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Device application of GO: Ag nanoparticles produced by bacterial synthesis method

Fatih SERÇEOĞLU [1]
[1] Department of Nanoscience and Nanoengineering, Graduate School of Natural and Applied Sciences, Atatürk University, Erzurum, Türkiye

Tuba ÇAKICI CAN [2]
[2] Department of Electricity and Energy, Ispir Hamza Polat Vocational School of Higher Education, Atatürk University, Erzurum, Türkiye

Murat ÖZDAL [3]
[3] Department of Biology, Faculty of Science, Atatürk University, Erzurum, Türkiye

ABSTRACT

In recent years, the bacterial synthesis method for nanoparticle production has gained significant attention in research due to its advantages over physical and chemical techniques. In this study, silver-doped graphene oxide (GO) nanoparticles were simultaneously reduced in composite form in a bacterial culture medium. The bacterial synthesis method simultaneously reduced the silver (Ag)-doped graphene oxide (GO: Ag) nanoparticles. The size and shape of the reduced GO:Ag nanoparticles were determined using advanced spectroscopic imaging techniques. Transmission electron microscopy (TEM) images of GO: Ag nanoparticles have reported their approximate dimensions to be around 30-70 nm. Thin films were created by spreading GO:Ag nanoparticles onto glass and p-Si surfaces and drying them at 350 °C. The optical, structural, and electronic properties of these thin films were investigated. The energy band gap value of the film was estimated as 0.75 eV employing the double-beam UV-Vis spectrophotometer technique to reveal its optical properties. The given value suggests the generation of an electron-rich thin film with a narrow energy band gap. X-ray diffraction (XRD) and Raman techniques were used to explore the structural properties of a GO:Ag semiconductor thin film. The Raman technique yielded peak values for the GO:Ag structure, specifically in the D and G band energy values, at 1348 and 1568 cm^{-1}. Rectifying contacts with a diameter of 1 micrometer were made using Ag metal on this film structure. The current-voltage characteristics of the Ag/GO: Ag/p-Si/Ag structure made after these contacts were investigated.

Keywords: Graphene oxide, Ag, Nanoparticles, Bacterial Synthesis, Current-Voltage

INTRODUCTION

Recent advancements in gas sensor applications have involved the creation of nanoparticles by physical, chemical, and biological methods. Biological procedures are desirable due to their simplicity, ecological sustainability, less toxic emissions, and lower costs compared to alternative manufacturing methods [1,2]. Moreover, employing microbes or bacteria for the production of nanoparticles with specific size, shape, and composition is a considerable benefit. The bacterial synthesis technique readily produces thin films on chosen substrates owing to its user-friendliness, cost-efficiency, energy-free characteristics, absence of costly components such as vacuum apparatus, and environmental safety [3]. The electrical, textile, energy, computer, medical food, optical, and aerospace sectors produce metal nanomaterials (including magnesium, gold, graphene, selenium, copper, zinc, silver, iron, titanium, and cadmium) for diverse uses. Certain bacterial synthesis mechanisms exhibit an exceptional capacity to withstand elevated chemical concentrations [4,5]. The synthesis must be scalable, straightforward, and economical, while also incorporating principles of "green" biological synthesis. The film deposition method should avoid energy-intensive procedures. Execute all processes with low thermal exposure and without the emission of hazardous gases.

This work is the inaugural publication of ecologically benign and readily available microbial biosynthesised complex GO: Ag nanoparticles. We examined the dimensions and architecture of GO:Ag nanoparticles via TEM. We similarly used approaches to directly generate high- quality GO:Ag compound thin films, grounded in the homogeneous nucleation and growth mechanism. Gold nanoparticles were sintered as a nano-thin layer on glass and p-Si substrates following their creation as compound nanoparticles via a bacterial manufacturing technique. The optical and structural characteristics of the synthesized GO:Ag thin films were examined. The Ag/GO: Ag/p-Si/Ag and device structures employed in this investigation were constructed on p-type silicon wafers with a (100) surface orientation and glass substrates. Several electronic properties of Ag/GO, Ag/p-Si/Ag, and the device structure were determined using I-V measurements.

