PROPERTIES OF GRAPHENE AND ITS APPLICATION ON ELECTRONIC INDUSTRIES – A REVIEW

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ABSTRACT: Graphene popularity is rapidly increasing due to the unique structural, excellent functional properties and also wide range of application in many industries. Graphene is an amazing man-made two-dimension (2D) with single atom thick material ever made in this world. It is the most lightweight material that has been discovered, which consists of a monolayer of sp^2 hybridized carbon atoms in two-dimensional (2D) hexagonal crystal structure. From past research, it was stated that graphene is useful in any industries especially in electronic industry. The aim of this paper is to discuss about graphene mechanical and electrical properties and also its application in electronic industry. In short details, this review also discusses the potential application of graphene in electronic industries.

KEYWORDS: *Graphene; Electronic Industry; 2D Material; Conductivity*

1.0 INTRODUCTION

The exploration of graphene was developed gradually since the late 20th century. The aim was to observe the mechanical and electrical properties from thin graphite or graphene layers [1]. The term graphene was used to replace the term 'graphite layer' that was found unsuitable for single carbon layer structure because of the three dimensional (3D) stacking structure of graphite. Since its discovery in 2004, graphene had been the center of attention in many research areas, either in fundamental studies of material application. This is due to the synergistic and novel properties of the graphene.

Several papers regarding graphene had been published and reached the peak to become a winner in the field of applied science. Thousands of papers about graphene are yielded by many search engines such as Google Scholar, Science Direct and many more. Since 2000, about 23,945 research papers had been published regarding various synthesis methods and large scale graphene fabrication [2]. V. Dhand (2013) stated on his paper that an analysis using Web of Science tool showed the majority of graphene publication came mostly from Asia and followed by Europe, Americas, Australia, and Africa. Based on the records, most of the publication were published in the area of physic, chemistry, material science and engineering.

Because of that, the aim of this review is to discuss about properties of graphene. Furthermore, it will discuss in detail about the potential and available applications of graphene in electronic industry.

2.0 GRAPHENE HISTORY

The history of graphene started with the observation made by Benjamin Brodie in 1859. He managed to obtained a carbonic acid that was believed to be 'graphon' by exposing graphite to strong acid [3]. However, there were some issues regarding the fabrication of graphene particularly the problem of isolating the single layer of graphene from graphite. Many researches had been done in order to find the method of synthesizing graphene. In 2004, graphene was successfully isolated by two researchers, Andre Geim and Kostya Novoselov. This technique was known as "Scotch-tape" method and also known as micromechanical cleavage. It is considered as one of mechanical exfoliation method. The top layer of high-quality graphite crystal is removed from a piece of adhesive tape with its graphitic crystallite and then pressed against the selected substrate. It is a safe and simple process and reduces the presence of impurity as compared to other methods. However, this method's process yield is intensely low and needs to scan large areas macroscopically in order to find a micrometer-sized graphene flake.

The early development of graphene continues with the use of chemical exfoliation. This method treats graphite with mineral acid, which initiates surface oxidation and cleaving process [4-5]. This technique is able to produce extremely thin and even monolayer of graphene but with poor quality.

From the past research demonstrated by Novoselov (2012), graphitic layers can be grown either on the silicon or carbon faces of a SiC wafer by sublimating Si atoms, thus leaving a graphitized surface. This method can produce high quality of graphene. On the contrary, the cost of SiC is very high and the temperature used is also high (approximately above 1,000 ˚C), which are not compatible with silicon electronic [6].

Nowadays, the most practical and popular technique used by a manufacturer to synthesize large scale of graphene is chemical vapor deposition (CVD) [7]. Chemical vapour deposition method uses transition metal (Ni, Cu) as a substrate [8]. For example, when Ni is used as substrate during the synthesis of graphene, the molten carbon is first dissolved into the layer of Ni. Then, carbon is precipitated to the surface of Ni when it is cooled [5]. The major advantage of this technique is its high compatibility with the current complementary metal-oxide semiconductor technology. But, there are disadvantages of this technique such as the control the film thickness and the secondary crystal can be easily formed. An expensive substrate is needed in order to grow the graphene for large scale production. Figures 1 and 2 show the trend of publication of graphene.

