FACTA UNIVERSITATIS
Series: **Electronics and Energetics** Vol. 33, N^{o} 3, September 2020, pp. 351-378
https://doi.org/10.2298/FUEE2003351M

GRAPHENE-REINFORCED POLYMERIC NANOCOMPOSITES IN COMPUTER AND ELECTRONICS INDUSTRIES

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Abstract. *Graphene is the newest member of the multidimensional graphite carbon family. Graphene is a two-dimensional atomic crystal formed by the arrangement of carbon atoms in the hexagonal network. It is the most rigid and thinnest material ever discovered and has a wide range of uses regarding its unique characteristics. It is expected that this material will create a revolution in the electronics industry. Graphene is a very powerful superconductor as the movability of charged particles is high on it, and additionally, because of the high surface energy and π electrons being free, graphene can be used in manufacturing many electronics devices. In this paper, the applications of graphene nanoparticles reinforced polymer nanocomposites in the computer and electronics industry are investigated. These nanoparticles have received much attention from researchers and craftsmen, because graphene has unique thermal, electrical and mechanical properties. Its use as a filler in very small quantities substantially enhances the properties of nanocomposites. There are various methods for producing graphene-reinforced polymer nanocomposites. These methods affect the amount of graphene dispersion within the polymer substrate and the final properties of the composite. The application and the properties of graphene-reinforced polymer nanocomposites are discussed along with examples of results published in the papers. To better understand such materials, the applications of these nanocomposites have been investigated in a variety of fields, including batteries, capacitors, sensors, solar cells, etc., and the barriers to the growth and development of these materials application as suggested by the researchers are discussed. As the use of these nanocomposites is developing and many researchers are interested in working on it, the need to study and deal with these substances is increasingly felt.*

Key words: *Graphene, NanoComposite, Electrical Conductance, Electromagnetic Waves, Capacitor, Solar Cells, Light Absorption, OLED*

Received September 26, 2019; received in revised form May 7, 2020
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1. INTRODUCTION

Up to 1980, only three kinds of three-dimensional carbon allotropes were recognized that the most popular of them were diamond, graphite, and amorphous type of carbon. In diamond, as the hardest kind of natural material each carbon atom binds with four other carbon atoms and hybridization of carbon atoms in this structure is as sp^3 form. In graphite carbon atoms have sp^2 hybridization and carbon hexagons create planes that each of these planes are bounded to underlying planes though weak and Van Der Waals bond. These single planes in graphite called Graphene and attracted considerable attention. Special features of Graphene have made it usable for electronic applications. Every study on graphene has led to the development of electronic components with lower volume and higher speeds. Graphene has remarkable mechanical properties which make it a wonderful material for reinforcing metal matrix composites. Due to its unique optical and thermal properties, graphene is a perfect filler for multilayer composites, especially for metal matrix composites. Additionally, it is taken into consideration for its viability and outstanding mechanical properties. Researches on graphene and its nanocomposites is developing at many universities, research and development centers and by many people [1][2]. There are so many motivations for upgrading composites of Graphene metal. Reinforcing mechanism of Graphene is related to its unique mechanical and structural characteristics and good binding of Graphene and matrix. There are so many challenges in this area that one of them is dispersion of Graphene in metal matrix of composite despite usual metallurgical methods and processes which is related to great difference in density of Graphene Nano planes and metal matrix. More contact surface in comparison with carbon Nanotubes , reaction in matrix-reinforce interface because of higher reactive metals and also slight dispersion of Graphene in matrix are among other problems in this area [2][3]. There are widespread researches in making and application of polymer Nano composites aiming improvement of polymer features and increasing their application capability in different areas [4]. Along with this, carbon based Nano particles like carbon Nanotubes [5-9] and Graphene [10-16] have attained special position in making polymer Nano composites. It should be noted that these Nano particles have different features like mechanical reinforcement, electrical conductance and heat stability in comparison with each other [16-18].

Despite wonderful advancements in using carbon Nanotubes as reinforcement phase, case like tendency of Nanotubes to agglomeration during process, limited access to high quality carbon Nanotubes in large amounts and also their high prices have restricted manufacturing polymer Nano composites reinforced with carbon Nanotubes so, Graphene Nano particles because of mechanical and electrical features and also their dominant comprising material i.e. graphite in nature, are considered good alternative for carbon Nanotubes for manufacturing polymer Nano composites [19]. Graphene, or in other words, Chemically Modified Graphene (*CMG*) are suitable alternatives for different applications like energy saving materials, semi-paper material, polymer composites, liquid crystal tools and mechanical oscillators [1].On the other hand, the unique properties of graphene, including its electrical, thermal, electrochemical and high specific surface properties, have increased the usability of this material in many applications such as sensors, catalysts, energy suppliers and composite types [20-26]. Fabbri et al.[27] produced reinforced poly butylene terephthalate Nano composites reinforced with Graphene by insitu polymerization method. They found that by increasing Graphene amount, obtained molecule mass of polymer decreases, but no significant change in heat resistance of Nano composite is occurred. Shen et al. [28] synthesized polycarbonate nanocomposites reinforced with modified graphene through melt blending. According to their results, process conditions significantly affect final properties of the resulting nanocomposite and the degree of polycarbonate grafting on the surface of graphene sheets. Dong *et al.*, [29] prepared graphene-reinforced polyimide fibers by in-situ polymerization. Fibers containing 0.8% graphene showed a tensile strength 1.6 times greater than pure fibers with 200% increase in the Young's modulus. Wang *et al.*, [30] studied the effect of adding graphene to glass fiber-reinforced epoxy resins on mechanical and fire resistance (flammability) properties of the resulting nanocomposite. They found an increase in both mechanical and fire resistance properties of the nanocomposite, if graphene is to the polymeric matrix. Researches performed by Researches by Rafiee et al. [31] [32] and Verdejo *et al.*, [33] on polymer nanocomposites reinforced with modified carbon and graphene nanotubes shows that properties of nanocomposites reinforced by modified graphene is more improved than carbon nanotubes [31] [32] [34]. The researchers correlated the results to the higher contact surface area and the great ratio of the length to the width of graphene plates compared to carbon nanotubes. In the following sections of this paper, the structure of graphene (Section 2), graphene-reinforced metal matrix composites (Section 3), the use of graphene in lithium batteries (Section 4), the effect of graphene on the electricity conductivity (Section 5), increasing the cooling power of electronic components by combining different materials with graphene (Section 6), using graphene in sensors (Section 7), using graphene to protect against electromagnetic waves (Section 8), using graphene in construction of capacitors (Section 9), using graphene in touch pads (Section 10), using graphene in lamps and optical LEDs (Section 11), using graphene in the construction of microphones (Section 12), the use of graphene in the manufacture of OLED displays (Section 13), the use of graphene in the manufacture of ink (Section 14), the use of graphene in reinforcing electrical circuits against moisture (Section 15), the use of graphene in industrial applications of IoT (section 16), the use of graphene in transistors (section 17), the development of nanoelectromechanical switches using graphene (section 18) and the use of graphene in the manufacture of cameras (section 19) are investigated.

