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"Electrical Conductivity Studies of Graphene Oxide Incorporated Polyvinyl Alcohol - Polypyrrole - Silver Nanoparticle"

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Abstract
Polymer nanocomposites incorporated conductive fillers are getting lots of interest in these nanocomposites fields because they boost electrical properties, mechanical properties, and thermal performance. In this work, we made a nanocomposite of Polyvinyl alcohol (PVA), Polypyrrole (PPy), Silver nanoparticles (AgNPs), and Graphene oxide (GO). We used in situ polymerization method for polymerization of films. X-ray diffraction (XRD) technique has been used for structural analysis, and using two-point probe method, electrical conductivity was measured at room temperature. Adding AgNPs and GO with PVA-PPy base by creating better paths for electrons and lowering resistance to charge movement. The combination of PPy, silver nanoparticles, and graphene oxide builds good network that conducts electricity very well. The electrical conductivity of prepared nanocomposite is around 0.44 to 1.16 S/cm. Overall, this PVA-PPy-AgNP-GO material looks great for flexible electronics, sensors, and energy storage.
Keywords: Polypyrrole, Graphene Oxide, Silver Nanoparticles, Nanocomposites, Electrical Conductivity.

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1. Introduction

Conductive polymer nanocomposites are very popular in today's electronics and electrochemistry world as they offer adjustable electrical properties with good flexibility. Polyvinyl alcohol (PVA) is a synthetic polymer has good chemical stability, and biocompatibility & has great film-forming ability. However, PVA doesn't conduct electricity on its own, so it's not ideal to used PVA for electronic gadgets directly. To fix that, we need to mix a conductive stuff like polymers, metal nanoparticles, and carbon nanomaterials.[1–4] The most popular conductive polymers that naturally good at carrying electricity is Polypyrrole (PPy), PPy holds up well in different environments, and is super easy to make. Adding PPy in PVA boosts the composite's electrical conductivity.[5–7] Metal nanoparticles, such as AgNPs, are most widely used to enhance electrical conductivity, as they're good at both electrical and thermal conduction. AgNPs act like bridges linking polymer chains, making it easier for charges through the whole composite.[8,9] Graphene oxide (GO) is another conductive filler material as it has very large surface area, it has good mechanical strength, and solid electrical conductivity as well. When GO is mixed into polymer matrices, it builds conductive pathways that boost the material's overall electrical performance.[10–12] Mixing conductive polymers, metal nanoparticles, and graphene-based material creates a synergy that supercharges the electrical conductivity in polymer nanocomposites.[13] So, making hybrid nanocomposites with PVA, PPy, AgNPs, and GO has become an interesting research area. The aim of this study is to evaluate how the incorporation of AgNPs and GO influences the conductive properties of the PVA-PPy matrix and to explore its applications in advanced electronic materials.[14,15]

2. Methods

Preparation of stock solution

The aqueous solution of 4% (w/v) PVA prepared by dissolving PVA in distilled water. Later stirred it hard for 3 - 4 hours around 68°C on a hot plate using a magnetic stirrer, once dissolved solutions were kept to cool at room temperature. The final PVA solution came out clear, almost colourless, and pretty viscous.[14,16,17]

Preparation of Silver (Ag) nanoparticles

Using the Turkevich method we synthesised silver nanoparticles. In typical process, dissolve silver nitrate in deionized water to make a 1 mM solution. Heat 500 mL of it to boiling, then add 50 mL of 10 mM trisodium citrate drop by drop about 1 per second. The solution slowly turns golden yellow, signalling AgNP formation. [18–20]

Synthesis of Graphene Oxide

We used Modified Hummer's technique to prepare GO. In a beaker, 1g graphite & .5g $NaNO_3$ with 25 mL concentrated H_2SO_4 were mixed together. The mixture was stirred for 25 – 35 mins at around 0°C to 5°C. "While stirring, slowly added 3g of $KMnO_4$ to the suspension and the temperature was maintained to below 18°C. After addition of $KMnO_4$, the reaction mixture was then stirred at 30°C till it became pasty & light brownish in colour". Later, 30 mL H_2O was added slowly to the obtained pasty substance with vigorous stirring. The diluted yellow suspension was again stirred at around 97°C for 24 hours. 10 mL 30% H_2O_2 was added finally for termination of the reaction. The whole reaction mixture was washed by centrifuging with 1.5M HCl followed by distilled water for 8 to 10 times and filtered to obtain grey GO sheets.[10,21–24]