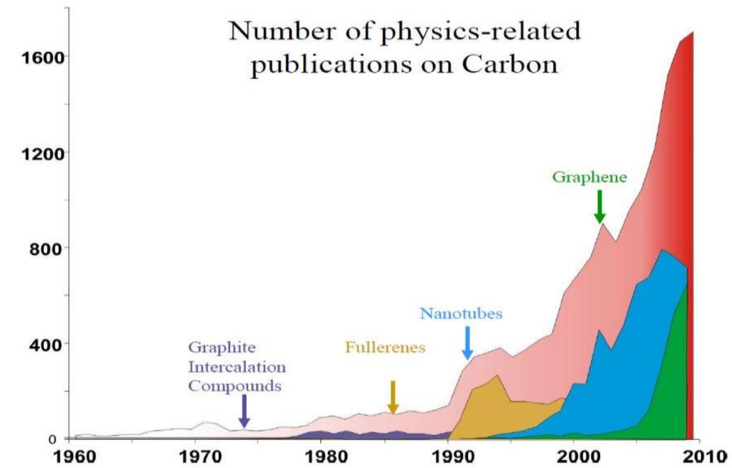

Figure 1: Number of Publication Related to Carbon Material [2]

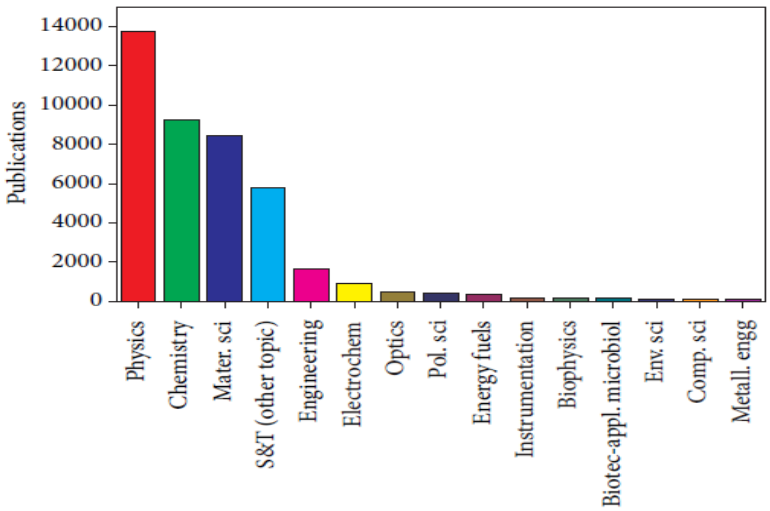

Figure 2: Publication on Graphene since 2000 to 2012 in Various Fields [2]

3.0 GRAPHENE STRUCTURE AND PROPERTIES

Carbon is an organic based material and possesses numerous great characteristics . Due to its bonding flexibility, carbon-based material shows a number of different structures along with different physical properties. Among the carbon-based system, graphene plays a significant role in understanding the two-dimensional (2D) material. Graphene is an amazing man-made two-dimension (2D) carbon-based single atom thick material ever made in this world. This is due to its incredible electrical, mechanical, chemical and also the optical properties. Graphene is the most lightweight material that has been discovered, which consists of a monolayer of sp^2 hybridized carbon atoms in two-dimensional (2D) hexagonal crystal structure [1, 9-10]. Figure 3 shows the structure of monolayer of graphene. Graphene is also the strongest material with Young's Modulus of 1 TPa and tensile strength of 130 GPa. This make graphene 100 times stronger than steel and harder than diamond [9-10]. Furthermore, graphene has high permeability characteristic. Even helium (He) atom is not able to pass through the structure. Miao.M (2013) stated that the hexagonal structure of graphene expands when a hydrogen atom squeezes through it. However, proton penetrates more easily as compared to into graphene. When the ce C-H bond is formed, the chances of the hydrogen atom to tunnel through the graphene is difficult [11].

