A Novel Synthesis of the Graphene Oxide-Silver (GO-Ag) Nanocomposite for Unique Physiochemical Applications

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ABSTRACT: Graphene oxide-silver nanocomposite (GO-Ag) was fabricated via the sonochemical method, which shows unique physiochemical properties. Graphene oxide (GO) and silver nanoparticles (AgNPs) were synthesized by modified Hummer’s and Chemical reduction methods, respectively. The synthesized nanocomposite was characterized using powder X-ray diffraction, Raman spectroscopy, and Fourier-transform infrared spectroscopy. The surface morphology of synthesized nanoparticles was studied using scanning electron microscopy and transmission electron microscopy. The thermoluminescence property of the nanocomposite was analyzed by irradiating the samples in gamma radiation at 1 kGy. Electrochemical reversibility of the GO-Ag nanocomposite was examined by cyclic voltammetry. The photocatalytic application of the nanocomposite was studied using degradation of methylene blue dye. Results reveal that doping of AgNPs on the GO surface not only improves its dye degradation property but also enhances its thermoluminescence property. This knowledge will be helpful in determining the antibacterial property of the GO-Ag nanocomposite in the future.

1. INTRODUCTION

Over the last few decades with the advent of nanotechnology, scientists have drawn extreme research interest regarding nanomaterial development. Among the nanomaterials, graphene and related compounds have emerged as a distinctive class of materials because of their unique structure and functionalities. Graphene oxide (GO), a monolayer sheet of graphite, serves as a precursor for the synthesis of reduced graphene oxide (rGO).1 Like graphene, GO has a similar hexagonal carbon structure with hydroxyl (–OH), alkoxy (C–O–C), carbonyl (C=O), carboxylic acid (–COOH), and other oxygen-based functional groups as shown in Figure 1.2,3 Due to the presence of these functional groups, GO exhibits hydrophilic character that makes it a water-soluble nanomaterial.4 Moreover, the surface functionalization of GO has presented many opportunities regarding its application in the development of nanocomposite materials. GO has high conductivity and shows diverse applications in the field such as sensors, anticancer properties, electronics, biomedicine antibacterial coatings, photocatalytic activity, water decontamination, solar desalination, and drug delivery.5–21 However, the nanocomposite enhances GO properties. Among all transition elements, silver (Ag) is the most conductive and reactive material and has also been used recently in fabricating silver-
doped graphene oxide with favorable properties of low resistance, good dispersion, and enhanced mechanical strength. Recently, due to its bactericidal nature, AgNPs are getting much attention in antibacterial applications. AgNPs are dispersed on the surface of GO and intercalated in between the layers of GO to study the electrochemical properties and photocatalytic dye degradation rate of the samples.

Here in the present work, the GO-Ag nanocomposite was synthesized by the sonochemical method coupled with subsequent shock freezing. The effect of doping on various properties such as size, morphology, and composition of GO nanocomposite was also analyzed. The electrochemical reversibility and capability of GO-Ag nanocomposite working as a photocatalyst for removal of dye from wastewater were also examined. Results concluded that this will add additional knowledge to develop GO-Ag nanocomposites for various applications.

2. RESULTS AND DISCUSSION

2.1. Scanning Electron Microscopy (SEM). SEM micrographs of GO and GO-Ag nanocomposite are shown in Figure 2. Different layers of GO are observed in Figure 2a, whereas the deposition of AgNPs on the GO surface is observed in Figure 2b. The elemental analysis of the GO-Ag nanocomposite was performed by using EDX, which confirmed that 36.17% of AgNPs were deposited on the GO surface. A peak near 1.0 keV was observed, which corresponds to carbon, and a peak around 3 keV was correlated to the binding energy of AgL₂. Results indicate that a synthesized GO-Ag nanocomposite was composed of GO/AgNPs in the 2:1 ratio and no other impurities were detected in the EDX spectrum. This kind of AgNP-functionalized GO nanocomposite could be a promising material in the field of water purification.

2.2. Transmittance Electron Microscopy (TEM). The morphology of the GO-Ag nanocomposite was examined by using TEM (Figure 3). It represents the exfoliated GO sheet, whereas GO exhibits the lamellar structure where AgNPs were embedded (Figure 3b). The average size of AgNPs was about 18 nm (calculated using ImageJ software). This result was in good agreement with XRD, which suggests the FCC pattern of AgNPs and also proposed that AgNPs are intercalated on the GO surface.