2. GRAPHENE

Graphene is Two-Dimensional (2D) sheet with binding carbon atoms in hexagonal configuration like bee hive that atoms have been bound with SP2 hybrid. This monolayer and bee hive structure has been shown in figure 1. Graphene because of containing great mechanical, electrical, temperature, optical, high surface area and ability to control all of these features through chemical factors has attracted attention of scientists [1][2][35]. The thinnest and strongest material known so far, is a two-dimensional sheet of carbon atoms called Graphene [36]. Graphene is a Nano particle with two-dimensional plane structure and its thickness is about one carbon atom. In these planes, carbon atoms have been bound in hexagonal network. The material structure is flawless so Graphene has desirable physical properties like: electrical conductance, heat transmittance, high mechanical strength, 98% transparency and very high specific surface area [37][38][39].

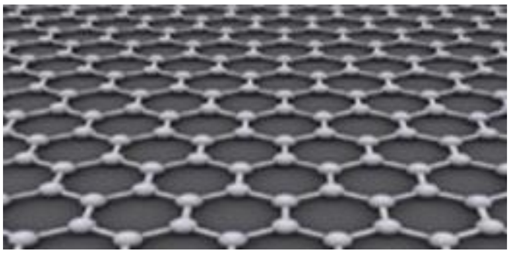

Fig. 1 Graphene monolayer and bee hive structure [2]

According to research [1] Graphene features are: high Young's Modulus (about 1100 Giga Pascal), high resistance against breaking (125 GPa), good heat conductance (5000W/mk), high mobility of load carries or in other words high electrical conductance (200000 Vs/Cm^2), high specific surface area, calculated amount: 2630 (m^2/g) and wonderful transmittance events like Quantum Hall effect. Some of the most important physical and mechanical properties of Graphene have been presented in table 1.

Table 1 some of the most important physical and mechanical properties of Graphene [2]

Property	Graphene
Electron mobility	1500 cm^2 V^{-1} s^{-1}
Resistivity	10^{-6} Ω-cm
Thermal conductivity	5.3*10^3 Wm^{-1}K^{-1}
Transmittance	>95% for 2nm thick film >70% for 10nm thick film
Elastic modulus	0.5-1 Tpa
Coefficient of thermal expansion	-6*10^{-4}/K
Specific Surface area	2630m^{2}g^{-1}
Tensile strength	130 GPa

The less Graphene layers, the higher its properties [40][41]. So methods by which few layered Graphene are produced in high scale are more important. Electrochemical exfoliation is among top-down graphene synthesis methods with a higher production rate and lower costs than other methods [42]. Also with many solvents, so many kinds of graphite can be produced in room temperature [43]. A variety of methods are used for graphene synthesis including micromechanical exfoliation, epitaxial growth, chemical vapor deposition (CVD) and chemical methods [1][2].

3. GRAPHENE REINFORCED METAL MATRIX COMPOSITES

Proper scattering of nanoparticle reinforcers within the polymer field is an essential parameter to achieve enhanced properties compared to Matrix polymer. If the graphene is properly scattered within the polymer phase and there are strong interactions between the graphene and the polymer interface, the overall properties of the polymer matrix will be significantly improved. Much efforts have been invested to achieve a homogenous system with good dispersion of graphene sheets in the polymer matrix through covalent or non-covalent bonds on the graphene surface [33]. There are so many researches on Graphene-reinforced metal matrix composites for example Graphene-platinum composites, Graphene-gold, Graphene-cobalt, silicon-Graphene, Aluminum powder- Graphene, magnesium-Graphene, composite foil copper-Graphene and nickel-Graphene [2]. Some of the Graphene-reinforced metal matrix composites, their properties, applications have been listed in table 2.

Table 2 An illustration of metal-Graphene composites [2].

Composition	Properties and Applications
Pt-Graphene	Super capacitor-fuel cell applications Electrochemically active surface area-Catalyst carrier in electrocatalysis and fuel cells applications
AI/Pd/Pt	Acts as catalytic methanol oxidation-methanol fuel cell applications
Au-graphene	DNA gets adsorbed faster than only Au surface Biosensors, Biodevices and DNA Sequencing applications Voltammograms of electrolytic reduction of oxygen and glucose oxidation shows more Au-Graphene than alone Au-fuel cell and bioelectroanalytical chemistry applications Apparent electrode area environmental monitoring-detection of mercury Electroactive surface area-electrochemical detection of DNA specific sequence applications
Co-Graphene	Anode material for Li-ion battery applications
Si- Graphene	Anode material for Li-ion battery applications
AI powder-graphene	Graphene as reinforce-Strenghening of Composite applications Decreased strength and hardness Lower failure strain and higher Vickers hardness
Mg-graphene based composite	Production of Ultra high performance metal matrix composite
Cu-graphene composite foil	Higher the electrical conductivity and hardness compare to copper alone
Mg-1%A-1%Sn reinforced graphene	Superior Nano-filler adhesion and increased and tensile strength
Au-graphene-HRP-CS	H_2O_2 Biosensor applications

4. USE OF GRAPHENE IN LITHIUM BATTERIES

Lithium ion batteries nowadays have been used extraordinarily. At the moment all new laptops use lithium ion batteries. The reason for the popularity of these batteries is their high capability in rendering more power than other batteries. Ion lithium battery electrodes have comprised lightweight materials such as lithium and carbon. Lithium is also very reactive metal. It means that this metal can save so much energy in its atomic structure. Because of this, ion lithium batteries have high energy saving density. Ion lithium batteries are at present standard batteries for computers and laptops. They're light with high life cycle. These batteries aren't restricted by memory effect; it means that it doesn't need to completely discharge them before recharging and they can be charged in any time in random order. Finally these batteries don't become hot in cases of extra charge and their explosion possibility is so low. They are also thinner and smaller than any other batteries used in laptops. This issue makes them ideal for using in very lightweight and small laptops produced nowadays. When these batteries are charged, lithium ions from inside electrolyte material and positive pole move to negative pole and bind with carbon.Normally, lithium-ion batteries can be charged between 950 and 1200 times. There have been so many researches about adding Graphene as second phase to lithium for lithium batteries anode used in laptop batteries. Silicon because of high nominal capacity and low discharge potential is a suitable material for lithium batteries. But its mass change in charge and consequential discharge lowers its capacity. By adding graphene to silicon because of high conductance capability, chemical stability, and also good mechanical properties, these problems can be removed. So adding graphene to silicon improves its stability as a material for lithium batteries anode [3]. Chou et al, considered 15% higher output for Graphene-silicon composites. Although original charge capacity (2185 mAh/g) is less than silicon (3026 mAh/g); but this composite preserved 54% of original capacity after 30 cycles; while silicon only preserved 11%. Graphene-silicon composites have higher capacity related to silicon or Graphene in more cycles numbers [3].

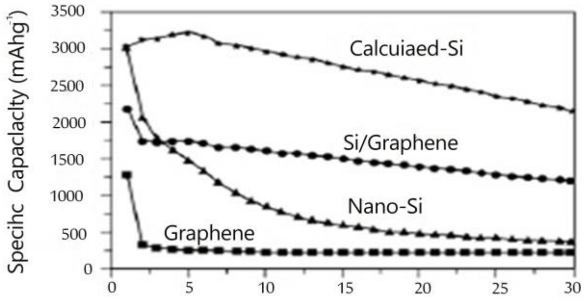

Fig. 2 Graphene stability cycle, silicon in Nano dimensions, silicon- Graphene composite electrodes and share of calculated net silicon [3].

