IJREB

ISSN 2321-743X

International Journal of Research in

Engineering and Bioscience

Volume 3 Issue 5 (Pages 01- 10)

Journal home page: www.ijreb.org

MINI REVIEW ON GRAPHENE – SYNTHESIS, PROPERTIES AND APPLICATIONS

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ABSTRACT

There is intense interest in graphene in fields such as physics, chemistry, and materials science, among others. Interest in graphene's exceptional physical properties, chemical tunability, and potential for applications has generated thousands of publications and an accelerating pace of research, making review of such research timely. Here is an overview of the synthesis, properties and applications of grapheme.

KEYWORDS: Graphene, Massless fermion, Ultrafiltration, Photovoltaic cell.

INTRODUCTION

When Neil Armstrong stepped onto the moon, he called it a small step for man and a giant leap for mankind. Nano may represent another giant leap for mankind, but with a step so small that it makes Neil Armstrong look the size of a solar system rather we could do everything with nanotechnology. Nanotechnology is having applications in almost in all the fields. Recently Graphene has emerged with greater properties to join in the nano family to make a new revolution in the society to change the way of human life.nanotechnology researchers are so excited is that graphene and other two dimensional crystals – it's called 2D because it extends in only two dimensions: length and width; as the material is only one atom thick, the third dimension, height, is considered to be zero. Graphene, the "wonder material", is made of a single atom thick carbon atom layer in a honeycomb-like hexagonal lattice and is the thinnest, strongest and hardest material available. The last few years has seen extensive research into the properties and applications of graphene, and the material has been suggested as being a potential replacement for silicon in many electronics applications. Graphene has several useful properties that include high mechanical strength, very high electron mobility, and superior thermal conductivity. The properties and the applications of graphene in various components of electronic devices are discussed in this.

Nanotechnology

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering. The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled *"There's Plenty of Room at the Bottom"* by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (CalTech) on December 29, 1959, long before the term nanotechnology was used.The word Nano comes from the greek word dwarf. The prefix "Nano" means one billionth. One nanometer (abbreviated as 1 nm) is 1/1,000,000,000 of a meter. . The smallest things seeable with the unaided human eye are 10,000 nanometers across. Professor Norio Taniguchi coined the term nanotechnology. It wasn't until 1981, with the development of the scanning tunneling microscope that could "see" individual atoms,that modern nanotechnology began.

Graphene

Carbon is the one of the common and widely available material in the earth. The allotropes of carbon are graphite, CNT, amorphous carbon, and diamond. In that the graphene is also added. In simple terms, graphene, is a thin layer of pure carbon; Figure 1-shows that graphene sheets as a single, tightly packed layer of carbon atoms that are bonded together in a hexagonal honeycomb lattice.In more complex terms, it is an allotrope of carbon in the structure of aplane of sp^2 bonded atoms with a molecule bond length of 0.142 nano-meters. Layers of graphene stacked on top of each other form graphite, with an inter-planar spacing of 0.335 nano-meters. It is the thinnest compound known to man at one atom thick.Having honeycomb lattice of graphene gives rise to new quasi-particles that have lost their mass, or 'rest mass' (so-called *massless Dirac fermions*). That means that graphene never stops conducting.

Preparation

Several production techniques for mass production of graphene encompassing bottomup and top-down methods ranging from the mechanical exfoliation of high quality graphite to the direct growth on carbides or suitable metal substrates and from the chemical routes using graphene oxide have been developed.

1) Mechanical Exfoliation
2) Thermal Decomposition of SiC
3) Chemical Vapor Deposition.
4) Growth on Nickel.
5) Sonication
6) Solvent/surfactant-aided
7) Microwave Assisted Oxidation

8) Growth on Copper.
9) Molecular Beam Deposition
10) Unzipping Carbon Nanotubes.
11) Sodium-Ethanol Pyrolysis
12) Wet Chemical Synthesis
13) Plasma Functionalization.

There are several other ways to produce graphene such as electron beamirradiation of PMMA nanofibres, arc discharge of graphite, thermal fusion of PAHs, and conversion of nanodiamond.

