GRAPHENE COATED POLYMER ELECTRODES FOR ENERGY STORAGE APPLICATIONS-AN EXPERIMENTAL APPROACH

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ABSTRACT

The graphene/polymer composites have many desirable qualities. In addition to adsorption, antimicrobial, hydrophobic, electrical, and thermal conductivities were found. As electronic devices become more integrated and miniaturized, the growing demand for effective thermal management has driven increased interest in these composite materials. Two significant potential discoveries have further boosted research in this area. researchers have now developed methods for producing graphene on a large scale, as well as creating flexible graphene electrodes. These breakthroughs open the door to manufacturing larger graphene-based items and allow for greater design flexibility by leveraging graphene's unique properties The main focus of this paper is on the different methods used to create graphene as a flexible electrode. Although it mainly covers various production methods, it also briefly mentions large-scale production. Researchers have been exploring the potential of graphene-coated polymer electrodes to enhance energy storage capabilities. The objective of this experimental strategy is to enhance the functionality and longevity of electrodes made of polymers by utilising graphene's exceptional electrical conductivity and mechanical strength.

1. Introduction

Graphene is thought as be A new nanotechnology material characterised by a hexagonal crystal lattice of one layer of carbon atoms and a stiff, planar nanostructure. Benzene, being a repeating structural unit of graphene, imparts the material's two-dimensional macromolecule characteristics [1]. To be more precise, all of the carbon atoms in the molecular structure are sp2-hybridized, dispersed, and involved in C-C Θ and π bonds [2]. The process of creating graphene can be accomplished in various ways, including chemical or mechanical exfoliation of graphite, reduction of graphene oxide, or chemical vapour deposition [3]. In terms of efficiency and reliability, micromechanical cleavage stands head and shoulders above the other technologies for producing high-quality graphene. Composites using graphene will be a long way off due to the material's low dispersibility in common organic and inorganic solvents. Improving graphene's solubility in organic solvents is essential for a wide range of industrial uses. [4]. One of the most promising approaches is to incorporate graphene into polymer matrices to create multifunctional composites. This is because polymer composites often possess high specific modulus and specific strength, and therefore find extensive use in the aerospace, automotive, and defence sectors [5]. In addition, the structure and characteristics of graphene may be superbly preserved by manufacturing polymer composites into complexly formed components utilising standard processing techniques. Since polymer molecules cannot reach the inner surface of graphene nanotubes, its surface-to-volume ratio is higher than that of carbon nanotubes (CNTs), a previously promising filler for composites [6]. Polymer matrices can benefit from graphene's enhanced mechanical, electrical, thermal, and microwave absorption capabilities because of this. Because it imparts several useful properties to polymers that would otherwise be unavailable, the graphene nanostructure is an attractive filler for thermoplastic and thermosetting resins [7]. The addition of graphene or graphene oxide improves the electrical and mechanical characteristics of fibres [8]. Tensile and compressive testing must be performed on the construction. A different method to detect layer delamination is via scanning electron microscopy (SEM). Reportedly has strong wear resistance and excellent frictional characteristics. This research suggests that graphene may have potential as a coating to prevent scratches and other forms of physical harm [9]. Due to its perceived inertness in the presence of chemical reactions from other substrates, graphene has also demonstrated its effectiveness as a corrosion barrier. Therefore, it is possible to guarantee that a coating system's anti-corrosion capabilities would be enhanced [10].

1.1Applications of graphene polymer composites and significance

Applications of graphene-polymer composites have been extensively studied in various fields, such as energy storage, sensors, biomedical, thermal engineering, energy, and electronic devices. For energy storage, graphene-coated polymer electrodes are a promising material because of their increased conductivity and mechanical strength. The experimental approach focuses on optimizing the coating process to achieve maximum efficiency and durability in various energy storage systems.