Li *et al.*, [44] prepared silicon-graphene foams using silicon film deposition on graphene foam. They used highly flexible nanocomposites as an anode for the manufacture of lithium batteries. Both experimentally and theoretically (using Density Function Theorem (DFT)), Kumar *et al.*, [45] found that the use of organic species such as porphyrins as columns between graphene oxide sheets was a promising method for development of highly flexible stable anode electrodes in sodium-ion batteries. The cell constructed by Kumar et al. showed a capacity of 200 mA h⁄g with a current density of 100 mA h⁄g. The electrode showed an insignificant capacity reduction even after 700 charging/discharging cycles. The specific capacitance of the cell remained stable after leaving it for 1 month. Both experiments and DFT calculations revealed that the higher efficiency (stability and capacity) of the anode prepared from porphyrin graphene oxide framework could be related to an increase in the space between graphene layers.

5. ELECTRICITY CURRENT CONDUCTANCE

Any material which conducts electricity properly is called a conductor.Scientists believe that the main reason for conductance of some materials is that their electrons can easily release from atom and move. Electrical conductance has an important role in computer industry and data transfer in electronic and computer systems. Adding nano material to conductors increases their conductance. According to the literature, carbon nanotubes show an electrical percolation threshold at low concentrations. Also, graphene or modified graphene in same amounts or less than carbon nanotubes are capable of forming conductive network [34]. In Graphene-resin epoxy nano composite, electrical conductance has been increased considerably (12 times) [46]. In specified amount of nano particle called as percolation threshold, nano particle is capable to form network structure. This causes sudden increase in nano composite electrical conductance [47]. Inherent conductance and length to width ratio of filler nano particles based on carbon make them a suitable alternative for obtaining this percolation threshold in less amounts of filler phase. The research results as indicated that flawless graphene planes indicate signs of ballistic transport [48]. Although electrical conductance of graphene using modified chemical methods is not as well as flawless graphene, but it is still suitable alternative for producing electrical conductance nano composites. The first and the most common used method for chemical reduction and layering graphene oxide is using dispersion in colloid form inside hydrazine hydrate [49][50]. Chemically modified graphene as product of this method contains carbonyl, epoxy, and carboxylic acid groups. Conductance of a sample powder was measured about 200±2400 S/m that is comparable with 20±2500 S/m for graphene oxide [49]. Graphene oxide is reduced and thermally exfoliated through continuous heating at high temperatures [50]. The resulting chemically-modified graphene contains carbonyl, epoxy and carboxylic acid functional groups with structural defects and surface shrinkage. Despite these surface defects, a bulk conductivity of 1000 to 2300 S/m has been measured for modified graphene. Kuang *et al.*, [51] used electrodeposition technique for preparation of nickel nanocomposite films. According to hardness and Young's modulus measured for nickel-graphene composites, mechanical properties of the composite were significantly improved in comparison with neat electrodeposited nickel samples. While nickel-graphene composite showed a hardness and Young's modulus of 6.85 and 252.76 GPa respectively, the corresponding values measured for pure nickel were only 1.81 and 166.70 GPa, respectively. The electrical conductivity of the nickel-graphene composite rose also by 15% compared with pure nickel, as shown in Figure 3.

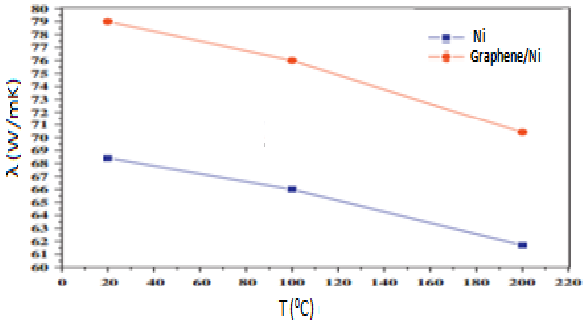

Fig. 3 Comparison of electrical conductance of pure nickel and graphene-nickle composite [51].

Tchernook *et al*., [52] produced nanocomposite from nanocrystal of heavy poly ethylene and graphene as ethylene insertion polymerization in water. Graphene dispersion in monocrystal water solution poly ethylene led to increasing the electrical conductance. High electrical conductance and low percolation threshold may be related to composite microstructure. Small size particles of polyethylene nanocrystals form homogenous mix of graphene in polymer matrix. Kim *et al.,* [53] produced nanocomposites from LLDPE and graphene by solution method. In this research, graphene nanoparticles were covered by paraffin. Results indicated that adding paraffin decreases electrical conductance percolation threshold. Electrical conductivity of the above-mentioned composites revealed the lower conductivity of the samples prepared by solution blending than nanocomposites synthesized using other methods. In a similar research, Jiang *et al.,* [54] produced HDPE graphene nanocomposites (HDPE/Graphene) and HDPE multi wall carbon nanocomposite tubes (HDPE/MWCNT). Both nanoparticles were covered by paraffin. The results indicated that manufactured nanocomposites by multi wall carbon nano tubes in less amounts in relation to graphene reach percolation threshold. In another research, Mohamadzadeh *et al.,* [55] have synthesized polyaniline-graphene oxide with polymerization method in monomer aniline adjacent to graphene oxide planes as mild oxidant agent. In this method any external oxidant agent hasn’t been used and obtained composites has high electrical conductance and crystal traits.

6. INCREASING THE COOLING POWER OF ELECTRONIC COMPONENTS BY COMBINING DIFFERENT MATERIALS WITH GRAPHENE

Cooling electronic parts is one of the ever present problems of users and because of that they have always attempted to cool their system in order to preserve its output and efficiency in long term. Despite that it has attempted to use lower voltage and frequency in producing computer parts, especially CPU, Hard Disk and Graphic Cards produce so much heat during their working. The heat generated in the electronic components must be balanced for the components to be able to operate in safe heat so that the system does not have any problems with data loss and crash. New portable computer and telecommunication systems (laptop) use small heat pipes for removing heat, as nowadays computer advancement is such that while showing higher capabilities more heat is produced. Heat pipes are widely used in cooling computers. These pipes are empty inside containing heat transfer fluid. When the fluid is vaporized in warm part of the pipes, transfers heat to cool part of the pipes and there the fluid is condensed and returns to the warm part of the pipe. Increasing heat conductance of material by manufacturing polymer-graphene nanocomposites has been boomed incredibly. Most studies have focused on the effect of modified graphene on thermal properties of polymeric nanocomposites such as thermal stability, glass transition temperature (Tg), melting point (Tm) and crystallinity [33].