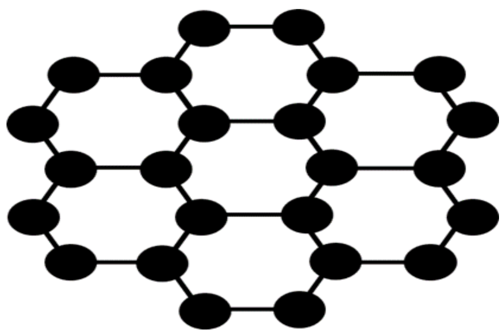

Figure 3: The Monolayer of sp^2 Hybridized Carbon Atoms in Two-Dimensional (2D) Hexagonal Crystal Structure of Graphene [11]

Another remarkable properties of this "miracle material" is the high thermal conductivity of 5,000 W/mK, which corresponds to the upper bound of the highest value for single-wall carbon nanotube bundles and high electrical conductivity up to 6,000 S/cm [12]. Furthermore, what makes graphene unique is because of its transparent and flexible properties [13]. Unlike other strong material, the flexible property means that it can be further stretched before reaching failure mode. It is because, each carbon atom of graphene is connected to three other carbon atoms by a very strong bond and it is repeated throughout the graphene structure. Graphene shows an outstanding electron movement due to the hexagonal structure and the existence of charge carriers behave as massless particles [14]. The carrier mobility reaches the value of 200 000 $cm^2/V.S$ [9]. As compared to carbon nanotube (CNT), graphene is more promising two-dimensional (2D) material due to its excellent electron transport properties, which can be assembled into film electrode with lower roughness [7].

Despite of the incredible properties, graphene is lacking in area such as the bandgap. Bandgap plays an important role for semiconductor transistors to switch between on and off state in order to form the zeroes and ones of digital technology. According to Neil (2012), a theoretical physicist, Philip Russell Wallace predicted the electronic structure of graphene in 1947. However, other researcher assumed that 2D materials were too unstable [15] and there was possiblity that energy band gap of graphene could be changed by uniaxial strain on graphene. The changes of the uniaxial strain able to affect the electronic properties [16].

Most of materials just have a single function and are expected to do a single function, in which either to be strong or to conduct electricity. But, graphene possesses multifunctional characteristic, which can be strong and conduct electricity simultaneously. Two-dimensional (2D) and wrinkle surface of graphene enables it to deflect the cracks more effectively as compared to one-dimension (1D) carbon nanotubes (CNT) or low aspect ratio nanoparticles [9].

4.0 GRAPHENE AND ELECTRONIC INDUSTRY

Based on graphene electronic structure theory, the material has one-atom-thick allotrope of carbon, with unusual two-dimensional of Dirac-like electronic excitation. In addition, these Dirac electrons are controlled by the application of external electric and magnetic field and also by the altering sample geometry and the topology of the graphene itself. Besides, the electron in graphene behaves in unusual ways due to tunneling, confinement and the integer quantum hall of effect. Due to electronic effects, it has a stacking order and number of layers. For the surface, it depends on the edge termination of zigzag or armchair, where both can affect the surface states of physical properties of graphene. Then, the effects of electron-electron and electron-proton interact in single layer and also in multilayer of the materials. Figure 3 illustrates the electronic surface of graphene. Graphene becomes a potential material to almost every sector of industries. It is successfully replacing many existing materials in great number of applications. One of the popular industries involves in the utilization of graphene is electronic industries [16-24].