METHOD

Fabrication and electrical characterization of the Ag/GO: Ag/p-Si/Ag device structure

The initial step in acquiring the Ag/GO: Ag/p-Si/Ag device structure was the chemical cleaning of a p-Si crystal wafer orientated in the (100) direction. The literature offers a detailed description of the chemical cleaning process [6]. In a vacuum chamber at a pressure of 1×10^{-5} Torr, we established an

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Corresponding author:
Tuba ÇAKICI CAN
E-mail:
tuba.cakici@atauni.edu.tr

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ohmic contact by thermally evaporating Ag onto the substrate's backside. The p-Si/Ag structure underwent annealing at about 550 °C for 3 minutes in a flowing dry nitrogen atmosphere to attain a low resistance back ohmic contact. The precursor with GO:Ag nanoparticles was applied to the polished surface of the p-Si/Ag structure, yielding low-resistance ohmic contact. This was accomplished by depositing roughly 5 cc at a substrate temperature of 350 °C. As a result, a GO:Ag thin film was fabricated.

The Ag metal, functioning as a rectifier contact with a diameter of roughly 1 mm on the pole of this film, was produced using a shadow mask in a vacuum chamber maintained at a pressure of 1×10^{-5} Torr. This procedure resulted in the creation of the Ag/GO: Ag/p-Si/Ag device architecture. The current-voltage (I-V) measurements of this structure were obtained using the Keithley 2400 source meter equipment.

RESULTS

Figure 1 illustrates the optical absorption spectra of a GO: Ag thin film deposited on a glass substrate as a function of wavelength in the range of 300 to 1000 nm. To figure out the numerical band gap energy of the GO:Ag thin film sample, the absorption coefficient as a function of photon wavelength is required. The below mathematical formula defines the transmission of light through a medium:

$$I = I_0 e^{-\alpha d} \qquad \textbf{Eq. 1.}$$

In this context, I, I_0, and d indicate the transmitted light intensity, incident light intensity, and the thickness of the thin film sample, respectively.

The outcome of graphing $(\alpha h\nu)^2$ against hν is displayed in Fig. 1, where a curve is depicted in the inset. The band gap energy value of the GO: Ag thin film was determined to be 0.75 eV through the application of the extrapolation method to the linear section of the curve.

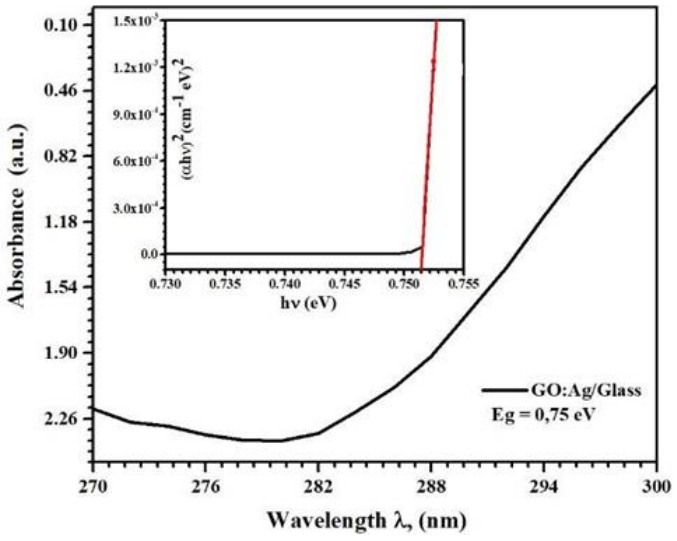

Fig. 1. The optical pilot of GO:Ag thin film on the glass substrate; Absorption vs. wavelength and band gap energy.

The XRD pattern of the GO:Ag thin film deposited on the glass substrate is illustrated in Fig. 2. The five XRD peaks positioned at 2Θ angles, as presented in Table 1, are clearly identified and match closely with the JCPDS 00-021-1016 pattern associated with a hexagonal phase of GO thin film. The analysis reveals that the GO:Ag thin film exhibits a polycrystalline nature, while the Ag thin film is characterized by a cubic crystal structure with a nano-crystalline nature.

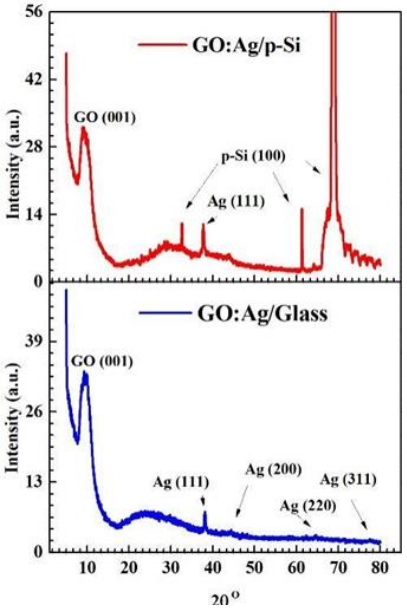

Fig. 2. XRD pilots of GO:Ag thin films on glass (blue line) and p-Si substrates (red line).