Fang *et al.,* reported increasing heat conductance of polystyrene film filled with 2% graphene weight bound with polystyrene from 0.158 W/m.K to 0.413 W/m.K [56]. Noorunnisa Khanam *et al.,* [57] prepared LLDPE/graphene nanocomposites by melt blending and studied the effect of nanoparticle concentration and extruder rotor speed on thermal stability of the resulting nanocomposites. In this study motor rounds of 50, 100 and 150 rpm were used respectively for polymer blending and nanoparticles. The results indicated that in prepared nanocomposites with motor round of 150 rpm, degradation temperature increases because of better dispersion of nanoparticles in polymer beds. Also graphene nanoparticles act as heat block and improve the heat resistance. Kuila *et al.,* [58] prepared LLDPE nanocomposites and modified graphene with dodecylamine (DA-G) with solution method and examined their heat properties. The results of Thermal Gravimetry Analysis (TGA) indicated that graphene increases polymer heat stability. Kim *et al.,* [59] prepared graphene and LLDPE nanocomposite and effect of graphene nanoparticles on crystal features. The results indicated that by increasing graphene nanoparticles, the crystallization temperature does not change but crystallization rate decreases. In other words, physical presence of graphene nanoplanes blocks movement of polymerized chains and crystallization rate decreases. Park *et al.,* [60] prepared fluids with high heat conductance using combined graphene planes with pure fluid like water. These researchers reported that fluids containing oxidized graphene have better heat properties in comparison with fluids containing graphene. Choi *et al.,* [61] used poly methyl methacrylate nanocomposites and prepared graphene with very low graphene rate for removing produced heat in electronic equipment. They observed heat conductance of these nanocomposites is 3 times of pure samples. These nanocomposites have higher transparency in addition to being light weighted.

Boron Nitride (BN) was combined with graphene to construct a tool capable of effective heat removal and cooling of electronic devices [62]. To this end, graphene is deposited on boron nitride. A graphene-based transistor was developed on a boron nitride substrate. This system is able to cool electronic devices 10 times more effective than conventional methods. The mechanism used in this tool takes advantage of the 2D nature of graphene and boron nitride to create a thermal bridge with the substrate. To this purpose, they used boron nitride crystal with a thickness of several ten nanometers. This layer is mounted on the gold surface. Then, the layer containing graphene-based transistor is mounted on the gold surface. The heat flow in the boron nitride crystal was measured by Raman spectroscopy. The cooling mechanism in this tool was explained by dielectric anisotropy of the boron nitride layer. Due to the anisotropic property, the insulator enters a photothermal mode called Hyperbolic Polariton (HP) in which heat flows in the matter in places considered forbidden zones in other insulators. Thus, this system removes heat more effectively than other methods. This mode opens a real thermal bridge between graphene and back electrode leading to heat removal with 10 times higher efficiency. The efficiency of the transistor increases by 10 times when entering the Zener-Klein zone. This tool makes use of hyperbolic polariton mode to transfer heat to the substrate without any damage to the graphene network.

7. GRAPHENE CONTAINING SENSORS

Moisture is called water vapor in the air. Water vapor is totally transparent and we can’t see it by naked eye, but high moisture causes may problems especially short connection in electronic machines and damages computer parts. Moisture resides as water drops on objects. The air can keep so much water vapor. When the air becomes warmer, the air moisture increases. Sensors can be made of materials with a large range of electrical conductivity from polymeric composites with conductivities close to percolation threshold to polymeric nanocomposites which are used for the manufacture of gas, PH, pressure or temperature sensors [44][63][64][65].

Wang et al [66] prepared sensors stimulant to PH fluctuations and heat using graphene oxide and poly methyl methacrylate derivatives. They observed that sensitivity level of these sensors is related to combined graphene oxide. Qin *et al.*, [67] prepared membranes for separating gases using graphene. They found that these membranes have high capability in separating hydrogen and methane gases and we can use them for removing efficient environmental problems. Li *et al.*, [68] prepared new version of sensors sensitive to moisture using combination of graphene with polypyrrole in different amounts of graphene. Their study results indicated that sensors with 10% graphene weight are more sensitive in relation to other sensors with response time 15 to 20s and this sensor can be used in protecting electronic parts against moisture. One of the materials in industrial and chemical areas that damages electronic and computer parts is presence of ammonia. In research [69] prepared a sensor for detecting ammonia using reduced graphene oxide with chemical method. They observed that these kinds of membranes have more sensitivity in detecting ammonia with very low densities that can be used in industrial centers with electronic server and equipment for protecting this equipment.

8. PROTECTION AGAINST ELECTROMAGNETIC INTERFERENCE (EMI)

Electro Magnetic Interference (EMI) means disruption or decrease in efficient performance of equipment and tools because of electromagnetic flames from an unsolicited source in the frequency range the same as working frequency. The purpose of protection against electromagnetic waves is to attain a certain attenuation level of these waves. This is performed through reflection and absorption of these waves by protective material. Generally, material performance in electromagnetic fields is determined by moving electrons freely and their atomic movement in the magnetic field. The main mechanism of electromagnetic protection includes producing magnetic field opposed with striking magnetic field and as a result energy loss in protective area and weakening entering waves (Figure 4) [70]. In using nanoscale materials, this protection because of high conductance of nanocomposites is more effective than other protective materials.

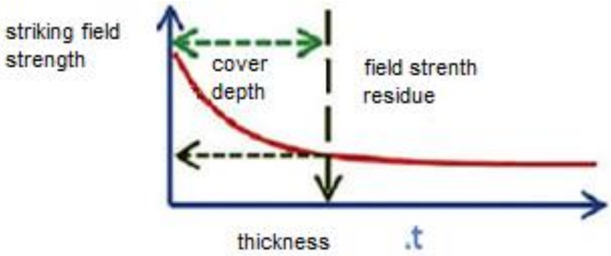

Fig. 4 Electromagnetic protection mechanism (EMI). Waves crossing protection cover lose considerably their strength when existing [70].

Mainly effectiveness of electromagnetic protection of a composite material depends on inherent conductance of protective material and its electrical permittivity coefficient. Among this, application of nanomaterial like carbon nano fibers and graphite layers because of unique thermal, electrical, mechanical and physical features for using in composites has attracted so much attention. Small diameter, high dimensional ratio, high conductance, high mechanical stability of carbon nanotubes has made these materials a great alternative for applying in electromagnetic interference protection with low weight percent and high performance. Graphene is a good alternative for EMI shielding because of unique features. Graphene even in lower weight percent is also effective in improving composite shielding features. According to figure 5 it can be observed that EMI shielding effectiveness increasing by higher nano material and it has acceptable trend for all frequency ranges. Shielding effectiveness level for 15 weight percent of graphene (8.8 mass) is obtained 21 decibel [71]. Song *et al.*, [72] prepared composite films containing ethylene vinyl acetate and graphene and studied their capability for application in electromagnetic interference shielding.

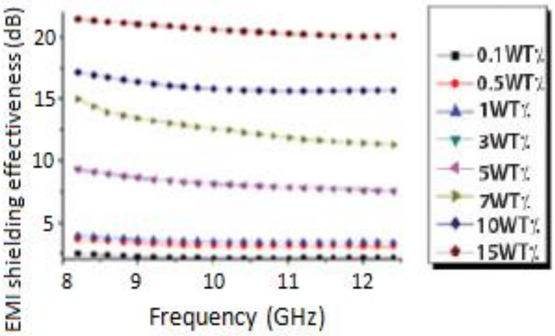

Fig. 5 Process of EMI shielding effectiveness for different weight percentages of graphene in graphene-epoxy nano composite [71].

