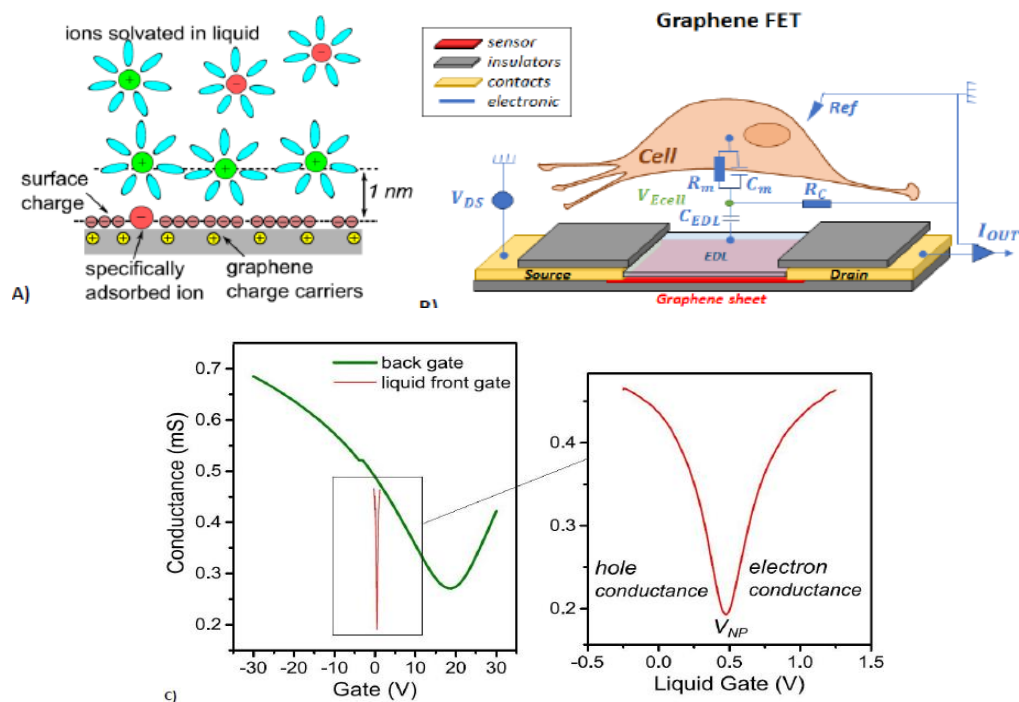
For Solution Gated FETs (SGFETs), the applied gate voltage drives ions to the surface of the graphene channel, forming a very thin Electrical Double Layer (EDL) that acts as a nanoscale interface capacitor which replace the gate oxide. The Electrical double layer is a thin diffusive layer that is directly in contact with graphene surface. This thin layer will have a higher capacitance than a conventional gate oxide, it will increase the incidence of small ionic changes occurring in the liquid, conferring graphene transistor a very high gain.

Using front liquid gating instead of back gating will thus change the oxide capacitance  $C_{OX}$  in an electric double layer capacitance  $C_{EDL}$ . The relationship between these two capacitance is given by the conductance ratio between Liquid Gate (LG) and Back Gate (BG) regimes.

Assuming a constant mobility  $\mu$  of the transistor for both regimes, we can express:

$$C_{EDL} = \frac{\partial \sigma}{\partial V_{LG}} \bigg/ \frac{\partial \sigma}{\partial V_{BG}} * C_{OX}$$

Measurement of the electric double layer capacitance were made by simultaneous back gating and front liquid gating a GFET device built on a 285nm silicon oxide in order to compare liquid gating influence on transconductance. Due to the thinness of the EDL, around 1nm, the gate capacitance is higher than for back gate through 285nm SiO<sub>2</sub>, and thus requires lower gate voltage to induce the same charge carrier density. As shown in the Figure below, the cellular activity acts as a gate and the EDL acts as a gate dielectric. Graphene being a 2D material, it has only 2 surfaces and no bulk, in consequence, the electron gas of graphene will be directly exposed to the biological medium and allows a very good coupling between sensor and cells, thus providing a better signal to noise ratio than with conventional oxide gated silicon transistor. The EDL acts as a layer of bio-recognition composed of extracellular ions among which those resulting of cellular activity and a layer of ions migrated on top of graphene thanks to the applied potential ( $V_{DS}$ ). This possibility to use graphene to build high sensitivity robust biosensors leads us to another very interesting graphene property: its cytocompatibility.