The newly formed graphite regions resulting from Ag doping in GO exhibit an increase in quantity, although they remain relatively minor, as illustrated in Fig 3. The spectra indicate the presence of the D (defect) and G (graphite) bands, along with a hexagonal structure. The characteristic Raman spectroscopy peaks of the GO crystal structure are observed at 1580 cm^{-1} and 1600 cm^{-1}. The incorporation of Ag in GO resulted in a minor shift in peak energy values when compared to the literature [5]. These results align consistently with the existing literature [5,6]. The intensity of the G peak (IG) observed in this study exceeds that of the D peak (ID). The operation performed on the sample maintains its regular structure.

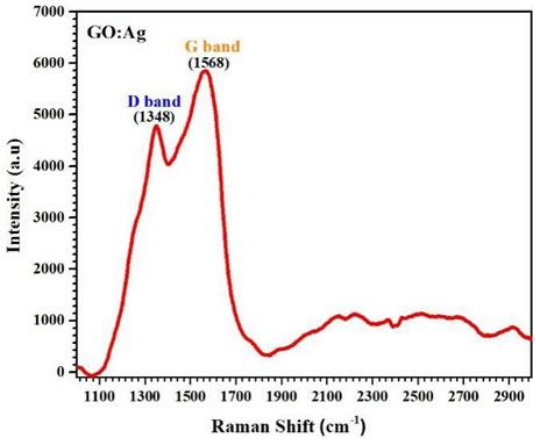

Fig. 3. Micro Raman shift result of GO: Ag thin film.

Table 1. The structural parameters of GO:Ag thin film evaluated on glass substrate

(hkl)	FWHM	FWHM (rad)	Intensity (a.u.)	2 (observed)	d-values ($n.$)	Crystal size (D) (nm)	Crystal
(001)GO	2,71682	0,047417	32,45833	9,92847	8,901	2,935	Hexagonal
(111)Ag	0,55367	0,009663	7,4375	38,19067	2,354	15,183	Cubic
(200)Ag	0,41185	0,007188	3,53125	44,38114	2,039	20,832	Cubic
(220)Ag	0,51917	0,009061	3,01042	64,60547	1,441	18,103	Cubic
(311)Ag	0,57497	0,010035	2,19792	77,60219	1,229	17,729	Cubic

Figures 4 (a) and (b) illustrate TEM micrographs of Ag and GO, exhibiting Ag nanoparticles at an average size of 200 nm. Silver nanoparticles are spherically distributed and significantly more apparent in Fig. 4 (a). In Fig. 4 (b), remarkable spherical particles are evenly dispersed throughout the GO structure within the typical sheet structures. The identified nanoparticles at the nanoscale measure between 30 nm and 70 nm. Comparison of the TEM micrographs of Ag and GO:Ag nanoparticles at 200 nm revealed that the aggregation of Ag nanoparticles in a cubic configuration resulted in the formation of nano-sized, regular spherical nanoparticles. Nonetheless, inside the two-dimensional characteristic sheet-like structure of GO, uniformly distributed Ag spherical nanoparticles were identified for GO:Ag.