Synthesis of PVA-PPy-AgNP-GO Nanocomposite

To synthesize the nanocomposite, in-situ chemical oxidative polymerization method was used for the polymerization of pyrrole in PVA, along with some GO and a silver nanoparticle colloid. First, we stirred the PVA solution with GO and AgNP suspension using a magnetic stirrer for 10 minutes in an ice bath to maintain the temperature. Then, added double distilled pyrrole drop by drop and kept stirring for another 30 minutes. Next, slowly poured pre-cooled 1M ferric chloride solution (the oxidant) to kick off pyrrole polymerization. The mixture reacted for 3hours under constant stirring in the ice bath, ensuring full polymerization. After that, gently stirred it for 24 more hours, ending up with a smooth, black solution. For films, we used solvent casting method, we poured a small amount (5-6 mL) onto a glass petri dish or polypropylene sheet to get ~30-40 micrometre thick films. Left them to dry at room temp, then peeled off the black nanocomposite films & stored all films in a vacuum desiccator for later tests.[14]

3. Results and Discussion

UV-Visible Spectroscopy

The UV-Visible absorption spectrum shows a characteristic SPR peak at around 423 nm, which is a typical signature of silver nanoparticles. The presence of a single and well-defined absorption band indicates the successful synthesis of predominantly spherical and relatively well-dispersed AgNPs. The observed SPR band in the range of 400–450 nm is consistent with previously reported values for silver nanoparticles, confirming the formation and stability of the synthesized nanoparticles.[19]

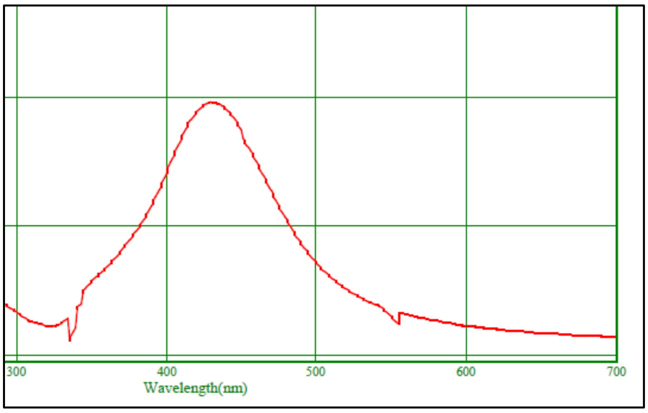


Fig.1 UV-Visible spectroscopy

X-Ray Diffraction Analysis

The XRD pattern of the PVA/PPy/AgNP/GO of different ratios of GO nanocomposite shows a broad peak centered near 20.4° indicates the semicrystalline structure of PVA. The peak at approximately 23.8° is attributed to π–π stacking interactions of polypyrrole chains. The diffraction peaks observed between 36° to 45° correspond to the silver nanoparticles, confirming the successful incorporation of AgNPs into the composite matrix. The similar curves with no new GO-specific peak indicate that GO does not introduce new crystalline phases detectable by XRD, and the PVA lattice remains the dominant contributor to the diffraction pattern. GO dispersed well within the matrix of PVA, as no distinct GO diffraction peak is observed and no phase separation is evident in the XRD data. The reduction in the intensity of the (101) peak with increasing GO content points to a decrease in overall crystallinity of the PVA–GO nanocomposite. This often means GO disrupts PVA crystallite formation or act as a barrier to crystalline growth.

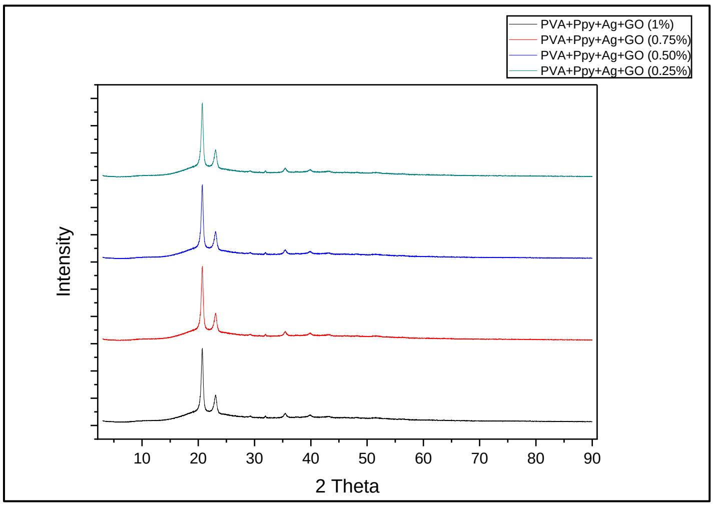
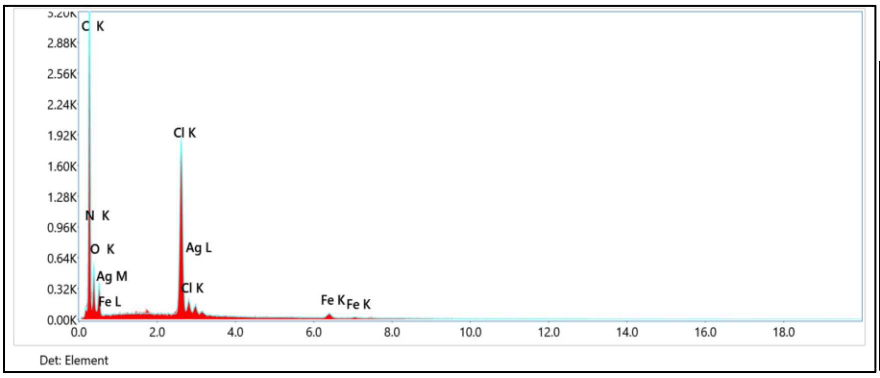


