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STUDY OF GRAPHENE AS A SMART MATERIALS THROUGH NANOTECHNOLOGY - A GLOBAL CHALLENGE

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ABSTRACT

Smart materials are defined as materials with properties engineered to change in a controlled and desired way. There are several open challenges that our society has to address in the near future like production of sufficient amounts of clean energy from renewable sources, design new technologies that enable a sustainable economic growth, quality of air and water or waste recycling, improve our standard of life via more accurate diagnostic tools. Most of these challenges deal with the design, synthesis, characterization and industrial production of new smart materials. Nanoscience and nanotechnology today offer an incredible potential for the conceptual design and the practical realization of radically new smart materials that can help solve some of the aforementioned global challenges. Graphene, the well-publicized and now famous two-dimensional carbon allotrope, is as versatile a material as any discovered on Earth. Its amazing properties as the lightest and strongest material, compared with its ability to conduct heat and electricity better than anything else, mean that it can be integrated into a huge number of applications. Initially this will mean that Graphene is used to help improve the performance and efficiency of current materials and substances, but in the future it will also be developed in conjunction with other two-dimensional (2D) crystals to create some even more amazing compounds to suit an even wider range of applications. Existing smart materials like Piezoelectric Materials, Thermoresponsive Materials, Shape Memory Alloys, Polychromic, Chromogenic or Halochromic Materials are already an intrinsic part of modern society.

Keywords- *Biocompatibility, Diagnostic, Graphene, Nanotechnology, Smart, Shape Memory, synthesis, Thermoresponsive.*

I. INTRODUCTION

Smart materials can be obtained by applying a specific external stimulus like a temperature change, an external voltage, a force, a magnetic field, a change in pH, or a change in concentration of chemical species. For instance, piezoelectric materials produce a voltage when stressed and are essential parts of telecommunication devices; shape memory alloys alter their shape under the influence of the ambient temperature and are used in aircraft and automotive industries; electrochromic materials change their colour under the effect of a small voltage and find applications in smart windows. Future research and development needs to be carried out in order for graphene to replace silicone in electrical systems in the future.

The transition from traditional smart materials to smart nanomaterials where the reduced dimensions can provide radically new functionalities is expected to pave the way towards many more applications of practical and social interests. The production of nanosensors that can be used to predict mechanical failure of materials for the fabrication of airplanes, buildings, or bridges; or chemical sensors that can selectively detect the presence of low amounts of a given pollutant or toxic substance in the atmosphere or in the ambient. In the future we may be able to produce nanoparticles that can be incorporated in paints to efficiently capture solar light and convert it into electric energy at a low cost; or nanomaterials that can allow the design of new batteries with high power content and light weight.

Not to mention nanoelectronic devices like nanocomputers that can be incorporated in textiles and clothing and provide new functions like a change in hardness as a consequence of an impact. Probably, the field where smart nanomaterials are going to have the largest impact is in healthcare and medicine. We can think of implants and prostheses made from materials that can modify their surfaces and biofunctionality to increase biocompatibility; or specific functionalized nanoparticles that are able to deliver drugs and antibiotics in specific areas of a living organism; or synthetic "cells" that can produce protein drugs when triggered with light.

A. Applications of Smart Nanomaterials

Smart nanomaterials are expected to make their presence strongly felt in areas like:

- Healthcare, with smart materials that respond to injuries by delivering drugs and antibiotics or by hardening to produce a cast on a broken limb.

- Implants and prostheses made from materials that modify surfaces and biofunctionality to increase biocompatibility

- Energy generation and conservation with highly efficient batteries and energy generating materials.

- Security and Terrorism Defence with smart materials that can detect toxins and either render them neutral, warn people nearby or protect them from it.

- Smart textiles that can change colour, such as camouflage materials that change colour and pattern depending upon the appearance of the surrounding environment. These materials may even project an image of what is behind the person in order to render them invisible.

- Surveillance using “Smartdust” and “Smartdust Motes” that are nanosized machines housing a range of sensors and wireless communication devices. Individually they can float undetected in a room with other dust particles. By combining the information gathered from hundreds, thousands or millions of these tiny specs can give a full report on what is occurring with the area including sound and images.

