SYNTHESIS OF A POLYANILINE–SILVER NANOCOMPOSITE AND INVESTIGATION OF THE TEMPERATURE DEPENDENCE OF ITS ELECTRICAL CONDUCTIVITY

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Abstract: Polyaniline-based nanocomposites containing metallic nanoparticles have attracted significant attention due to their enhanced electrical, thermal, and electrochemical properties. In the present study, a silver nanoparticle–polyaniline nanocomposite (AgNPs–PANI–H_2SO_4) was synthesized through the adsorption of silver ions onto sulphuric acid-doped polyaniline followed by chemical reduction with ascorbic acid. The adsorption capacity of PANI–H_2SO_4 towards silver ions was determined to be 50 mg g^{-1}. The temperature dependence of the electrical conductivity of the resulting nanocomposite was investigated in the temperature range of 25–84°C under a constant applied voltage of 11 V. Experimental results showed that the electric current increased from 5 μA at 25°C to 21 μA at 84°C, indicating a significant increase in electrical conductivity with temperature. This behaviour is characteristic of semiconducting materials and can be attributed to enhanced charge carrier mobility, increased polaron and bipolaron transport, and improved electron transfer pathways provided by silver nanoparticles within the polymer matrix. The obtained results demonstrate that the AgNPs–PANI–H_2SO_4 nanocomposite is a promising temperature-sensitive conductive material with potential applications in sensors, thermistors, and electrochemical devices.

Keywords: Polyaniline, silver nanoparticles, nanocomposite, electrical conductivity, temperature dependence, sulphuric acid doping, electrochemical materials.

Polyaniline (PANI) belongs to the class of intrinsically conducting polymers and is widely used in sensors, energy storage devices, and electrochemical systems due to its high electrical conductivity, chemical stability, and relatively simple synthesis. The electrical properties of PANI strongly depend on its oxidation state and the nature of the dopant, and its conductivity increases significantly upon protonation with acids. The protonated emeraldine salt form is considered the most conductive state of PANI [1].

Polyaniline doped with sulphuric acid (H_2SO_4) is characterised by a high degree of protonation and good environmental stability. Under the action of H_2SO_4, the imine nitrogen atoms in the polymer chain become protonated, leading to the formation of polaronic and bipolaronic charge carriers. This enhances the electrical conductivity of the material and improves electron transport between polymer chains. Studies involving various dopants have confirmed that the type of acid significantly influences the morphology and electrical properties of polyaniline [2].

Silver nanoparticles (AgNPs) are nanomaterials distinguished by their high electrical and thermal conductivity, surface plasmon resonance properties, and antibacterial activity. The large specific surface area of nanoscale silver particles enhances their catalytic and electrochemical activity. Consequently, incorporating AgNPs into polymer composites can significantly improve their functional properties [3].

PANI–Ag composites are promising nanocomposite materials that combine the advantages of conducting polymers and metallic nanoparticles. Studies have shown that AgNPs are uniformly distributed within the PANI matrix and interact strongly with the polymer chains. Due to the high affinity of silver towards nitrogen atoms, AgNPs remain stably embedded within the PANI structure.

Gupta et al. investigated the morphological, optical, and electrical properties of PANI–Ag nanocomposites. TEM and SEM analyses revealed a uniform distribution of Ag nanoparticles throughout the polyaniline matrix. XRD results confirmed the presence of crystalline metallic silver within the composite. The researchers observed that increasing the silver content led to enhanced electrical conductivity. Furthermore, Ag nanoparticles were reported to improve the thermal stability of the composite [4].

The optical properties of PANI–Ag composites are also of considerable interest. The surface plasmon resonance (SPR) absorption band characteristic of silver nanoparticles is typically observed in the range of 380–450 nm. The presence of this band confirms the formation of metallic silver nanoparticles within the composite. Moreover, the incorporation of AgNPs has been found to reduce the optical band gap of polyaniline and facilitate electron transport.

Ghorbani and co-workers investigated the thermal properties of silver-containing polyaniline nanocomposites. TGA and DSC analyses demonstrated that the composites exhibited higher thermal stability than pure polyaniline. The authors attributed this behaviour to the strong interactions between the polymer chains and silver nanoparticles [5].

Thus, the literature review indicates that sulphuric acid-doped polyaniline and silver nanoparticle-based composites possess high electrical conductivity, good thermal stability, enhanced optical properties, and broad application potential. The incorporation of AgNPs into the PANI matrix improves charge transport processes, increases crystallinity and thermal stability, and makes the material a promising candidate for sensor and electrochemical applications.

Based on the literature findings, we carried out studies aimed at preparing a PANI-H_2SO_4 Ag nanoparticle nanocomposite and investigating its properties. The nanocomposite was synthesised using the following procedure.

A total of 2.098 g of PANI-H_2SO_4 was added to 200 mL of a 0.001 M $AgNO_3$ solution at 25°C. The mixture was left for 24 hours. Subsequently, the suspension was filtered, and the precipitate was separated and dried at 60°C. The concentration of silver ions in the filtrate was determined by titration. The amount of silver ions adsorbed onto PANI-H_2SO_4 was calculated from the difference between the initial silver ion concentration and the concentration after adsorption. The adsorption capacity of PANI-H_2SO_4 towards silver ions was found to be 50 mg g^{-1}.

To convert the silver ions retained within the PANI-H_2SO_4 structure into silver nanoparticles, a reduction reaction was carried out using a 0.03 M ascorbic acid solution for 2 hours at a mass-to-volume ratio of 1:100 (g/mL). The resulting mixture was filtered, and the precipitate was washed with distilled water. The obtained powder was dried. The temperature dependence of the electrical conductivity of the resulting AgNPs–PANI-H_2SO_4 nanocomposite was then investigated. For conductivity measurements, a constant voltage of 11 V was applied to the nanocomposite using a direct-current power supply. Subsequently, the temperature of the chamber containing the nanocomposite was gradually increased, and the current passing through the sample was measured (Table 1).

Table 1. Temperature dependence of the electrical conductivity of the AgNPs–PANI-H_2SO_4 nanocomposite

Temperature, °C	**Current, μA**	**Temperature, °C**	**Current, μA**
25	5	77	14
52	7	81	16
75	12	84	21

The obtained results clearly show that the electrical conductivity of the AgNPs–PANI-H_2SO_4 nanocomposite increased with increasing temperature. In particular, the current increased from 5 μA at 25°C to 21 μA at 84°C. This behaviour indicates that the nanocomposite exhibits semiconducting properties.

It is well known that electrical charge transport in polyaniline-based conducting polymers occurs mainly through polarons and bipolarons. As the temperature increases, the mobility of these charge carriers rises, and electron tunnelling processes between polymer chains become more active. Consequently, the electrical resistance of the material decreases, leading to an increase in conductivity. In sulphuric acid-doped polyaniline, protonated nitrogen centres increase the concentration of charge carriers and facilitate charge transport.

Silver nanoparticles present within the nanocomposite also play an important role in enhancing electrical conductivity. AgNPs create additional pathways for electron transport within the polymer matrix and facilitate charge carrier migration. With increasing temperature, charge transfer across the interfaces between polyaniline chains and silver nanoparticles becomes more efficient, resulting in an overall increase in the electrical conductivity of the composite.

The results suggest that the AgNPs–PANI-H_2SO_4 nanocomposite is a promising temperature-sensitive conductive material. The observed increase in conductivity with temperature indicates its potential application in temperature sensors, thermistors, and other electrochemical devices. However, to gain a deeper understanding of the charge transport mechanism, further studies involving a wider temperature range and detailed electrical resistance measurements are required.

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