9. GRAPHENE-BASED SUPERCAPACITORS

Supercapacitors with a higher power density and cyclic life than batteries are used to store electrical charge [73][74]. However, the widespread use of supercapacitors has been limited due to their energy density [75]. Accordingly, most studies in this area have focused on methods for increasing specific capacity of supercapacitors [78]. Graphene and its derivatives are extensively used for the manufacture of supercapacitor electrodes due to their lower costs than other materials such as metal oxides [76]. In addition, graphene-based electrodes provide a lower energy density than metal oxides [77]. The total capacitance of a supercapacitor can be increased through changes in electrode structure [75] [78][77][79].

According to Hwang (2012), quantum capacity is the factor limiting the total capacitance of graphene-based capacitors [79]. These calculations were repeated by Wood *et al.*, (2014) and same results were reported. The effect of graphene functionalization on quantum capacity was studied in 2015 [80]. According to the results, the use of functionalized graphene as the base material for the supercapacitor electrode will provide very favorable results. According to [81], modification of graphene sheets with *N*, *P*, *S* and *Si* atoms may affect quantum capacity. Studies have also shown interesting effects of graphene sheet functionalization [80]. The results of an experimental study confirmed the significant impact of functionalization of graphene sheets on energy density [82]. The structural defects also improve quantum capacity [77].

Graphite oxide all over its three dimensional structure has nano metric porosity and curvature walls with one atom thickness. This material is exceptionally a great electrode material for super capacitors that enables to use these energy saving wares in wide range of applications especially manufacturing electronic devices used in computer and telecommunication industry. We can convert Graphite oxide to individual and mono layer plates using methods like thermal or chemical operations. Graphite is exfoliated to produce graphene oxide monolayers due to polar oxygen functional groups on graphene sheets, which improve the distribution of graphene oxide sheets in polar solvents such as water and many other organic solvents. The graphene sheet can be subsequently reduced by reducing agents such as hydrazine hydrate, dimethyl hydrazine, sodium borohydride and ascorbic acid. This causes that graphene oxide plates recover their sp^2 carbon network. However, graphene oxide layers are not completely reduced leading to the formation of carboxylic acid and hydroxyl functional groups on the edges of graphene oxide sheets [83],[50]. At the moment activated carbon in most of available commercial super capacitors or two layered electrochemical capacitors used as electrodes because of high area and electrical conductance [84]. Carbon nanocomposite fillers can be added to polymers to improve the performance of electrodes. The results of a study indicated a specific capacity of 120 F/g for graphene-propylene carbonate by using tetraethyl ammonium tetrafluroborate as the electrolyte. According to the results of another study, the electrode made of polyaniline nanocomposite filled with graphene oxide reduced by microwaves in sulfuric acid showed a capacity of 408 F/g [85][86]. Yuan *et al.,* [87] invented a method for preparing three dimensional and porous structures from graphene oxide with high efficiency in making capacitors. These researchers used graphene oxide for preparing capacitor, and then by using chemical reduction methods, prepared porous structures of graphene.

Tu F. *et al.,* [88] invented a simple method for making three dimensional structures of reduction graphene oxide in ethylene glycol having capability of use in lithium capacitors. These researchers stated that such capacitors don’t lose their capability after 3000 cycles. Despite the reasonable double-layer electrochemical capacity of graphene (526 $F.g^{-1}$), experimental results are fewer than theoretical ones leading to the agglomeration of graphene sheets and reduced surface area and permeability of electrolyte ions into electrodes [89]. To solve this problem, a three-dimensional graphene network (3DGNs), with an intertwined structure, has been used as an ideal supercapacitor material. Intertwined 3DGNs with a very large surface area, high specific capacity, excellent mechanical properties and high electrical conductivity provide a unique supercapacitor material with a high charging-discharging capability and lifetime [90]. Table 3, lists specifications of some supercapacitor materials made of 3D graphene composite and transition metal oxides/hydroxides.

Table 3 Supercapacitor materials made of 3D graphene (3DGNs) and intermediate metal oxides/hydroxides

Ref	Synthesis method	Electrolyte	Power density (kW.kg^{-1})	Energy density (Wh.kg^{-1})	Number of cycles tolerated	Specific capacity (Cs) (F.g^{-1})	Composite
[91]	Chemical self-assembly	2M KOH	8.3	30	1000(~90%)	310	SnO_2/GA
[92]	Ultrasound waves and hydrothermal	0.5 M K_2SO_4	---	21.3	5000(95%)	426	V_2O_5 nanobelt/GH
[93]	CVD, electrochemical deposition	0.5 M Na_2SO_4	2.5	6.8	5000(82%)	130	MnO_2/GF
[94]	Dip coating	1 M Na_2SO_4	47	8.34	10000(90%)	450	Sponge-rGO/MnO_2
[95]	Sol-gel, electrochemical deposition	0.5 M Na_2SO_4	----	----	50000(95%)	410	MnO_2/GA
[96]	Self-assembly	1 M Na_2SO_4	---	21.2	1000(89.6%)	242	MnO_2/GH
[97]	electrochemical deposition	0.5 M Na_2SO_4	---	---	10000(98.5%)	234	MnO_2/GH/NF
[98]	CVD	2 M Li_2SO_4	128.01	39.28	8100(106%)	503	RuO_2/CNT/GF
[99]	Hydrothermal	6M KOH	142.9	9.3	500(94.5%)	757	Co_3O_4/GH
[100]	Chemical bath deposition	1M KOH	18	13.9	1000(74%)	1139	$Co(OH)_2$/GF
[101]	Hydrothermal	6M KOH	9	31.1	2000(95%)	1247	$Ni(OH)_2$/GH
[102]	Hydrothermal	6M KOH	44	6.9	10000(63.2%)	1560	$Ni(OH)_2$/GF
[103]	APCVD Hydrothermal	6M KOH	---	--	1000(78%)	1450	$Ni(OH)_2$/GF
[104]	CVD electrochemical deposition	3M KOH	---	--	2000(100%)	816	NiO/GF
[105]	GO solution hydrothermal Ultrasound waves	1M KOH	--	---	200(75%)	908	anode Fe_2O_3/GH
[106]	Thermal decomposition and ultrasound waves		14.43-52	15.32-66	1000(94%)	508	3D FMG
[107]	Gas foaming	1 MNa_2SO_4	0.5	32.1	8000(>99%)	231.2	3DG Layers
[108]	Solvothermal CVD				3000(~96.5%)	970	$NiCo_2O_4$ nanoneedles/3DGN
[109]	Hydrothermal	6M KOH	---	---	1000(94.5%)	727	NiO/GM
[110]	Ice-templating	6M KOH	---	----	5000(100%)	214	N-rGo

10. IMPROVING LIGHT ABSORPTION USING GRAPHENE

Graphene is two dimensional carbon page having network structure like bee hive and only has one atom thickness. Graphene has manifold light, electronic and heat properties. Dispersed electrons in graphene like weightless Dirac fermions behave in linear relation energy-size movement and cause increasing reaction of graphene carriers in area temperature to 10^5 cm/Vs and in lower temperatures it becomes 10^6 cm/Vs. Graphene absorption coefficient is higher than other conventional semi-conductors and another feature of graphene is high heat conductance as 5000 W/Mk for mono layer graphene and zero energy gap causing that graphene is used in devices such as light illustration, solar cells, light emitting diodes and so on. It should be noted that graphene with high light absorption depending on short interaction length only absorb 3.2 percent of visible light to infrared. This amount of light absorption in graphene is not enough for using in illustration devices. Recently light technologies have been used for improving graphene light absorption. Echtermeyer *et al.,* [111] combined graphene layer with plasmonic nanostructures that increased efficiency of graphene Photodetectors. Abajo *et al.,* [112] used periodic graphene pattern for improving light absorption in the ultrared area. Zhao *et al.,* [113] used metal grating for increasing light absorption in graphene. Zhu *et al.,* [114] figured out that blending plasmonic array of empty pores in nano scale in visual light area, increases graphene light absorption to 30%.