2. LITERATURE REVIEW

The review provides an overview of the current and future methods for graphene/polymer composite preparation, synthesis, fabrication, and use. Research into new polymer materials that combine well with graphene and graphene oxide in composites has been extensive, with an emphasis on these materials' electrical, thermal, and other properties. **Chaohe Xu [11]** This study compiles previous research on graphene-based materials for electrodes used in electrochemical energy storage. After a brief introduction to the main features of single-layer graphene, the techniques for creating graphene and its derivatives, such as reduced graphene oxide and graphene oxide, are discussed. **Razaq, A.; Bibi et al [12]** in their study to the in-depth analysis of the latest developments in the production and utilisation of composites derived from graphene. The remarkable thermal stability, high conductivity, and exceptional mechanical strength of composite materials derived from graphene, conducting polymers, metal matrices, carbon-carbon matrices. **Bhavana M. Itapu [13]** This article summarises the most current findings in graphene and polymer composites. As a nanofiller for polymer-based composites, graphene has a lot of potential because it can improve their properties even when loaded at low concentrations. Novel polymer/graphene composites and a number of cutting-edge processing methods are covered, including melt intercalation, in-situ polymerization, and solution processing. **Cai, X.; Sun et al [14]** When utilised as electrode materials for SCs, graphene/CP composites exhibit remarkable electrochemical performance. Additionally, we cover the topic of synthesising electrode materials to enhance electrochemical performance. **Wang, Z., et al [15]** In this study, we survey the research on electrode materials based on graphene for electrochemical energy storage. **Gadakh, D., Dashora, P [16]** This study provides a concise overview of the numerous graphene manufacturing methods and briefly discusses several types of fibres. There have been a number of investigations into the effects of graphene coating on various fibres, both physically and chemically. **Silva, M., Pinho, I.S., Covas [17]** The present review focuses on This article presents an overview of the many manufacturing techniques that can be used to fabricate graphene/polymer scaffolds and biosensors, talks about the various biomedical applications of these materials, and discusses graphene-based polymer nanocomposites that have been produced for additive manufacturing. **Ye, X., Zhou, Q [18]** An effective method for producing graphene paper by in-situ chemical reduction was devised in this study. Graphene paper with exceptional durability and easy folding properties is created by forming and reducing the film at the same time using this method.

3. Methodology and materials

When it comes to energy applications, there are a variety of process approaches that offer distinct advantages for graphene coated polymer electrodes. Chemical vapour deposition (CVD), step-by-step assembly, and processing in a solution are common procedures in these approaches. In terms of efficiency, cost, and the final graphene coating quality, each approach has its own set of benefits. Comparable to batteries, fuel cells transform the chemical energy in fuel into electrical energy; however, unlike batteries, fuel cells do not need to be recharged, and the reaction typically produces harmless byproducts, such as heat and water, which are good for the environment. If the fuel supply is steady and sufficient, the cell can operate reliably and optimally without replacement. The elimination of combustion in fuel cells allows for a 40-60% improvement in energy conversion efficiency as compared to thermomechanical technology. Because of these factors, fuel cell technology has emerged as an acceptable, cost-effective, and dependable alternative to traditional power sources. As far as commercially available energy storage options go, fuel cells have one of the highest energy densities (over 500 Wh/kg), but their poor power density prevents them from being used in high power applications.

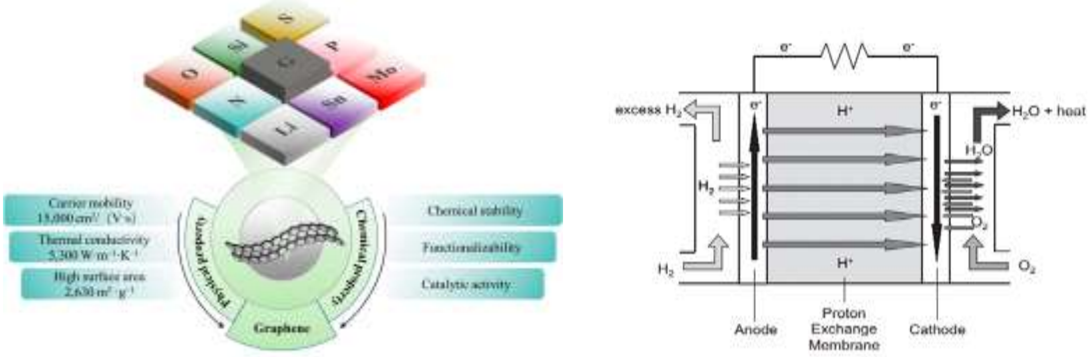

Figure:1 Graphene oxide advantages with Schematic of a proton exchange membrane fuel cell

A cathode, an anode, and an electrolyte are the standard fundamentals of a fuel cell. The electrolyte is the main differentiator between the many fuel cell types. Ceramic oxide, polymer membranes, and aqueous alkaline solutions are common electrolytes in both industrial and academic devices. The proton exchange membrane (PEM) fuel cell, which uses hydrogen as its primary fuel, is the most common design.