B. Nanotechnology Enabled Smart Materials

Initial nanotechnology influenced improvements to smart materials will be relatively simple changes to existing technologies. The future however holds possibilities for extremely complex solutions for producing not only smart materials but ones that are highly intelligent.

These new materials may incorporate nanosensors, nanocomputers and nanomachines into their structure. This will enable them to respond directly to their environment rather than make simple changes caused by the environment. As an example materials may be able to shape shift – comfortable, flexible clothing for motorcyclists could go rock hard if it detects an impact, or similar material worn by a police office could detect an approaching projectile and turn itself bullet proof. The current emerging technology of surface treatments for a wall that allows it to change colour might be impressive now, but what if the wall material could change itself to produce a window where and when required.

II. METHODOLOGY

The first time graphene was artificially produced; scientists literally took a piece of graphite and dissected it layer by layer until only 1 single layer remained. This process is known as mechanical exfoliation. This resulting monolayer of graphite (known as graphene) is only 1 atom thick and is therefore the thinnest material possible to be created without becoming unstable when being open to the elements (temperature, air, etc.). Because graphene is only 1 atom thick, it is possible to create other materials by interjecting the graphene layers with other compounds (for example, one layer of graphene, one layer of another compound, followed by another layer of graphene, and so on), effectively using graphene as atomic scaffolding from which other materials are engineered. These newly created compounds could also be superlative materials, just like graphene, but with potentially even more applications.

After the development of graphene and the discovery of its exceptional properties, not surprisingly interest in other two-dimensional crystals increased substantially. These other 2D crystals (such as Boron Nitride, Niobium Diselenide and Tantalum (IV) sulphide), can be used in combination with other 2D crystals for an almost limitless number of applications. So, as an example, if you take the compound Magnesium Diboride ($MgB2$), which is known as being a relatively efficient superconductor, then intersperse its alternating boron and magnesium atomic layers with individual layers of graphene, it improves its efficiency as a superconductor. Or, another example would be in the case of combining the mineral Molybdenite ($MoS2$), which can be used as a semiconductor, with graphene layers (graphene being a fantastic conductor of electricity) when creating NAND flash memory, to develop flash memory to be much smaller and more flexible than current technology.

Graphene as a Biological EngineeringMaterial:

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 revolutionise 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.

Graphene as an Optical Electronics Material

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 106 Ω1m1 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.

In terms of potential real-world electronic applications we can eventually expect to see such devices as graphene based e-paper with the ability to display interactive and updatable information and flexible electronic devices including portable computers and televisions.

Graphene as an Ultrafiltration Material

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 and can also be developed as a barrier that electronically measures strain and pressures between the 2 substances (amongst many other variables). A team of researchers at Columbia University have managed to create monolayer graphene filters with pore sizes as small as 5nm (currently, advanced nanoporous membranes have pore sizes of 30-40nm). 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). What does this mean? Well, it could mean that graphene is developed to be used in water filtration systems, desalination systems and efficient and economically more viable biofuel creation.

Graphene as Composite Materials

Graphene is strong, stiff and very light. Currently, aerospace engineers are incorporating carbon fibre 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 (probably integrated into plastics such as epoxy) 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. In this example, the same graphene coating could also be used to measure strain rate, notifying the pilot of any changes in the stress levels that the aircraft wings are under. These characteristics can also help in the development of high strength requirement applications such as body armour for military personnel and vehicles.

Graphene as 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. Recently published research has proved that 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.

Graphene as Energy Storage Material

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 which states that the number of transistors used in electronic circuitry will double every 2 years), 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 (comparatively speaking). 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 and could potentially be commercially available within the next 5-10 years. Graphene-enhanced lithium ion batteries could be used in much higher energy usage applications such as electrically powered vehicles, or they can be used as lithium ion batteries are now, in smartphones, laptops and tablet PCs but at significantly lower levels of size and weight.