The photoresponsivity and photocurrent of several photodetectors have been compared at a communication wavelength of 55.1 µm [115]. This research indicates the superiority of designed photodector in relation to other cases. Table 4 compares the photoresponsivity and photocurrent of the proposed photodetectors with those proposed in [115].

Table 4 Comparison of photoresponsivity and photocurrent of the proposed photodetector with those in [115]

References	Power or Input Intensity	Photo Responsivity	Photo Current
[116]	80 mW/cm	1.0 A/W	765.2 mA
[117]	5.0 Mw	9.0 mA/W	45.0 µA
[118]	5.0 mW	273.0 A/W	137.0 mA
[119]	6.0 µW	37.0 A/W	222.0 µA
[120]	5.0 mW	100 A/W	50 mA

11. GRAPHENE APPLICATION IN SOLAR CELLS

One of the issues for providing energy for portable electronic devices that has been examined is using photovoltaic cells. Photovoltaic cells are considered one of the energy providing resources in the future of the world. It is estimated that up to 2050, 15 to 30 percent of world power will be provided by solar energy. At the moment, most of the photovoltaic cells are made of mono crystals or silicon poly crystals. Among the new combinations used at the moment in making photovoltaic cells, are many kinds of carbon nanostructures [121]. Carbon nanotubes used in composite structures can increase efficiency of solar cells because of high surface area and current conductance. Researchers have relied on using graphene for making solar cells. Using nanotube structures and graphene in photo electrode can increase the velocity of electron movements. However, increasing nanotube amounts and also graphene increase rate of electrons returning from photo electrode. So, an optimal amount in this area should be considered. According to the graph of converting current based on voltage, three electrodes were compared from graphene, Multi Wall Carbon NanoTubes (MWCNT) and Graphene Based Multi Wall Carbon NanoTubes (GMCWNT); transferring load in electrode based on Graphene Multi Wall NanoTubes (GMWNT) has been higher than other two electrodes [122].

Jeon et al [123] prepared Hole Transport Layer (HTL) for the manufacture of solar cells by thermal reduction of graphene oxide. According to their results, graphene dispersed in polystyrene sulfonate increased the efficiency of solar cells compared with those manufactured by adding polyethylene dioxythiophene to polystyrene sulfonate. Adding small amount of gold nanoparticles and boron doped carbon nanotubes (Au:BCNT) improves light excitation and electron hole pair separation as charge carriers for charge transport to the electrodes in solar cells. Multiple synergistic effects led to a high efficiency of 9.81% [124].

12. GRAPHENE-BASED TOUCHSCREENS

Touchscreens as Input/Output (I/O) tools allow users to communicate or control what is seen on the screen by touching the screen with one or multiple fingers or with a stylus tip (a pen-like tool). Due to the need for Transparent Conductive Materials (TCMs), extensive studies have been conducted to find out alternatives for Indium Tin Oxide (ITO) as the most commonly used TCM. Transparent conductive electrodes are used in numerous optoelectronic devices. Currently, Indium Tin Oxide (ITO) is used as a transparent conductive electrode due to high electrical conductivity and optical transparency. However, it may not be a suitable choice due to technical and economic limitations.

The use of ITO is limited for two reasons. First, indium is a very rare expensive element. Second, ITO is brittle and its electrical conductivity is irreversibly decreased with a small bending. This limits the use of ITO in applications requiring high flexibility [125][126]. ITO as an oxide ceramic material is very brittle and susceptible to cracking. Today, graphene is considered as a good alternative for transparent conducive electrodes in many applications. Graphene is combined with silver nanowires for facile manufacture of novel touchscreens with a higher strength. Furthermore, graphene-based touchscreens consume less energy and are easily bending due to their high flexibility. Touchscreens available on the market are usually constructed from an Indium Tine Oxide (ITO) layers, which are very expensive and brittle despite their high electrical conductivity. Touchscreens constructed from silver are not economically feasible, so it is better to manufacture touchscreens by combining graphene and silver. This type of touchscreen has a low mechanical strength, and most of its users have complained of the fracture of touchscreens. Metal NanoWires (MNWs) integrate high flexibility, optical transparency and good electrical conductivity. Despite the use of fewer raw materials, MNWs show a good transparency and electrical conductivity like ITO electrodes due to a large length to diameter ratio. To achieve an optimal electrical conductivity and transparency, a higher indium level is used in ITO electrodes compared with silver level used in the manufacture of silver nanowire electrodes. Adding graphene to silver nanowires increased their electrical conductivity up to around 10000 tines. This shows the possibility of obtaining similar or even better results with an improved performance and less energy consumption only with part of the silver used earlier in the manufacture of such electrodes. According to the literature, the use of graphene significantly reduces manufacturing costs of touch films. It should be noted that silver is darkened when exposed to air, but the graphene layer preserves silver against air molecules. Furthermore, the electrical properties of graphene films do not change with bending. While previous samples faced many limitations in this regard, this new material paves the way for the manufacture of flexible devices [127].

13. GRAPHENE-BASED BULBS AND LIGHT EMITTING DIODES (LEDS)

According to the light spectrum emitted from graphene, it could be heated to temperatures above 2500℃ and warmed enough to emit light. The light emitted from this thin graphene layer is very intense and visible to the naked eye, without magnification. A visible light source using graphene strings on a chip is developing, and many studies are currently being conducted in this field. This new type of broadband light emitters can be integrated with chips to pave the way for the manufacture of flexible transparent displays with an atomic thickness as well as graphene-based optical communications. Light emission in small structures on a chip is essential for development of photonic circuits that work with light. Graphene is able to resist against overheating without melting of metal or silicon substrate. Moreover, graphene is not able to conduct heat and, therefore, heat is concentrated at the center of carbon strings leading to intense light emission [128][129][130].

Graphene bulbs are similar to ordinary light bulbs in appearance but contain a thin graphene layer leading to a higher efficiency and light emission. Graphene bulbs with a lower manufacture cost and higher brightness and lifetime reduce power consumption. Compared to the ordinary lightbulbs and Light Emitting Diodes (LEDs), graphene bulbs consume less energy. Graphene-based LEDs are used in LED displays and monitors with color and quality setting, cell phones, TVs and LED lightweight textures with color adjustment.