3.1 Fabrication of graphene / polymer composites

In comparison to pure graphene, the physical qualities of most graphene/polymer composites made with GO, CRGO, or TRGO fillers are often subpar. One way to make graphene more water-soluble is to add oxygen-containing carboxylic, hydroxyl, or epoxy groups to the surface of graphene oxide (GO) before using it as a composite filler. For this reason, composites made from GO sheets and hydrophilic polymers like PEO and PVA have better mechanical qualities and greater thermal stability. The majority of organic polymers are incompatible with GO because of its preference for dispersing in water. The mechanical characteristics of the resultant composites were significantly improved. Because polymers are present in the solutions used for in-situ chemical reduction, they not only restore graphene's conductivity but also prevent it from agglomerating. The resultant in-situ CRGO is coated with polymers to prevent graphene from restacking and maintain the dispersion of GO in polymer matrices. The insulating characteristics of the composite samples made with unreduced phenyl isocyanate-treated GO are superior to those of the CRGO/PS composite, which has an electrical conductivity of 0.1 vol.% at ambient temperature.

3.1.1 Coating:

Fibres can have their qualities directly enhanced by coating them with graphene or one of its derivatives. One can cover graphene or a derivative of it in one of two ways. First, there was the "dip and dry" approach, where the fibre was dipped into a graphene or derivative dispersion and then either reduced or washed. Direct spraying of graphene onto the fibre was the second technique. Both methods were easy to implement and had great practical use. Preparing graphene-coated fibres has traditionally involved dip and dry coating. Coated polyester textiles with RGO have been synthesised and characterised using electrochemical and chemical methods. The first step of the synthesis was bringing the fabric into touch with the GO solution so that the sheets of GO could be adsorbed onto the cloth's surface. Textiles treated with GO were thereafter let to dry naturally. Step two of the production process involved reducing graphene oxide (GO) to reduced graphene oxide (RGO). Placed in a solution containing the reducer were fabrics coated with GO.

3.2 Modified Hummers' method:

A supercapacitor electrode made of bacterial cellulose, polyaniline, and graphene Making graphene-based supercapacitors using silver fibre fabric as the current collector and an in situ chemical reduction technique to create large-area, foldable graphene paper Flexible supercapacitors based on reduced graphene oxide showed considerable improvements when Cu particles were applied. Composites of graphene hydrogel framework and polypyrrole with controllable morphology, as determined by cyclic voltammetry with the help of poly(sodium-4-styrene sulfonate) [18] for use as a flexible supercapacitor electrode 3D carbon frameworks produced from biomass assembled onto conductive substrates for flexible supercapacitors using graphene aerogels

3.3 Bonding Structure of Graphene/ Polymer Interface

The Manufacturing graphene/polymer composites mostly involves physically mixing a negligible quantity of graphene with polymer. After a homogeneous mixture is produced, the crosslinks between the graphene/polymer interface can be strengthened by in-situ polymerization, solvent processing, or melt-processing. Graphene dissolves evenly in polymers by the use of solvent processing. A further viable option for producing homogeneous graphene/polymer composites is to combine GO with polymers in an appropriate solvent before adding a reducing agent. Graphene/polymer composites that are made by in-situ polymerization are more uniform and have better interaction between the two materials. While electrostatic integration, hydrogen bonding, and coordination bonding are three methods that have been used to increase the strength of polymer composites, there are very few others. Composite materials made of graphene have been created by electrostatically combining the carboxylic acid groups that are still present on the substance with the amino groups that are on amine-terminated PS.