2.3. Powder X-ray Diffraction (PXRD) Analysis. Figure 4 represents the PXRD pattern of synthesized GO, AgNPs, and GO-Ag nanocomposites. The PXRD pattern of GO exhibits a strong 2θ = 10.19° value that corresponds to the plane (001). Additionally, a small peak at 2θ = 20.93° was observed, which reflects the (002) plane. In GO, the interlayer spacing increased as compared to graphite due to addition of
oxygen-containing functional groups during oxidation of graphite.\textsuperscript{26} AgNPs exhibited a major diffraction peak with the 2θ value of 38.152° representing the (111) plane and are in good agreement with the previously reported literature.\textsuperscript{27} The GO-Ag nanocomposite (with interlayer spacing of 1.456 nm) exhibited a peak related to both GO and Ag nanoparticle. But a slight shift in the peak position toward lower 2θ value confirms the intercalation of AgNPs within GO sheets, as shown in Figure 4c.\textsuperscript{28}

2.4. Raman Spectroscopy. The Raman spectra of GO and GO-Ag nanocomposite are shown in Figure 5. As seen from the figure, GO exhibited D and G bands at 1347 and 1583 cm\textsuperscript{−1}, respectively, whereas the D and G bands of the GO-Ag nanocomposite appeared at 1353 and 1592 cm\textsuperscript{−1}, respectively. The D band was assigned to the breathing mode of k-point phonons with A\textsubscript{1g} symmetry, and the G band was ascribed to E\textsubscript{2g} phonon of sp\textsuperscript{2} carbon atoms.\textsuperscript{29} After doping, the D and G band values increase due to intercalation of AgNPs on the GO surface. The result is in good agreement with the corresponding PXRD data.

2.5. Fourier Transform Infrared Spectroscopy (FTIR) Analysis. The FTIR spectra of synthesized GO and GO-Ag nanocomposite ranging between 4000 and 400 cm\textsuperscript{−1} are presented in Figure 6. In GO, an adsorption band appeared at 3675 cm\textsuperscript{−1}, corresponding to intermolecular H-bonding, which disappeared in the GO-Ag nanocomposite. Additionally, other bands appeared at 2979, 1392, and 1046 cm\textsuperscript{−1}, corresponding to C–H, C=O, and C–O, respectively. After doping, a decrease in intensity of C=O and –OH band reflected intercalation of AgNPs on the GO surface. A blue shift was observed for these peaks after doping.\textsuperscript{30,31}

2.6. Cyclic Voltammetry (CV). The electrochemical properties of the synthesized nanocomposite were studied using cyclic voltammetry, as shown in Figure 7. CV graphs of GO show a cathodic peak potential at 0.04 V and an anodic peak potential at −0.6 V because of the presence of favorable oxygenated species on the GO surface, which create edge plane defects during the electrochemical reaction. It has been noted that oxygenated species can alter the observed electrochemistry of this redox probe.\textsuperscript{32} The CV plot of the GO-Ag composite shows a pair of redox peaks at −0.64 and −0.80 V for cathodic and anodic sweeps, respectively, representing Ag\textsuperscript{0/1+} interconversion.

2.7. Thermoluminescence (TL). Thermoluminescence (TL) is a well-known process that occurs due to thermally assisted release of irradiation-induced electrons from traps of the material. The TL curve provides important information such as kinetic parameters (activation energy, frequency factor, and order of kinetics) of materials, which have been subjected to radiations earlier. Thermoluminescence (TL) for GO and GO-Ag nanocomposite were recorded using a Harshaw TL reader 3500 after irradiation by a gamma irradiation source (Co\textsubscript{60}).\textsuperscript{33} Figure 8a represents the glow curve of GO and GO-Ag nanocomposite at a gamma irradiation dose of 1 kGy. GO shows a prominent TL peak at 422 K due to the relaxation of defects such as lattice defects or disorders, which were trapped by charge carriers during gamma irradiation.\textsuperscript{34} However, in the case of GO-Ag nanocomposites, the TL intensity increases with a peak position at 410 K along with a shoulder at 510 K. An increase in TL intensity after doping AgNPs concludes that Ag creates more traps between the valence band and the conduction band along with the increase in initial concen-
tration of charge carriers. The two apparent TL peaks of the GO-Ag nanocomposite in the glow curve signify that there are possibly two kinds of trapping sites (defects) present. However, it can be seen that these TL glow curves are asymmetric and complex curves; therefore, after careful analysis of the TL glow curve using the deconvolution method based on Kitti’s general-order equations, it is found that there are four kinds of traps exist in both samples, as shown in Figure 8b. The order of kinetics, activation energy, and frequency factor was calculated using Kitti’s general-order equation, as listed in Table 1. It can be observed from the activation energies of all four traps that Ag doping in GO shifts trap distribution.