Properties of Graphene

Electronic Properties

One of the most useful properties of graphene is that it is a zero-overlap semimetal (with both holes and electrons as charge carriers) with very high electrical conductivity. Carbon atoms have a total of 6 electrons; 2 in the inner shell and 4 in the outer shell. The 4 outer shell electrons in an individual carbon atom are available for chemical bonding, but in graphene, each atom is connected to 3 other carbon atoms on the two dimensional plane, leaving 1 electron freely available in the third dimension for electronic conduction.

These highly-mobile electrons are called pi (π) electrons and are located above and below the graphene sheet. These pi orbitals overlap and help to enhance the carbon to carbon bonds in graphene. Fundamentally, the electronic properties of graphene are dictated by the bonding and anti-bonding (the valance and conduction bands) of these pi orbitals. Researchershave proved that at the Dirac point in graphene, electrons and holes have zero effective mass which could be seen in figure 2.This occurs because the energy – movement relation (the spectrum for excitations) is linear for low energies near the 6 individual corners of the Brillouin zone. These electrons and holes are known as Dirac fermions, or Graphinos, and the 6 corners of the Brillouin zone are known as the Dirac points. Due to the zero density of states at the Dirac points, electronic conductivity is actually quite low. However, the Fermi level can be changed by doping (with electrons or holes) to create a material that is potentially better at conducting electricity than, for example, copper at room temperature.

Recent tests have shown that the electronic mobility of graphene is very high, with results above 15,000 $cm^2 \cdot V^{-1} \cdot s^{-1}$ and theoretically potential limits of 200,000 $cm^2 \cdot V^{-1} \cdot s^{-1}$ (limited by the scattering of graphene’s acoustic photons). It is said that graphene electrons act very much like photons in their mobility due to their lack of mass. These charge carriers are able to travel sub-micrometer distances without scattering; a phenomenon known as ballistic transport. However, the quality of the graphene and the substrate that is used will be the limiting factors. With silicon dioxide as the substrate, for example, mobility is potentially limited to 40,000 $cm^2 \cdot V^{-1} \cdot s^{-1}$.

Mechanical Strength

Another of graphene’s stand-out properties is its inherent strength. Due to the strength of its 0.142 nm-long carbon bonds, graphene is the strongest material ever discovered, with an ultimate tensile strength of 130,000,000,000 Pascals (or 130 gigapascals), compared to 400,000,000 for A36 structural steel, or 375,700,000 for Aramid .Not only graphene is extraordinarily strong, but also very light at 0.77milligrams per square meter (for comparison purposes, 1 square meter of paper is roughly 1000 times heavier).

It is often said that a single sheet of graphene (being only 1 atom thick), sufficient in size enough to cover a whole football field, would weigh under 1 single gram. Atomic force microscopic (AFM) tests were carried out on graphene sheets that were suspended over silicone dioxide cavities. From the figure 3 ,we could infer that graphene sheets (with thicknesses of between 2 and 8 Nm) had spring constants in the region of 1-5 N/m and a Young's modulus (different to that of three-dimensional graphite) of 0.5 TPa.

Optical Properties

Graphene's ability to absorb a rather large 2.3% of white light is also a unique and interesting property, especially considering that it is only 1 atom thick. This is due to its aforementioned electronic properties; the electrons acting like massless charge carriers with very high mobility. It was proved that the amount of white light absorbed is based on the Fine Structure Constant, rather than being dictated by material specifics.

Adding another layer of graphene increases the amount of white light absorbed by approximately the same value (2.3%). Graphene's opacity of $\pi\alpha \approx 2.3\%$ equates to a universal dynamic conductivity value of $G=e2/4\hbar$ (±2-3%) over the visible frequency range. Due to these impressive characteristics, it has been observed that once optical intensity reaches a certain threshold (known as the saturation fluence) saturable absorption takes place (very high intensity light causes a reduction in absorption). This is an important characteristic with regards to the mode-locking of fiber lasers.Figure 4 shows the Transparency nature of graphene sheet.Due to graphene's properties of wavelength-insensitive ultrafast saturable absorption, full-band mode locking has been achieved using an erbium-doped dissipative solitonfiber laser capable of obtaining wavelength tuning as large as 30 nm.