Fig.2 XRD Analysis

EDAX Analysis

EDAX spectrum shows prominent peaks corresponding to carbon, nitrogen, oxygen, chlorine, and silver elements. Carbon represents the major component of the composite (68.2 wt%), originating from graphene oxide, polyvinyl alcohol, and the polypyrrole polymer backbone. The presence of nitrogen (21.2 wt%) confirms the successful polymerization of pyrrole monomers within the composite structure. Oxygen (7.5 wt%) is attributed to the oxygen-containing functional groups present in graphene oxide and the hydroxyl groups of PVA. A small chlorine peak (2.5 wt%) is likely due to dopant ions originating from the oxidizing agent used during polypyrrole synthesis. The presence of silver (0.4 wt%) confirms the incorporation of silver nanoparticles into the composite matrix. The small amount of iron signal (0.2 wt%) may arise from residual oxidant or trace contamination.



eZAF Quant Result

Element	Weight %	Atomic %	Net Int.
C K	68.2	73.4	591.7
N K	21.2	19.5	79.4
O K	7.5	6.1	57.3
Cl K	2.5	0.9	571.7
Fe K	0.2	0.0	20.4
Ag L	0.4	0.0	32.5

Fig.3 EDAX Analysis

Electrical Conductivity

Electrical properties were calculated using V-I measurements. Resistance (R) from the slope of the V-I curves via Ohm's law: $V = IR$. Then, conductivity (σ) was calculated with $\sigma = \frac{L}{RA}$, where σ is in S/cm, L is film thickness, A is cross-sectional area, and R is resistance. Resistance has been taken from the straight-line of the V-I plots for each GO amount. Conductivity went up steadily as we added more GO, this might happen because PPy, AgNPs, and GO nanosheets teams up to form a connected network for electrons to travel through. GO helps electrons to flow between fillers, cutting down resistance in the matrix. Fig.4 shows the V-I curves for PVA/PPy/AgNP/GO nanocomposites at different GO levels. All samples had nearly straight lines, meaning ohmic conduction & no big barriers at the electrodes. Current increases smoothly with voltage and amount of GO, showing great charge transport. At the same voltage, 1 wt% GO had the highest current, followed by the rest. The electrical conductivity of prepared nanocomposite is around 0.44 to 1.16 S/cm. This proves conductivity improves with increase in GO concentration. The PPy-AgNP-GO combo creates linked pathways that lower resistance and let electrons flow through easily. The 1 wt% GO performs best electrically, perfect for flexible electronics, sensors, and conductive devices. [18,19,25]

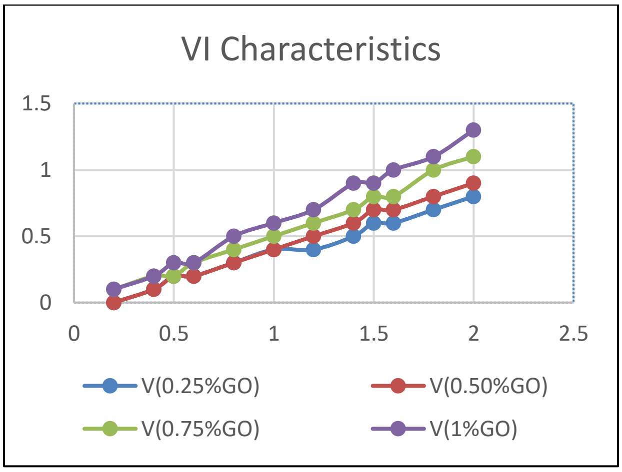


Fig.4 VI Characteristics

4. Conclusion

In this study, a nanocomposite of PVA-PPy-AgNP-GO was synthesized successfully using an in-situ chemical polymerization technique. Structural & morphological analyses confirmed the successful incorporation and uniform distribution of conductive fillers within the polymer matrix. Electrical conductivity measurements revealed a significant enhancement in conductivity due to the synergistic interaction between polypyrrole, silver nanoparticles, and graphene oxide. The improved conductive properties make this nanocomposite a potential candidate for applications in flexible electronics, sensors, conductive coatings, and energy storage devices. Future research may focus on optimizing filler concentration and exploring temperature-dependent electrical properties.

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Conflict of Interest

None

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