Transconductance curves obtained by back gate and liquid front gate, with a close view on the liquid gate

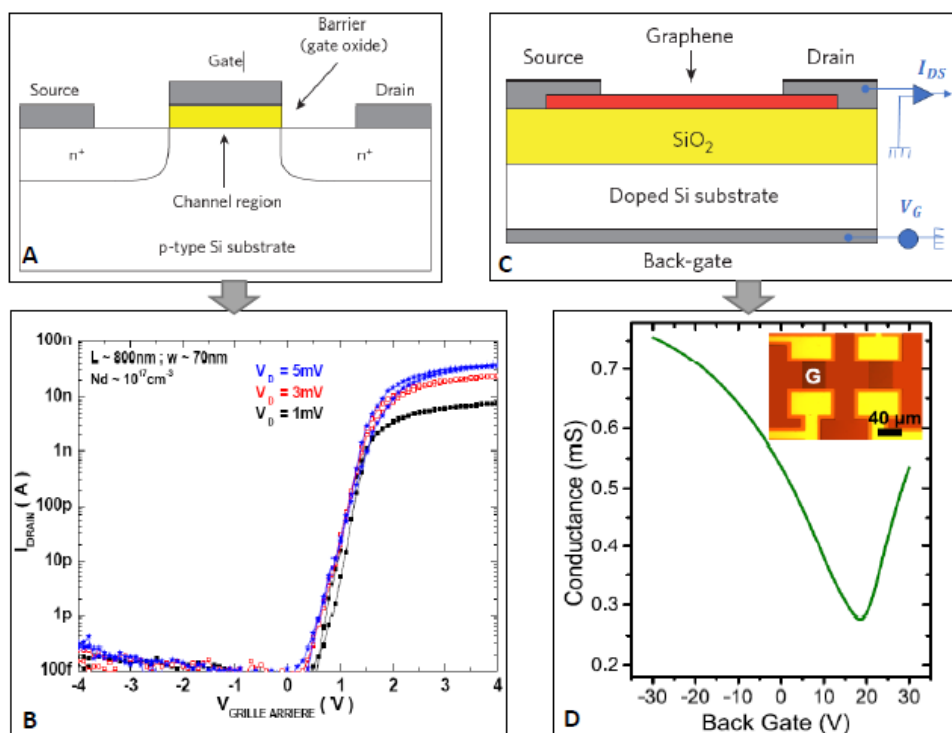
Ref: Antoine Bourrier [4]

### Graphene Cytocompatibility

Graphene has been demonstrated excellently in most of the work to be cytocompatible by favoring neurons adhesion and improving neuronal network development in vitro. Cytocompatibility is defined as the affinity that cells have for a material by their tendency to attach, grow and differentiate when cultivated on its surface. In vitro cytocompatibility studies can predict a tissue behavior when in contact with the tested material or surface. However, because in vitro is processed with neurons cells only (monoculture), the complexity of the tissue with its own immune and nutritive system might cause differences between in vitro cytocompatibility and in vivo bio-acceptance. In vitro cells culture is generally processed on glass slides coated by adsorption of adhesion polymer to favor neurons attachment. Bare graphene (without surface functionalization) has been able to allow neurons adhesion without using adhesive polymer when produced locally. However, conventional poly-L-lysine coating of graphene on glass enhances the adhesion and growth of neurons on the substrate. These two analysis shows that graphene does not exhibit cytotoxicity for primary hippocampal neurons in cultures, thus graphene can be considered as a bio-accepted material. Graphene can be used to offer a “matrix” platform -i.e. a scaffold to promote and guide the growth of neural cells. This can be reproduced with several substrates such as soft, transparent and stretchable PDMS substrate. Indeed, cytocompatibility is improved by lowering surface Young modulus and thus reducing mechanical mismatch between cells and interfacing material. A good mechanical compliance is indeed paramount to reduce adverse reaction of neural interfaces.