Applications

Biological Engineering

Bioengineering will certainly be a field in which graphene will become a vital part of in the future; though some obstacles need to be overcome before it can be used. Current estimations suggest that it will not be until 2030 when we will begin to see graphene widely used in biological applications as we still need to understand its biocompatibility (and it must undergo numerous safety, clinical and regulatory trials which, simply put, will take a very long time). However, the properties that it displays suggest that it could revolutionize this area in a number of ways. With graphene offering a large surface area, high electrical conductivity, thinness and strength, it would make a good candidate for the development of fast and efficient bioelectric sensory devices, with the ability to monitor such things as glucose levels, haemoglobin levels, cholesterol and even DNA sequencing. Eventually we may even see engineered 'toxic' graphene that is able to be used as an antibiotic or even anticancer treatment. Also, due to its molecular make-up and potential biocompatibility, it could be utilised in the process of tissue regeneration.

Optical Electronics

One particular area in which we will soon begin to see graphene used on a commercial scale is that in optoelectronics; specifically touchscreens, liquid crystal displays (LCD) and organic light emitting diodes (OLEDs). For a material to be able to be used in optoelectronic applications, it must be able to transmit more than 90% of light and also offer electrical conductive properties exceeding 1 x $10^{6\Omega^{-1}}m^{-1}$ and therefore low electrical resistance. Graphene is an almost completely transparent material and is able to optically transmit up to 97.7% of light. It is also highly conductive, as we have previously mentioned and so it would work very well in optoelectronic applications such as LCD touchscreens for smartphones, tablet and desktop computers and televisions.

Currently the most widely used material is indium tin oxide (ITO), and the development of manufacture of ITO over the last few decades time has resulted in a material that is able to perform very well in this application. However, recent tests have shown that graphene is potentially able to match the properties of ITO, even in current (relatively under-developed) states. Also, it has recently been shown that the optical absorption of graphene can be changed by adjusting the Fermi level. While this does not sound like much of an improvement over ITO, graphene displays additional properties which can enable very clever technology to be developed in optoelectronics by replacing the ITO with graphene. The fact that high quality graphene has a very high tensile strength, and is flexible (with a bending radius of less than the required 5-10mm for rollable e-paper), makes it almost inevitable that it will soon become utilized in these aforementioned applications

Ultrafiltration

Another standout property of graphene is that while it allows water to pass through it, it is almost completely impervious to liquids and gases (even relatively small helium molecules). This means that graphene could be used as an ultrafiltration medium to act as a barrier between two substances. The benefit of using graphene is that it is only 1 single atom thick.

The monolayer graphene filters with pore sizes as small as 5nm (currently, advanced nanoporous membranes have pore sizes of 30-

40nm) which can transform salt water to drinkable water. While these pore sizes are extremely small, as graphene is so thin, pressure during ultrafiltration is reduced. Co-currently, graphene is much stronger and less brittle than aluminium oxide (currently used in sub-100nm filtration applications). Graphene is developed to be used in water filtration systems, desalination systems and efficient and economically more viable biofuel creation.

High Strength and Low Weight

Graphene is strong, stiff and very light. Currently, aerospace engineers are incorporating carbon fiber into the production of aircraft as it is also very strong and light. However, graphene is much stronger whilst being also much lighter.

Ultimately it is expected that graphene is utilized to create a material that can replace steel in the structure of aircraft, improving fuel efficiency, range and reducing weight. Due to its electrical conductivity, it could even be used to coat aircraft surface material to prevent electrical damage resulting from lightning strikes. These characteristics can also help in the development of high strength requirement applications such as body armour for military personnel and vehicles.

Photovoltaic Cells

Offering very low levels of light absorption (at around 2.7% of white light) whilst also offering high electron mobility means that graphene can be used as an alternative to silicon or ITO in the manufacture of photovoltaic cells. Silicon is currently widely used in the production of photovoltaic cells, but while silicon cells are very expensive to produce, graphene based cells are potentially much less so. When materials such as silicon turn light into electricity it produces a photon for every electron produced, meaning that a lot of potential energy is lost as heat. But when graphene absorbs a photon, it actually generates multiple electrons. Also, while silicon is able to generate electricity from certain wavelength bands of light, graphene is able to work on all wavelengths, meaning that graphene has the potential to be as efficient as, if not more efficient than silicon, ITO or (also widely used) gallium arsenide. Being flexible and thin means that graphene based photovoltaic cells could be used in clothing; to help recharge your mobile phone, or even used as retro-fitted photovoltaic window screens or curtains to help power your home.