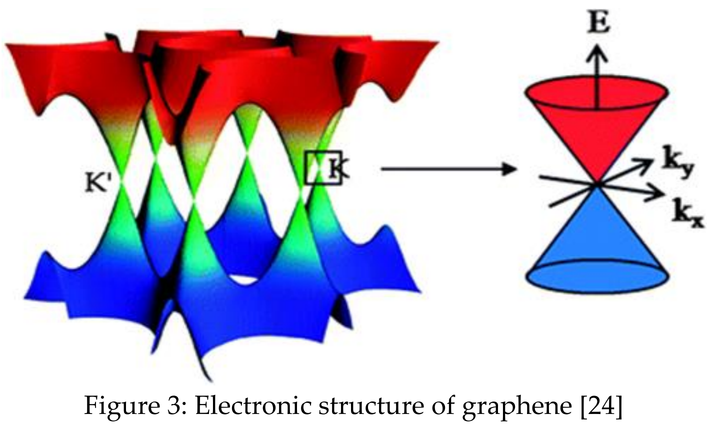

Figure 3: Electronic structure of graphene [24]

Vivekchand et. al (2008) reported that graphene was a good electrode material for supercapacitor application [17]. The specific capacitance of the graphene is better than activated carbon and carbon nanotube (CNT).

According to Prolongo et. al (2014), the stiffness, two-dimensional geometry and low thermal interface resistance had turned graphene to become an excellent filler in the composite material field [18]. Apart from its lower manufacturing cost, graphene in the form of nanoplatelets is known to have a higher surface area. Hence, it enhances the lower filler loading if a good dispersion is reached. Based on Kuilla et. al (2010), graphene was preferred as nanofiller e over other existing nanofiller such as CNT, CNF and EG due to its high aspect ratio, high tensile strength and high electrical conductivity [19]. Nanofiller is proven to act as barriers that can prevent the propagation of heat generated from external environment in polymeric matrices. Thus, it improves the thermal stability of polymers [9, 20].

A study conducted by Wang et. al (2008) implemented graphene as transparent and conductive graphene electrodes for dye-sensitized solar cell [21]. Rather than being a transparent and conductive electrode, graphene is also applied to transparent conductive coating. Transparent conductors are very crucial in many optical devices, from solar cell to liquid-crystal displays and touch screens [10].

Utilization of graphene can be considered as an excellent material for sensor application due to the environmental exposure to each atom. Zhu et. al (2010) demonstrated that monolayer graphene is a promising candidate to detect variety of molecules such as gas and biomolecules [22]. Graphene is sensitive and capable to detect one molecule of gas that intacts with the surface. The prospect of graphene in this application is being expanded with the combination of MoS_2, another 2D material system [23-24].

5.0 FUTURE OF GRAPHENE

Graphene is a promising material that can be applied to any application due to its high conductivity and high value of tensile strength. But, there are still number of issues that must be addressed before it can be used in any electronic application or other application as well. So, this paper discusses in brief the future of graphene.

Due to the excellent properties of graphene, it is chosen as an ideal candidate to be an efficient filler for high quality polymer matrix nanocomposite. Prolongo et. al (2014) reported that at higher loading of nanofiller decreases the dispersion degree of the composite and causes an agglomeration [18]. These agglomerations cause stress concentrations that decrease the mechanical properties of the composites [16]. In the future, more researches need to be done to evaluate the right amount of the nanofiller loading in order to prevent the agglomeration. Thus, it increases the conductivity of the filler.

The availability of graphene is also needs to be improved. At the moment, the fabrication of graphene is limited and can only be fabricated in small scale. By utilizing chemical vapor deposition (CVD), it can be produced in large scale but still have the limitations such as the chemical vapor deposition (CVD) defect that can weaken its mechanical properties [23]. Many researchers stated that the microscopic and macroscopic defects in graphene can degrade its electronic performance and poor fracture characteristics [16-24]. A new method to produce good quality graphene in a large scale is very crucial for a future work and more researches need to be done. The development of experimental methods is also needs to be established.

6.0 CONCLUSIONS

This paper demonstrated the excellent properties of graphene and its application in electronic industry. Based on the review, it was proven that the uniqueness of graphene had gained great attention from many industries especially electronic industry. However, there are still numerous limitations that needed to be overcomed such as the fabrication of graphene in large scale and also the quality of graphene. But, it shows great potential to be applied with further improvement in the material characteristics and production process.

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