H.Diker *et al.,* used graphene oxide and PEDOT: PSS composite for hole injection in Light-Emitting Diods (LEDs) [131]. To this end, various graphene sizes consisted of gangrene oxide were examined. Despite the low efficiency of LEDs, they found the significant effect of graphene oxide as a hole injector layer (HIL). It seems that graphene bulbs and LEDs are able to change computer and communications industry. The very small size of graphene bulbs and LEDs allows the manufacture of displays with a higher sensitivity and color capabilities. However, many studies should be conducted in this regard to use graphene-based photonic devices in future.

14. GRAPHENE MICROPHONES

Microphone are a type of device or transducer, which convert sound into an electric current. In other words, a microphone is a transducer capable of converting sound into electric signals. There are numerous studies on the use of graphene in the structure of microphones[132-135]. Graphene microphones are ultrasonic and lightweight. Both conventional speakers and microphones use either paper or plastic diaphragms, which play a key role in sound generation or recognition through vibration. The diaphragms used in new devices are made of a graphene sheet with a thickness of only one atom. It is lightweight diaphragm with high hardness and strength, which is able to respond to a wide range of frequencies from infrasound (≤20 Hz) to ultrasound (≥20 kHz). One of the great advantages of using graphene is that ultrathin graphene sheets well respond to various frequencies of an electronic pulse. Unlike currently used piezoelectric speakers and microphones, the frequency response of this lightweight membrane covers a very wide range capable of generating rapid frequencies for measuring distances more accurately than traditional methods. The membrane converts over 99% of energy into sound. The corresponding value for conventional microphones and speakers, however, is only 8% [133].

Graphene microphones constructed by Spanenović *et al.*, [132] were 32 times more sensitive than standard nickel microphones. They constructed a very sensitive graphene membrane to convert sound into electric current. Sensitivity of the graphene sheet was 15 dB greater than conventional models in the market. In their study, graphene membranes with 60 layers were grown on a nickel foil by Chemical Vapor Deposition (CVD). When graphene was produced, the nickel layer was removed from graphene and the grown layer was placed on the surface of microphone. According to the results, this microphone was more sensitive than commercial microphones by 15 dB. They simulated a 300-layer membrane with a high efficiency in infrasound range. A thick graphene membrane can be flexible with a good performance for infrasound waves. Graphene microphones are very useful for studying hearing signals in high frequencies. Beside electromagnetic waves, acoustic waves and highly-oriented long-range sounds are expected to be used in communication devices such as mobile phones.

15. GRAPHENE OLEDS

Organic Light-Emitting Diodes (OLEDs) have been widely developed and used due to their high image quality, low power consumption and ultrathin structure. OLEDs consist of a vibrant and active organic structure embedded between two electrodes. One of the electrodes should be transparent. Indium Tin Oxide (ITO) is commonly used in OLEDs. However, indium is an expensive rare element, which is hardly recovered. Graphene is a good alternative to make electrodes. Graphene is used to form Transparent Electrodes (TEs). It is also used as an electrode in OLEDs [136]. The graphene OLEDs showed similar performance as control tools made from ITO transparent electrodes indicating the potential application of graphene. The OLED designed by Lee and Yoo in [137] was very complex and yet efficient. In these displays, graphene was embedded between transparent thin titanium oxide and conductive polymer layers. The displays consist of 5 sticking layers. The displays are mounted on a plastic substrate. By applying voltage to the sheet, cathode emits electrons and holes are produced by the anode leading to photon emission by OLED. Photon emission occurs in one of the layers by recombination. The light emission path in this type of displays can be determined by cathode and anode adjustment. A titanium oxide layer with a high refractive index and a hole injection layer in the conductive polymer (with a small refractive index) have been used in this scheme. The whole structure is mounted on both sides of the graphene layer. The color can be controlled and the loss of surface plasmon polariton is reduced in this type of displays. The performance of the resulting display is improved due to concurrent use of two layers with different refractive indices.

16. GRAPHENE INKS

Highly flexible graphene inks with a very high electrical conductivity are used on a wide range of substrates including paper and plastics, and they are highly flexible. This type of inks shows a higher surface stability than conductive composites and carbon inks, and, they are much cheaper than metal inks. Graphene ink utilized graphene, various polymers and surfactants, and functional groups manufacturing techniques that reduce aggregation and enhance graphene ink dispersion. Graphene inks could accelerate the printing process of electronic devices leading to a decrease in the relevant costs. To produce graphene inks, graphene particles are dispersed in a solvent and then water is added to the base ink. The ratio of ingredients in the system is adjusted to preserve solvent properties without affecting ink and graphene composition in the solvent. Conventional ink is combined with highly conductive silver and used in printing machines leading to an increase in ink cost. Graphene inks are relatively cheaper than silver-containing inks. Silver cannot be recycled while graphene can be recycled and reused. There are numerous studies on the use of cheap nontoxic and environmentally friendly graphene inks [138-142].

Graphene inks and other two-dimensional Graphene Related Materials (GRMs) have received much attention for novel technical advances in smart texture industry to produce electronic devices combined with novel fabrics and textures. A method has been invented in [143] for deposition of graphene ink on cotton to produce conductive fabrics. Expensive metals such as silver are used for preparation of other conductive inks and thus are very unstable and expensive. However, the graphene used in this study is cheap, environmentally friendly and chemically compatible with cotton. This method allows direct placement of electronic systems on the human body. This is a novel technology to manufacture smart fabrics.

17. USE OF GRAPHENE IN REINFORCING ELECTRICAL CIRCUITS AGAINST MOISTURE

Graphene can be combined with metals to produce moisture-resistant connections in electronic circuits [144]. This can be useful for development of novel low-cost sensors. To produce highly efficient sensors, graphene should preserve its electrical conductivity after being combined with electronic circuits. A durable connection is necessary in any sensor, and it plays a key role in sensor function. However, graphene is sensitive to moisture, and water molecules may surround graphene by water adsorption on the surface of graphene. Electrical conductivity of graphene changes by water adsorption and thus wrong signals are sent to the sensor. If graphene attaches the metal in the electronic circuit, its resistance will not change in the presence of water molecules. In fact, moisture will not adversely affect graphene performance. According to Quellmalz, one of the researchers of the project, this technology will facilitate sensor design as moisture is not a concern and water will not negatively affect the circuit. They conducted experiments on the graphene connected to gold-metallized silica plates. This structure was then evaluated by different methods and computer simulations. According to Quellmalz, one can take advantages of graphene and electronics by combining them. Graphene has unique properties and conventional electronics is cheap on the other hand. Therefore, one can take advantage of both graphene and electronics. To combine these technologies, graphene is placed on the finished electronic component instead of metal deposition on the graphene surface.