### Graphene an Active Material for Transistors

A field Effect device is a circuit in which a current flowing in a conductive channel can be modulated with an electrostatic field. A semiconductor-based Field Effect transistor (FET) is composed of a channel and two electrodes, a drain and a source. The channel conductance will be modulated by the gate. The gate and the channel will be isolated with a barrier, generally an oxide. The standard gating is made in back-gate mode through back oxide. Comparing Si MOSFET with Graphene-FET with cross-sections and conductance curves, the voltage applied between source and gate electrodes exceeds to a threshold voltage where by a conducting channel is formed and a drain current  $I_{DS}$  flows. The length of the channel is the gate electrode length; the thickness of the gate-controlled channel region is the depth to which the electronic properties of the semiconductor are influenced by the gate. The transconductance is extracted from the curve, for several back gate voltages on a  $800 \times 70 \text{ nm}^2$  Si nanowire FET Back gated G-FET with widely exposed graphene 2D channel in red. The GFET transconductance is ambipolar as shown below.



Ref: Antoine Bourrier [3]

The slope of the curve ( ) is the transconductance  $g$  in figure B and C.

The sensitivity of a transistor is given by

$$S = \frac{g}{V_{DS}} = \mu \cdot C_{ox} \cdot \frac{W}{L}$$

Where,

W= width

L= length of the channel.

$\mu$  = carrier mobility of the channel material and

$C_{ox}$  = gate capacitance per unit area.

The 2-D dimension of graphene with no bulk avoid charges screening and thus favorites field effect detection. The electron cloud on its surface provide a very high carrier mobility and high interfacial capacitance to graphene and thus promises great sensitivity. The dimensionality dependence allows a better sensitivity with length reduction of the graphene channel. Graphene is a semi-metal –i.e. a zero gap semi-conductor- in which conductance can be modulated with an electrostatic field. The zero band gap of graphene limits on-off current ratios  $I_{on}/I_{off}$  compared MOSFET. A comparison of these values with standard MOSFET is given in the table below and shows GFET superior mobility, interfacial capacitance and transconductance, but limitations in term of cutoff current and a drawback in the transconductance shape: GFET are ambipolar and thus have a neutrality point.



	$\mu$ (cm <sup>2</sup> /Vs)	Cinterfacial ( $\mu$ F/cm <sup>2</sup> )	g (mS/V)	Ion/Ioff	R square ( $\Omega/\square$ )	Type
MOSFET	450	0.35	0.2	1.00E +08	25	Unipolar
GFET	4000	2	5	<10	500	Ambipoar

Transistors properties show GFET advantages and drawbacks.  
Ref: Antoine Bourrier [4]

In order to measure and trace the transconductance  $g$ , the charge  $Q$  is modulated applying a gate voltage  $V_g$  and gives a capacitive coupling as:

$$Q = V_g \cdot C_{ox}$$

For a SiO<sub>2</sub> back gated transistor with an oxide capacitance  $C_{ox}$ , induced surface's charge carrier concentration per Volt is given by:

$$n_{carrier}/V_g = \frac{\epsilon_{ox} \epsilon_0}{d \cdot e} \sim 7,56 \cdot 10^{10} \text{ cm}^{-2} \cdot \text{V}^{-1}.$$

With  $d$  being the oxide gate thickness,  $e$  being the elementary charge and  $\epsilon_{ox}$  the dielectric constant of SiO<sub>2</sub>.

In order to extract mobility and charge density, one must take into account elastic and inelastic scattering mechanisms. However, a fitting technique is require that will enable approximate efficiently those parameters and allows good evaluation of mobility.

Conductivity  $\sigma_{conduct}$  is depending on charge carrier concentration  $n_{carrier}$  and the residual carrier concentration  $n_0$  as the following quadratic mean:

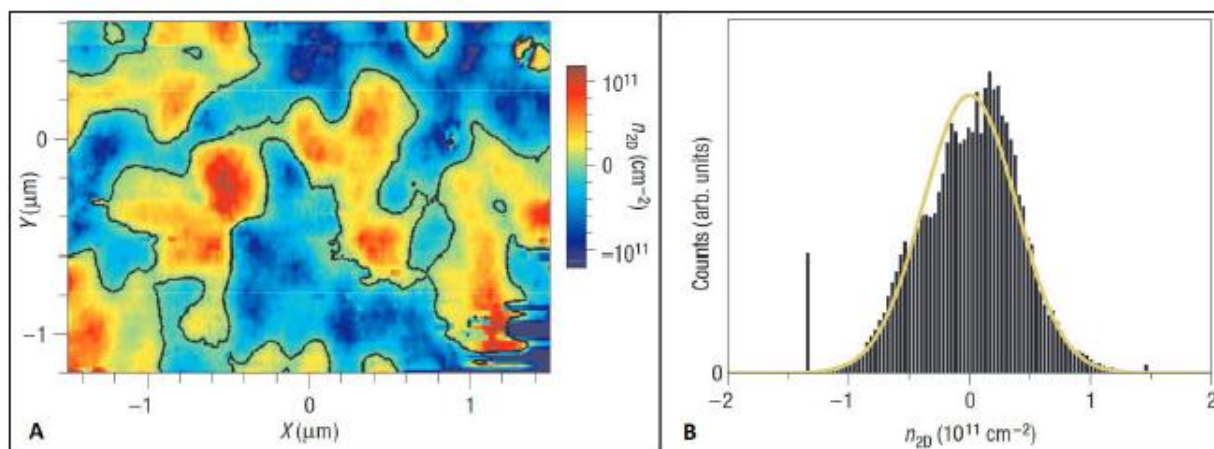
$$\sigma_{conduct} = \frac{1}{R - R_C} = \sigma_{sheetconduct} \cdot \frac{W}{L} = n \cdot e \cdot \mu$$

$$\text{Where } n = \sqrt{n_0^2 + (n_{carrier} \cdot (V_g - V_D))^2}$$

The residual carrier density  $n_0$  and the impurities related carrier density  $n_{imp}$  are related to the minimum conductivity according to the following expression:

$$n_0 = \sigma_0 * \frac{h \cdot n_{imp}}{20e^2}$$

When integrated in a device charged impurities adsorbed below or above the graphene surface generate charges fluctuations that can be seen as a random 2-D potential that locally shift the chemical potential of graphene. The typical amplitude and wavelength of these fluctuations can be assessed using scanning probe electrometers and shown to be of around  $10^{11} \text{ cm}^{-2}$  with electron-hole puddles of about 1 micron diameter.



Spatial density fluctuations of charge in graphene correspond to electron/hole puddles.  
Ref: Antoine Bourrier [4]

Graphene transistor resistance is then expressed as:

$$R = \frac{L}{W} \frac{1}{e \cdot \mu} \sqrt{n_0^2 + (n_{carrier.(V_g - V_D)})^2} + RC$$

With  $RC$  the contact resistance of the graphene transistor ( $RC = 0$  with 4 points measurement)  $V_D$  corresponding to the charge neutrality point or Dirac point of the transistor.  $n_0$  the residual carrier concentration and  $W/L$  the aspect ratio of the transistor channel, with  $W$  its width and  $L$  its length. This enables findings of the corresponding mobility  $\mu$  and residual carrier concentration  $n_0$  that is typically found in CVD graphene devices and  $n_0$  equal to  $5 \cdot 10^{11} \text{ cm}^{-2}$ , a value consistent with electron-hole puddle amplitude for graphene coating influence on charge density and mobility.

### Graphene Mechanical Robustness And Flexible Electronics

The sigma carbon-carbon bond is one of the most stable in nature. It gives graphene exceptional mechanical properties: sufficiently robust to withstand strong capillary force in liquid and not break under its own weight, leading to exciting novel application in liquid. It is exceptional in-plane stiffness (in plane Young modulus of 1 TPa, comparable to diamond) and can undergo elastic deformation to an important extend of around 25%. Graphene can in consequence be used on flexible and soft substrates as a conductive material, opening great perspectives for flexible devices and screens. Plastic bioelectronics is a rising research field as it could provide soft, stretchable and mechanically conformable devices to interact with biological systems using implantable or wearable devices. Many graphene based devices on soft substrate have been reported so far in many works; as well as robust graphene 3D assemblies. The ability to work with soft substrates in a perspective of lowering our future implants stiffness with different flexible materials like PDMS, Parylene and polyimide should be tested and viewed characteristics wise.