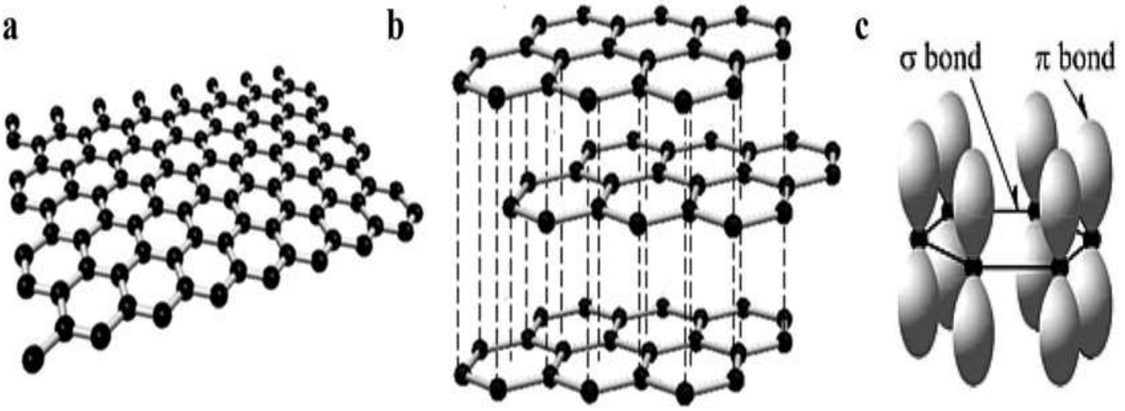

Figure2: (a) Graphene structure, (b) stacking of graphene layers and (c) distribution of σ and π bonds on the graphene structure.

3.3.1 Properties of graphene:

Graphene is a multilayer carbon nanosheet made up of two layers of sp2 carbon atoms linked together by s bonds. This delocalized network of electrons is created by the p orbitals of each carbon atom in the lattice. The incredible physical and chemical features of graphene, including an internal degree of freedom, robust electron-hole symmetry, and linear energy dispersion, are caused by its unique chemical structure, the Dirac fermion system.

3.3.2 Mechanical Properties

The mechanical characteristics of graphene were assessed using AFM, which yielded readings of 130 GPa for breaking strength and 1.1 TPa for Young's modulus. Research on chemically reduced graphene monolayers revealed an elastic modulus of 0.25 TPa.

Table: The graphene polymer composites' mechanical characteristics

Filler type and % loading	Matrix	%increase in tensile strength	%increase in elastic modulus
0.7 wt% GO	PVA	76	62
wt% GO	PVA	92.2	-
1 wt% in-situ CRGO	PMMA	60.7	-
1 wtt% TRGO	PMMA foam	13	20
0.5 wt% GO	PCL film	17	49
0.5 wt% graphene	PA12	32.2	-
0.05 wt% in-situ TRGO	Polyester	72.2	-
0.54 vol% GO	Epoxy	10	25

4. Experimentation

Graphene-coated polymer electrodes have the potential to convert renewable energy sources like wind and sun into usable electricity. Electrodes made of polymer and covered with graphene have potential applications in energy storage devices like fuel cells and batteries. Plus, you may use them to power electrochemical reactions and make electricity. Here is a schematic diagram showing how graphene can be applied to a polymer.