18. GRAPHENE INK FOR DEVELOPMENT OF INTERNET OF THINGS (IOT)

The Internet of Things (IoT) is making extensive changes in modern cities and human's everyday lives around the world. IoT deals with people's accessories, assets, information, knowledge, services, and businesses. Scientists have developed a flexible, soft type of graphene that is capable of bending, folding, etc., and can produce three-dimensional conductive objects in any form. These achievements will make it easier to produce IoT-based objects and smart products, and graphene can be used to produce advanced electrical products used in IoT. On the other hand, graphene can also be used to supply the power of IoT devices [149-151]. In research Pan K. *et al.,* [145], a method has been proposed for the manufacture of printed electronic components using 2D materials. While providing a high rate, this method is also cost effective. The graphene-based ink can be used for the manufacture of electronic devices, in particular those employed in Internet of Things (IoT). Graphene as a 2D material consisting of carbon atoms with high electrical conductivity can be used in IoT industry. However, two main problems limit the use of conductive inks in IOT: high price and rapid oxidation. These two challenges limit industrial use of 2D carbon materials. Dihydrolevoglucosenone known as cyrene was used to change graphene properties. According to the results, cyrene increases exfoliation rate of graphite to produce graphene at a lower cost by using a nontoxic and completely renewable method.

19. USING GRAPHENE IN CONSTRUCTION OF TRANSISTORS

Defect-free graphene is an ideal 2D lattice in which carbon atoms with sp^2 hybridization provide a high strength. However, the durability of polycrystalline graphene is not sufficient for industrial applications. This limits commercial application of graphene. Accordingly, it should be modified to be used in flexible electronics. Improper crystal structure and defects in the lattice are the most important drawbacks limiting commercial applications of graphene in electronics. To overcome this limitation, mechanical durability of single-atom polycrystalline graphene sheet should be improved as a necessary step for practical use of graphene in soft and flexible electronics. A low-cost simple method consistent with conventional processes should be provided for this purpose. Durability of large graphene sheets can be increased to produce a new generation of flexible electronics.

A method has been proposed to improve mechanical durability of graphene by chemical bonding of nanoscale packets on the surface of graphene [146]. The organosilane nanopatches are mounted on the graphene surface with a nanometric thickness. Nanopatches improve graphene resistance against severe media to enhance graphene applications. Nanopatches on the graphene surface increase its mechanical durability when used as an electrode in wearable sensors. Furthermore, when graphene is used as an electrode, orientation of semi-conducting organic layers on the surface is controlled, and charge is more effectively injected in organic transistors. This type of graphene can be used in Organic Field-Effect Transistors (OFETs).

Using graphene and boron nitride, researchers in [152] produced a two-dimensional field effect transistor. Unlike silicon-based field effect transistors, this transistor performance doesn’t decline at high voltages and provides high electron conductivity even when its thickness is reduced to a single layer. Researchers have succeeded in making this transistor using hexagonal boron nitride, transition metal dichalcogenides, and graphene plates tied together through van der Waals interactions. In constructing these transistors, each section is made up of a thin layer. These layers are designed to be similar in thickness, with no surface roughness, and have bonded using van der Waals force.

20. DEVELOPMENT OF NANOELECTROMECHANICAL SWITCHES USING GRAPHENE

The Graphene-based nanoelectromechanical switches can be used for Electrostatic Discharge (ESD) protection of electronic devices [147]. The Switches consist of two terminals with a gap between them. The gap is placed in the lower conductive substrate and the graphene membrane is placed on the lower substrate. This is a new concept in ESD protection of electronic components on chips. According to Chen, ESD switches have numerous advantages in comparison with conventional PN contact-based ESD devices. This passive mechanical switch with a nearly close leakage has a very low parasite capacity. In addition, the switch has a bi-functional polar performance while PN junction-based devices only provide unipolar protection. With a very high mechanical and thermal performance, graphene can be used to produce this type of switches. The switch can be produced by CMOS infrastructure through non-uniform aggregation. The CMOS-based process proposed in this study can be used to produce NEMES ESD graphene switches. This method was applied in a clean room, and the results were characterized by Transitional Linear Pulse (TLP). This device can be used to produce a new generation of ESD protectors on the chip.

21. USE OF GRAPHENE IN THE MANUFACTURE OF CAMERAS

Graphene image sensors are more sensitive to light than commercial sensors known as CMOS and CCD under identical conditions. They also consume less energy than commercial sensors. The use of this type of sensors in surveillance equipment and satellites may cause a great difference. The quality of images decreases by downsizing cameras due to a decrease in image sensor dimensions. The graphene sensor increased camera resolution despite camera downsizing [148]. The use of graphene in Complementary Metal-Oxide Semiconductors (CMOS) may produce high-resolution low-noise images. This technology allows integration of cameras in small electronic devices. Graphene can be used in the production of image sensors. It can also be used as phototransistors in digital image sensors to convert light into an electric current. A digital imaging system was constructed from graphene and quantum dots capable of imaging visible, ultraviolet and infrared lights simultaneously [148]. The sensor was constructed using PbS quantum nano-charges mounted on the graphene sheet. The resulting hybrid system was then connected to a CMOS and the whole system was connected to a reading circuit. The resulting high-resolution imaging sensor was sensitive to a wide range of wavelengths from UV at 300 nm, visible light at moderate wavelengths to infrared at 2000 nm. This imaging sensor was able to detect visible and invisible lights simultaneously. The thin graphene layer reduces the size of final product while increasing its resolution. Each pixel in the sensor is covered by graphene with a layer of quantum dots on this layer. The dots in this layer absorb light and transfer their electrons to graphene. Using this graphene sensors, there is no need to downsize pixel dimensions. The number of pixels is not the only factor determining the imaging quality of a camera, but sensor size also plays a key role in this regard. Unlike CMOS sensors, increased noise in this new sensor is not a concern. The imaging cameras made with this sensor are able to record images at low-light using infrared waves with a wavelength of 1100-1900 just as night vision cameras. They are also able to record images under normal conditions. The highly sensitive cameras constructed from this type of phototransistors are cost effective and can be easily used in computers, laptops and other electronic devices.

22. CONCLUSION

Graphene is emergent material that has important role in developing advanced technologies. Graphene composites relative to polymer matrix composites or other carbon based composites (composites reinforced with carbon nanotubes or carbon fibers), have higher properties and better performance. In this research we examined reinforced polymer nanocomposites using graphene and recent advancements, properties and applications of these materials in computer and electronic industry. As the application of these nano materials in computer and electronic industry has many added values and economic interest and on the other hand, computer and electronic industry is faced with many challenges and difficulties in its progress path that should be solved. These problems can be solved by using polymer nanocomposites filled with graphene. On the other hand, preparation of graphene with high quality and reasonable price is a problem yet and should be synthesized and produced with new methods. There are different methods for producing graphene reinforced polymer nanocomposites that these methods affect dispersion amount of graphene inside polymer matrix and final properties of composites. Complete usage of graphene filled nanocomposites with distribution is related to amount of graphene and its orientation and increases economic saving and producing final material. Distribution and orientation of graphene for optimization of structural and practical effectiveness and efficiency is so critical. Prevention of random orientation of filler nanoparticles results in producing designed nanocomposites having controlled and exact configurations and on the other hand they are capable of functionalization for creating strong inter surface bonds, between graphene and chemically modified graphene with other materials and this cause they are used in making new computer and telecommunication parts, that nowadays it's required to examine and study these nanomaterial in computer and telecommunication industry more than before.

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