Energy Storage

One area of research that is being very highly studied is energy storage. While all areas of electronics have been advancing over a very fast rate over the last few decades (in reference to Moore's law), the problem has always been storing the energy in batteries and capacitors when it is not being used. These energy storage solutions have been developing at a much slower rate. The problem is this: a battery can potentially hold a lot of energy, but it can take a long time to charge, a capacitor, on the other hand, can be charged very quickly, but can't hold that much energy.

The solution is to develop energy storage components such as either a supercapacitor or a battery that is able to provide both of these positive characteristics without compromise.Currently, scientists are working on enhancing the capabilities of lithium ion batteries (by incorporating graphene as an anode) to offer much higher storage capacities with much better longevity and charge rate. Also, graphene is being studied and developed to be used in the manufacture of supercapacitors which are able to be charged very quickly, yet also be able to store a large amount of electricity. Graphene based micro-supercapacitors will likely be developed for use in low energy applications such as smart phones and portable computing devices. Graphene-enhanced lithium ion batteries could be used in much higher energy usage applications such as electrically powered vehicles.

Future Applications

Graphene could pave the way for bionic devices in living tissues that could be connected directly to your neurons. Figure 5 - shows the Graphene usage in bionic devices. So people with spinal injuries can lead an ordinary life. High-power graphene supercapacitors would make batteries obsolete .Just a single sheet of graphene could produce headphones that have a frequency response comparable to a pair of Sennheisers. Plug your phone in for five seconds and it would be all charged up. The downside here is that you won't be able to use a dead phone as an excuse anymore.