Problem with graphene

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 nano-electronic 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 silicone films. This essentially means that future research and development needs to be carried out in order for graphene to replace silicone in electrical systems in the future. In any case, these two examples are just the tip of the iceberg in only one field of research, whereas graphene is a material that can be utilized in numerous disciplines including, but not limited to: bioengineering, composite materials, energy technology and nanotechnology. The problem that prevented graphene from initially being available for developmental research in commercial uses was that the creation of high quality graphene was a very expensive and complex process (of chemical vapour disposition) that involved the use of toxic chemicals to grow graphene as a monolayer by exposing Platinum, Nickel or Titanium Carbide to ethylene or benzene at high temperatures. Also, it was previously impossible to grow graphene layers on a large scale using crystalline epitaxy on anything other than a metallic substrate. This severely limited its use in electronics as it was difficult, at that time, to separate graphene layers from its metallic substrate without damaging the graphene.

Present Status of Graphene Product:

Consumers can already purchase graphene-enhanced products to use at home. One company already produces and offers on the market conductive ink (first developed by researchers at the University of Cambridge in 2011). This is made by effectively mixing tiny graphene flakes with ink, enabling you to print electrodes directly onto paper. While this was previously possible by using organic semiconductive ink, the use of graphene flakes makes the printed material vastly more conductive and therefore more efficient.

Another use for graphene along similar lines to those mentioned previously is that in paint. Graphene is highly inert and so can act as a corrosion barrier between oxygen and water diffusion. This could mean that future vehicles could be made to be corrosion resistant as graphene can be made to be grown onto any metal surface (given the right conditions). Due to its strength, graphene is also currently being developed as a potential replacement for Kevlar in protective clothing, and will eventually be seen in vehicle manufacture and possibly even used as a building material.

As graphene has been proven to be much more efficient at conducting electrons than silicon, and is also able to transfer electrons at much faster speeds (relatively speaking, 1000 kilometres per second, 30 times faster than silicon), in the next few years you will begin to see products from consumer electronics companies, such as Samsung (who have been pouring money into researching the uses of graphene in telecommunications and electronics and have already taken out a huge number of patents concerned with the uses and manufacture of graphene in electronic devices) based on flexible, robust, touchscreen devices such as mobile smartphones and wrist watches.

This could mean foldable televisions and telephones and eventually electronic flexible newspapers containing all of the publications you are interested in that can be updated via wireless data transfer. Being extremely translucent, in the coming years you can also expect to be able to fit intelligent (and extremely robust) windows to your home, with (potentially) virtual curtains or displaying projected images of your choice.

Combining a few of these aforementioned potential uses, can you imagine car security systems that are connected to the paint on your vehicle? Not only would your car alarm be able to tell you if someone is touching your vehicle, it would be able to record that information and send it to you via your smartphone in real-time. It could also be used to analyse vehicle accidents to determine initial contact patches and resultant consequential energy dispersion.

Soon we will begin to see clothing containing graphene-enhanced photovoltaic cells and supercapacitors, meaning that we will be able to charge our mobile telephones and tablet computers in a matter of minutes (potentially even seconds) whilst walking to school or work. We may possibly even see security-orientated clothing offering protection against unwanted contact with the use of electrical discharge.

What all this means is that this discovery, made by a physics professor and his PhD student in a laboratory in Manchester, using a piece of graphite and some Scotch tape has completely revolutionised the way we look at potential limits of our abilities as scientists, engineers and inventors. The possibilities of what we can achieve with the materials and knowledge we have, have been blown wide open, and it is now conceivable to imagine such amazing prospective situations as lightning fast, yet super-small computers, invisibility cloaks, smart phones that last weeks between charges, and computers that we can fold up and carry in our pockets wherever we go.

In very basic terms graphene could be described as a single, one atom thick layer of the commonly found mineral graphite; graphite is essentially made up of hundreds of thousands of layers of graphene. In actuality, the structural make-up of graphite and graphene, and the method of how to create one from the other, is slightly different.

III. CONCLUSION

The attributes of graphene – transparency, density, electric and thermal conductivity, elasticity, flexibility, hardness resistance and capacity to generate chemical reactions with other substances – harbour the potential to unleash a new technological revolution of more magnificent proportions than that ushered in by electricity in the 19th century and the rise of the internet in the 1990s.

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