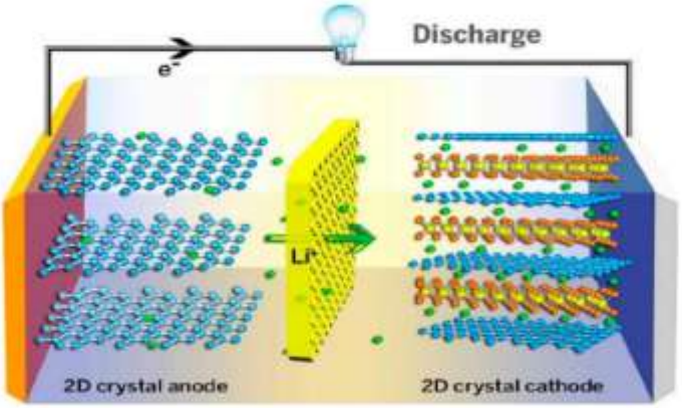

Figure:3 Schematic of working principle for graphene coated electrodes

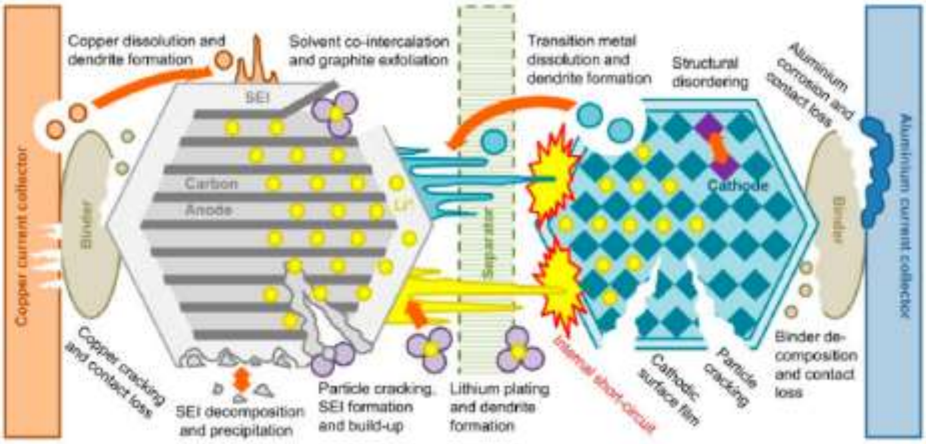

Figure:4 Deposition process for energy storage systems

The synthesis of fullerenes and carbon nanotubes with one or more walls has been accomplished using the arc discharge technique.The arc discharge technology allows for a rapid rise to temperatures above 2000 C.In light of this, it stands to reason that arc discharge can be employed to effectively deoxygenate GO, exfoliate graphite, and encourage its recovery. As per the findings of Rao et al., the inner wall of the arc chamber typically had 2-4 layers of graphene generated utilising the arc discharge process. Instead of utilising a mixture of hydrogen and oxygen, Graphene was successfully mass-produced in an air environment by Shi et al. by means of the arc discharge method. Graphene yield was found to be significantly correlated with air pressure. The synthesis of carbon nanohorns and nanospheres was supported by low pressure, whereas graphene creation was favoured by high pressure. Using $NH3$ as a buffer gas, the authors also discovered that pure graphite rods may undergo direct current arc discharge, enabling the creation of nitrogen-doped graphene. Another quick heating procedure that can be used to make graphene from a GO dispersion is hydrogen arc discharge. In comparison to the standard thermal exfoliation process, the produced graphene shown excellent thermal stability and electrical conductivity [19-23].

The electrode surfaces and anode media samples were preserved at a temperature of -20 °C. An Ultra Clean soil DNA isolation kit (the Power Soil DNA isolation kit) was used to extract genomic DNA in accordance with the instructions provided by the manufacturer. Using the following programming on a Techne TC-512 thermal cycler, we amplified the 16s rRNA gene's V3-V5 regions: after 5 minutes at 95 °C, 30 cycles of denaturation (30 s at 95 °C, 40 s at 56 °C, 60 s at 72 °C), and 10 minutes of final extension (at 72 °C). Following amplification, the PCR products were distributed onto a polyacrylamide gel using a denaturing gradient in a 1× Tris-acetate-EDTA (TAE) solution.