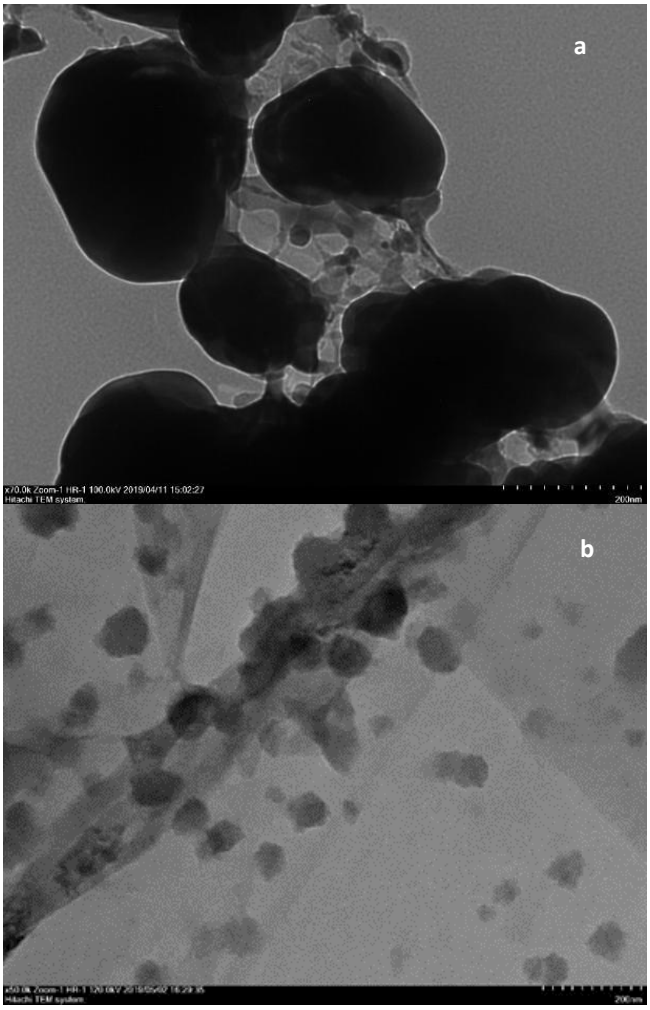

Fig.4. TEM image of Ag (a) and GO: Ag (b) nanoparticles at 200 nm.

Figure 5 shows the dark and room temperature semi-logarithmic I-V characteristic plots of the produced diodes. The rectifying activity of the Ag/GO:Ag/p-Si/Ag diode structure was easy within the bias voltage range that was examined.

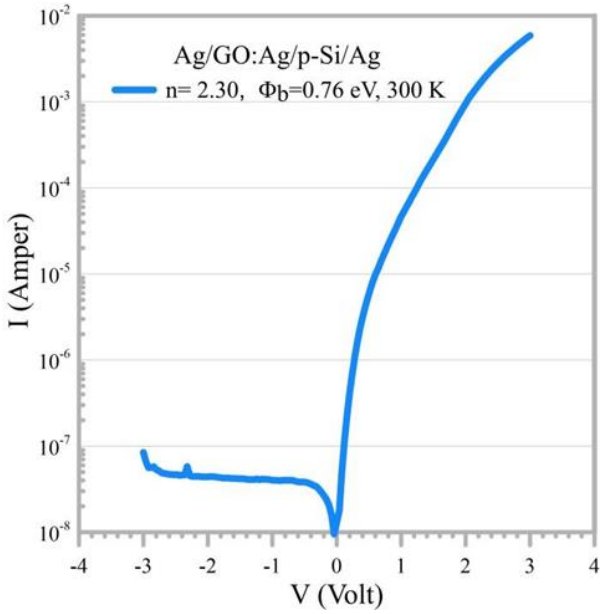

Fig.5. Semi-logarithmic I-V characteristic plots of the produced Ag/GO:Ag/p-Si/Ag at room temperature.

Diode parameters such as saturation current (I0), unbiased barrier height, and ideality factor (n) were derived from the forward bias region of the I-V characteristic plots to analyse the current transport mechanisms and performance of the produced diodes, based on various theoretical current conduction mechanisms proposed by the thermionic emission model [7]. The predominant current behaviour could be described through the thermionic emission model as:

$$I = I_0 \left[exp\left(\frac{eV}{nkT}\right) - 1 \right] \quad \textbf{Eq. 2.}$$

$$I_0 = A\ A^*\ T^2\ \ exp\ \ \left(-\frac{q\Phi_b}{kT}\right) \quad \textbf{Eq. 3.}$$

$$n = \frac{q}{kT}\frac{dV}{d(ln\ I)} \quad \textbf{Eq. 4.}$$

Equations 2, 3, and 4 were used to find the n and I_0 values for the Ag/GO: Ag/p- Si/Ag diode structure. They were 2.30 eV, 0.76 eV, and 1.27 x 10^{-8} Ampere, respectively. The n and I_0 values of the fabricated device were obtained by extrapolating the semi-logarithmic I-V graph (represented in Fig. 5) at low voltage values approaching the forward bias current, utilizing the slope equation.

CONCLUSION

This study presents the simultaneous reduction of GO: Ag nanoparticles within a single container using the bacterial synthesis method, indicating an innovative addition to the existing literature. Details regarding the approximate size and shape were obtained through the process of TEM analyses on GO: Ag nanoparticles. The nanoparticles were deposited and subsequently dried to create a film on glass and p-Si (100) by setting the substrate temperature to 350 °C. The dried nanoparticles underwent sintering, resulting in the formation of a thin film. The thin films underwent structural and optical characterization. The Ag/GO structure was established by directly applying Ag metal contacts onto these thin films, resulting in an Ag/p-Si/Ag configuration. The fundamental electrical parameters of this structure were analyzed under ambient conditions in the absence of light. This device structure demonstrates its effectiveness as a rectifier contact and shows potential applicability in photo-diodes for gas sensors.

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