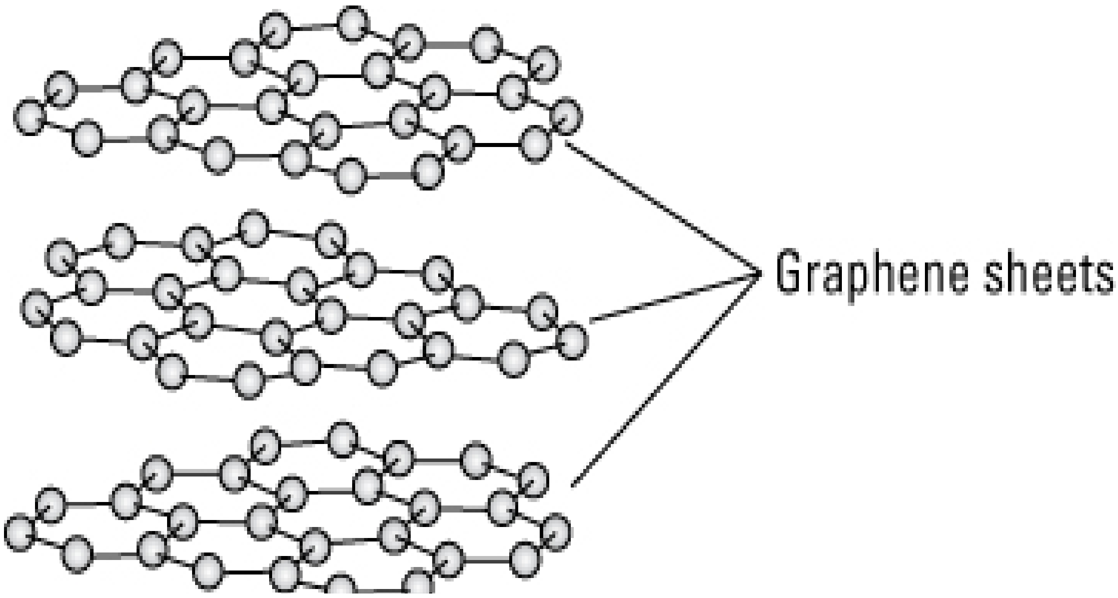

Figure 1. Structure of Graphene layers

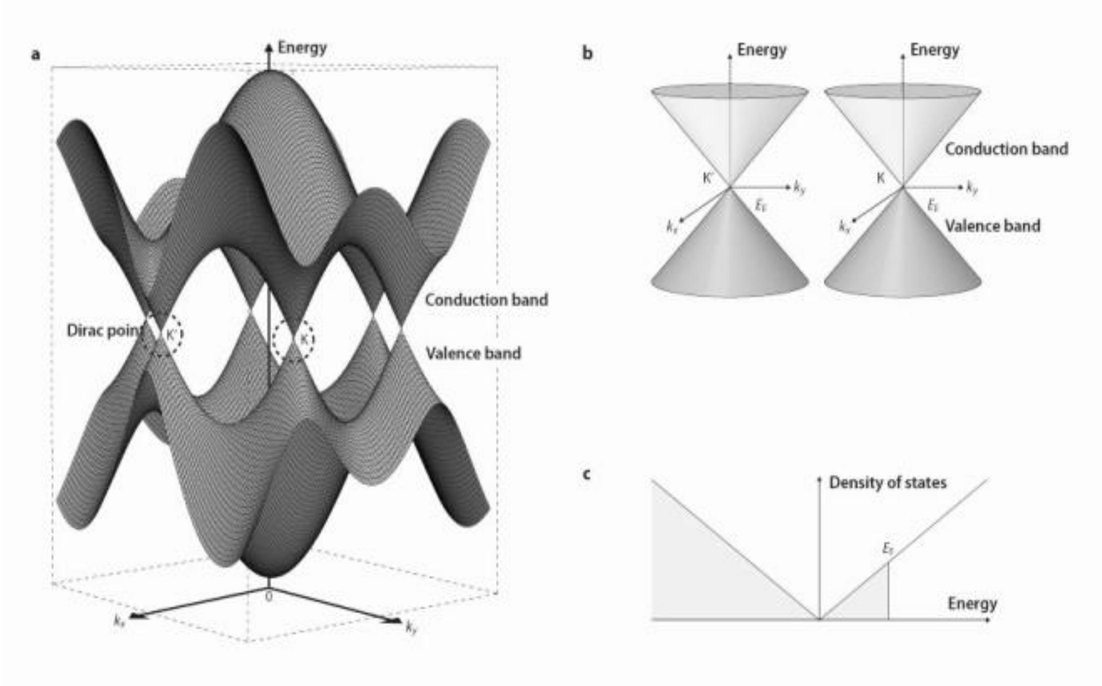

Figure 2. b) graphene π- and π*-band structure over the complete Brillouin zone

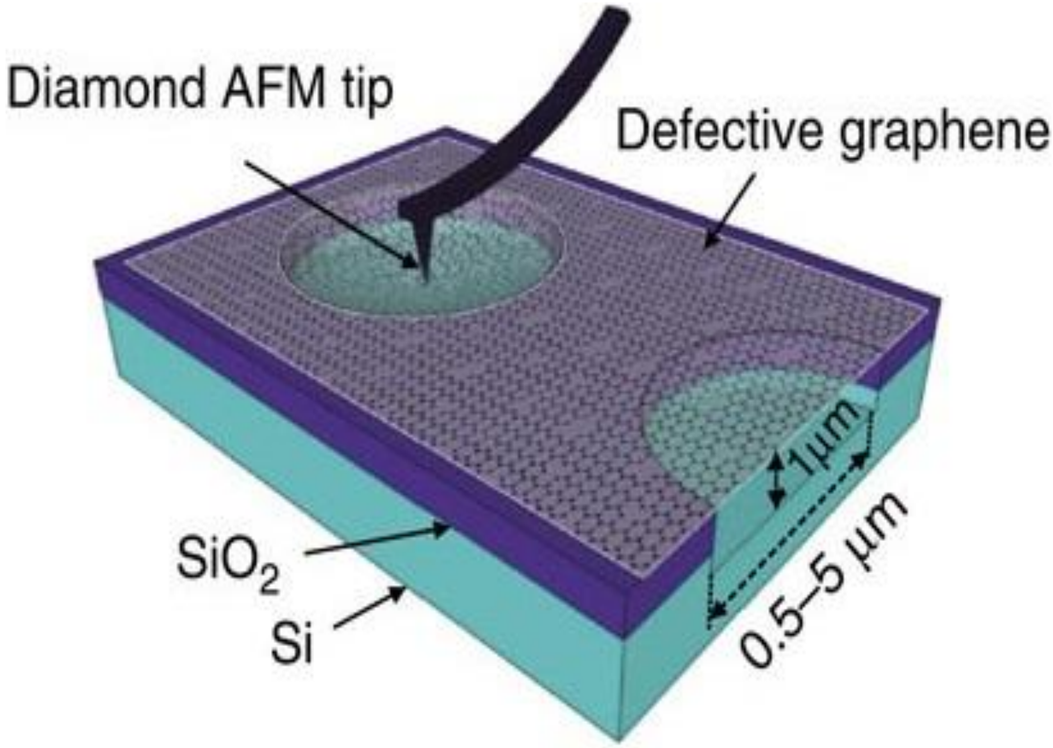

Figure 3. Graphene sheet testing by AFM tip

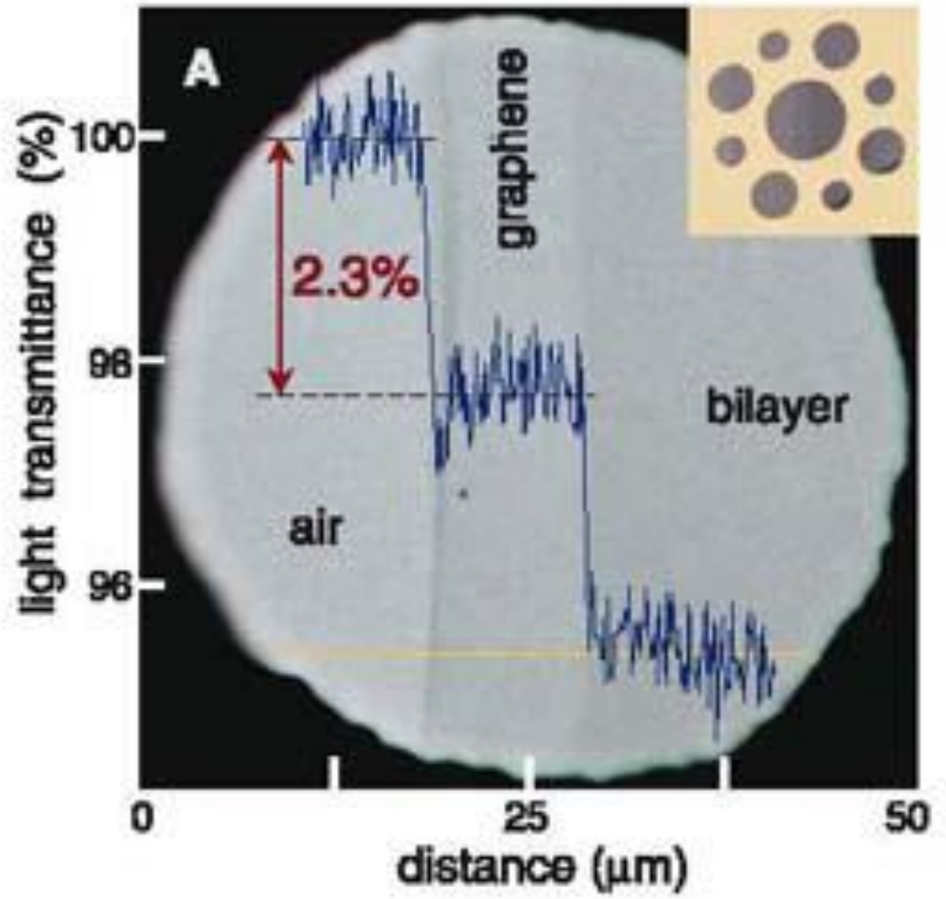

Figure 4. Transparency of Graphene Sheet

Figure 5. Spinal cords, brains, implants, and remote control

CONCLUSION

It has become evident that the exceptional properties of graphene made it compelling for various engineering and bio and electronic applications. However, graphene as a new material still faces many challenges ranging from synthesis and characterization to the final device fabrication. The synthesis of graphene has made substantial progress, especially over the past decade. Graphene has been synthesized by a wide range of chemical synthetic procedures. As a result of the fascinating properties of graphene, with respect to structures that can be oriented and surfaces that can be modified, it offers important advantages for technological applications, especially in the areas of bioelectronics, biosensors, displays, touch screens, bio imaging, ultrafiltration, optoelectronics, photovoltaic cells and medicine.

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