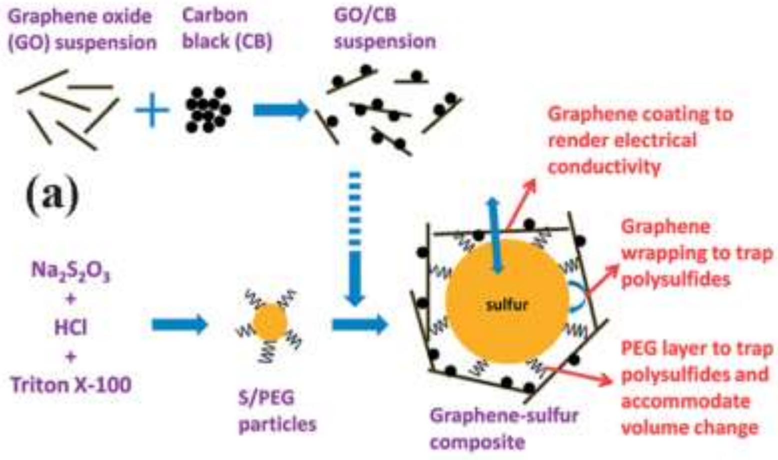

Figure: 5 Process of graphene deposition

Figure: 6 Sample preparation for testing of electrodes

5. Results and discussions

A graphene undergoes structural transformations, the Raman spectra reveal these changes. Figure 7 shows the G peak at 1581.31 cm-1 and the D peak at 1348.29 cm-1 in the Raman spectrum of graphene. These peaks are created by in-plane optical vibration, which is similar to the result with [19]. A TEM inspection confirmed the presence of a defect in graphene, as shown by the D peak. Raman characterisation was suggested as a means to differentiate graphene properties based on this result.

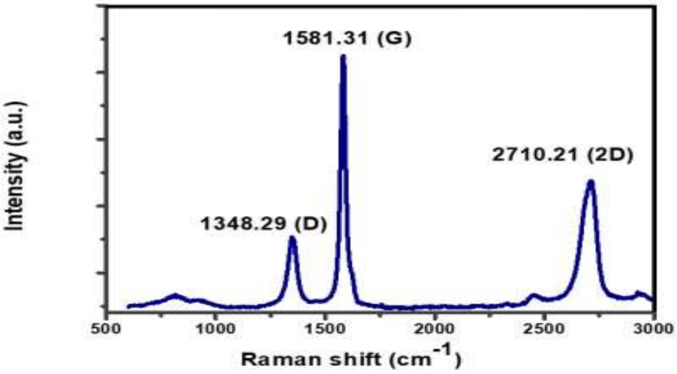

Figure:7 Raman spectra after coating

The initial work has focused on studying the graphene interface structure using high-resolution transmission electron microscopy (HRTEM). Through the use of the JEM ARM200F TEM, the imaging ranged from high-resolution, low-magnification images to examinations of specific fault areas at the atomic scale. So that spherical aberration corrected (Cs-corrected) can achieve atomic-scale accuracy. Figure 4 depicts an HR-TEM image of a carbon string–covered copper grid, which, according to the results, looks like graphene with crumpled sheets of paper and uneven shapes [21]. Both big (<3 µm) and small (<1 µm) sizes of graphene sheets are observed. Graphene sheets, on the other hand, typically measure around 800 nm in size. You can observe that the graphene sheet has flat edges and can be either one or more layers thick just by looking at the picture. The c-c distance, which measures 0.14 nm, is also significant.