### Applications of graphene based on bioelectronics.

The amazing properties of graphene have been explored for versatile applications ranging from electronic devices to electrode materials. It exhibits outstanding electronic properties, permitting electricity to flow rapidly through the materials. In fact, it has been shown that electrons in graphene behave as massless particles similar to photons, zipping across a graphene layer without scattering. This outstanding electronic property is crucial for many device applications and it is expected that graphene could eventually replace silicon (Si) as the substance for computer chips, offering the prospect of ultrafast computers/quantum computers operating at terahertz speeds. Unfortunately, a thorough understanding of the electronic property of graphene has remained elusive. The sensitivity of graphene single atomic layer geometry and its low capacitance exhibit great potential for biosensor applications. Any biological substance that can interact with graphene single atom surface layer can be detected; causing a large change in the electronic properties. One possible biosensor application under consideration is to study the antibody-antigen interaction by functionalizing the graphene surface with antibodies.

The extraordinary mechanical, optical, and electrical properties of graphene have been exploited by many scientists to develop actuators. Park *et al.* designed a bilayer paper composed of adjacent graphene oxide and multi-walled carbon nanotube layers and demonstrated a macroscopic graphene-based actuators. Xie *et al.*, developed a graphene film actuator by asymmetric surface modification of two opposite sides of monolithic graphene film with hexane and oxygen plasma, respectively.

The actuation motion was induced through asymmetric charging and discharging. A bimorph micro-actuator has been developed based on graphene-on-organic hybrid film. The graphene-on-organic film actuator generates a flapping and bending motion that can be controlled by varying the frequency and duration of the applied potential. Recently, Wu *et al.*, developed a remote-controlled transparent, large area grapheme-based robot. This grapheme-based actuator can curl and uncurl in the absence and presence of infrared (IR) radiation. This remote-controlled based robot picks up any object, moves it to a desired location, and drops it by the remote control of IR radiation which is undoubtedly an elegant demonstration of photo thermal energy transformation by graphene, based actuators.

Due to its unique structure and amazing physicochemical properties including high chemical inertness, large specific surface area, high electric conductivity, mechanical flexibility, and biocompatibility, graphene holds great potential for bioelectronics implants. One of the prominent uses of graphene in bioelectronics is recording of electrical signals from body parts, such as the heart or brain which involves brain activity detector for early warning of epileptic seizures, a retinal implant serving as optical prostheses for people who have lost their sight, a brain-computer interface containing graphene electrodes to measure brain activity, and a fully functional robotic hand controlled by a bracelet with graphene sensors.

The high electronic mobility and optical transparency of graphene make the material an excellent candidate for opto-electronic devices, such as solar cells, light emitting diodes (LEDs), touch screens and automated bioelectrical fluorescence for detecting crime, fake money and metal objects in bank and industry, photo-detector, and magnetic sensors. Currently ITO is the most widely used material for such applications.

## CONCLUSION

Increasing demand for Bioelectronics' devices and implants in health care system as well as industries accelerated the development of more efficient bioelectronics devices. Incorporation of nano-materials for developing novel bioelectronics devices provides immense opportunities for advanced diagnostics, drug delivery and biomaterial sensing, position detector, current monitoring and angular sensing. 2-D layered materials like graphene along with other upcoming materials have huge potential for significantly improving the performance of existing bioelectronics devices. The huge potential of nano-materials based flexible and stretchable bioelectronics needs to be thoroughly investigated especially for health bio-system. Nano-materials enabled flexible and stretchable bioelectronics devices may lead to significant expansion and application of these devices in various government and non- governmental systems. In this paper, we have provided some insight on fundamental aspects of graphene and its properties and at the same time discussed their use as transducers for the recording of the electrical activity of living cells. As a result of its outstanding chemical, electrical, and mechanical properties, graphene is an ideal material for the fabrication of bioelectronic devices based on field effect transistors. In particular, the high mobility of carriers in graphene together with the singular double layer formed at the graphene/electrolyte interface results in FET devices which far outperform current technologies in terms of their gate sensitivity. Further, even at this relatively early stage of development, graphene FETs exhibit a noise performance that equals or even surpasses that of already well-established technologies. New advancements in the growth of high quality graphene are expected to further increase the substantial advantages of graphene for bio-sensing applications. The only problem with graphene is that high-quality graphene is a great conductor that does not have a band gap (it can't be switched off). Therefore to use graphene in the creation of future Bioelectronics devices, a band gap will need to be engineered into it, which will, in turn, reduce its electron mobility to that of levels currently seen in strained silicon films. This essentially means that future research and development needs to be carried out in order for graphene to replace silicon in electronic systems in the full.

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