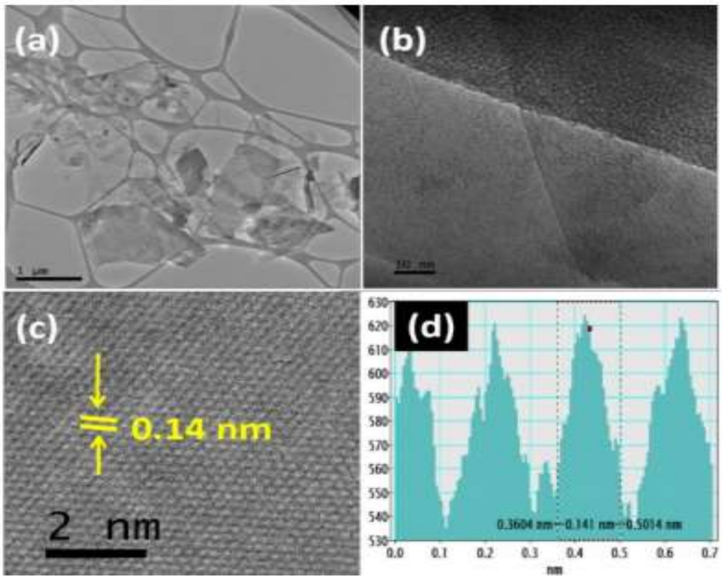

Figure:8 TEM images of graphene with different magnifications

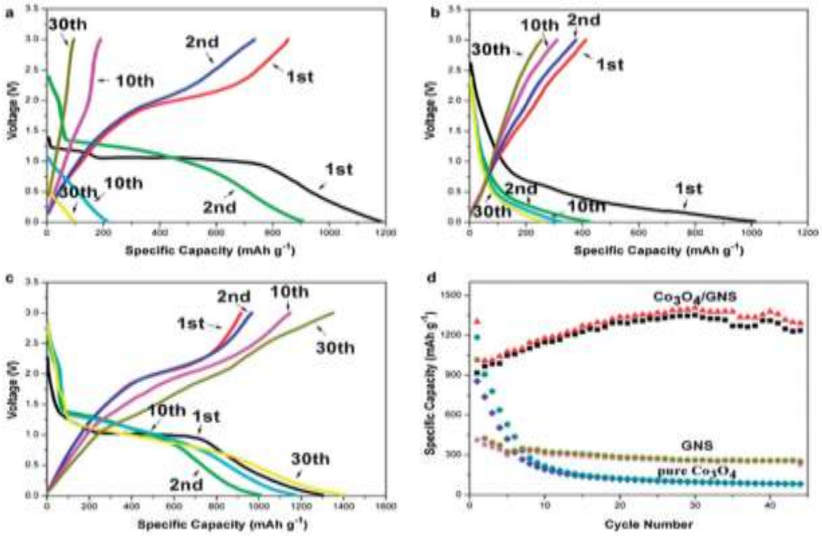

Figure:9 Specific capacity vs voltage for number of cycle tests in conduction

The electrical conductivity was measured. Surface current-voltage (I-V) measurements of the 1, 2, and 3 drops of graphene sheets were taken using a 2 Point Probe (TPP). By taking three measurements of each sample, we were able to calculate an average value for the resistance and the repeatability of the observed behaviour. To achieve this goal, prior to each measurement, the electrical connections between the board and the voltage source were always disconnected. A voltage range of ±10 V was used for the experiments, with each step being 1 V. Measuring at five separate sites yielded consistent results; one probe remained stationary at the reference site while the other was moved a constant distance for every sample. The samples with the highest current values utilised the following parameters: Coating speed of 500 rpm; graphene sonication period of 2.5 hours. As illustrated in Figure 10, the I-V values between the two sites for the graphene that was deposited for one drop are less than 0 Ar. Because its current value at 10 V is 27.7701 A, the highest of all the coatings examined, it is evident that the graphene coating has the best electrical properties. However, this might be affected by how well the graphene solution disperses over the substrate. Because of its higher surface area, well-dispersed facilitates electron motion more effectively. Films made of graphene exhibit excellent conductivity, since the current increases in a linear relationship with the applied voltage to the surface.

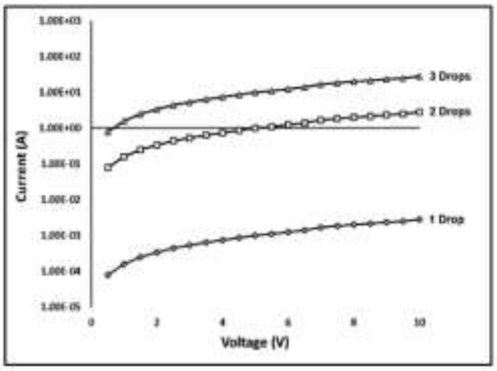

Figure :10 *I-V* properties for 1, 2 and 3 drops of graphene solution on polymer

6.Conclusion

In conclusion multitude of methods exist for creating graphene as a flexible electrode, and it is clear that there is a pressing need to expand graphene's applied capabilities. One reason graphene is so intriguing is because of its remarkable mechanical and chemical durability as well as its ballistic transport at ambient temperature. The development of electrode-equipped wearable, implantable, and portable sensing devices has the potential to influence destiny. Many fields of biomedical engineering stand to gain from tiny, powerful, biocompatible devices.110, 192-200 The objective of compiling and detailing numerous main and minor fabrication methods was to alleviate the burden of providing compressed educational and experimental pieces. This was done so that researchers could learn from them and manipulate them to make perfect graphene electrodes. The most important steps in creating the ideal electrode were modifying Hummers' process, using chemical vapour deposition, and exfoliating graphite oxide. Overall, the graphene films showed improved electrical properties after 3 drops, indicating that this was the preferable amount of graphene coating. Graphene-coated polymer electrodes are a more efficient way of transferring energy, as they can conduct electrical current much better than traditional electrodes. Graphene-coated electrodes are also more resistant to corrosion, making them more reliable for energy applications.

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