2.8. Photocatalytic Dye Degradation. To demonstrate the practical utility of our compound as a photocatalyst for the degradation of organic pollutants in aqueous solution under UV visible radiation, MB dye solution was chosen as a sample. The potential ability of our compound was evaluated using MB dye solution by measuring the successive decrease in the absorption intensity as a function of exposure time. The photolysis of dye solution does not show a considerable change in their absorbance spectra. The comparative absorption spectra were plotted by using the absorption maxima of individual photocatalytic activity shown in Figure 9a. The graph shows no appreciable change in absorbance after the addition of the catalyst under dark for nearly 30 min, which confirms its reactivity in light.

The decrease in the absorbance values of the chosen dye molecules (MB) after the exposure of suspension in UV−visible radiation was observed. The C/Co plot with respect to time shows that for GO-Ag nanocomposite MB dye molecules were degraded up to 88% while GO degradation is up to 64% (Figure 9b). To measure the photocatalytic ability of the catalyst, its kinetic studies were also performed. The kinetic plot of ln(C/Co) versus the exposure time shows the linear behavior, which confirms that it follows pseudo-first-order kinetics.

The GO-Ag nanocomposite exhibits enhanced catalytic activity. This may originate from the synergy of a number of processes occurring simultaneously during the photocatalytic

| material                     | 1 kGy | 1st trap | 2nd trap | 3rd trap | 4th trap |
|------------------------------|-------|----------|----------|----------|----------|
| GO                           |       | 0.70     | 1.42     | 1.03     | 0.96     |
| energy (eV)                  |       |          |          |          |          |
| S”                          | 8.7 × 10^7 | 4.3 × 10^15 | 1.4 × 10^10 | 1.7 × 10^8 |
| B                            | 1.00  | 2.00     | 1.98     | 2.00     |
| GO-Ag nanocomposite          |       | 0.77     | 0.79     | 0.79     | 0.99     |
| energy (eV)                  |       |          |          |          |          |
| S”                          | 1.4 × 10^7 | 1.9 × 10^10 | 1.3 × 10^7 | 1.2 × 10^6 |
| B                            | 1.98  | 2.00     | 1.48     | 2.00     |

The order of kinetics (B) and frequency factor (S”) increases after the doping of Ag in GO, which signifies that the doped material contains shallow traps represented in Table 1.

Figure 9. Dye degradation: (a) percent degradation versus t, (b) C/Co versus t, and (c) ln(C/Co) versus t plots for GO, AgNPs, and GO-Ag nanocomposite.
reaction. The degradation mechanism can be assigned to the generation of reactive oxygen species (ROS) produced continuously during the photocatalytic process under the UV light irradiation, as shown in Figure 10. The AgNPs on the surface of GO sheets enhance the absorption coefficient of UV light due to the strong surface plasmon resonance (SPR). GO being a good electron acceptor and excellent charge transporter provides trapping sites for the electrons and delays the recombination process of electron (e\(^-\)) and hole (h\(^+\)) pair. The e\(^-\) and holes interact with the dissolved O\(_2\) and water in the presence of light to produce reactive oxygen species (O\(_2\), OH, etc.; eqs 1–3). These reactive species attack the dye molecules, resulting in degradation to CO\(_2\) and H\(_2\)O (eq 4).

\[
\begin{align*}
O_2 + e^- & \rightarrow O_2^- \\
H_2O + h^+ & \rightarrow OH + HO \\
GO(e^-) + O_2 & \rightarrow GO + O_2 \\
MB + OH + O_2 & \rightarrow CO_2 + H_2O
\end{align*}
\]

(1) (2) (3) (4)

As shown by the results, the photocatalytic degradation of methylene blue had increased many folds when it was treated with the GO-Ag nanocomposite.\(^{24}\) The above analysis confirms that the GO-Ag nanocomposite could be used as a promising material for the treatment of wastewater in the future.

3. CONCLUSIONS

In this study, we have synthesized GO, AgNPs, and GO-Ag nanocomposite and studied their thermoluminescence as well as photocatalytic properties. The GO-Ag nanocomposite was prepared by the sonochemical method. SEM and TEM micrographs have clearly shown the deposition of AgNPs on the surface of GO. Electrochemical activity of the GO-Ag nanocomposite and GO was studied using CV. The results have clearly shown inherent redox activity and chemical reversibility of the GO-Ag nanocomposite, so it could be used as a promising material for biosensors or other electrochemical applications. Thermoluminescence of the GO-Ag nanocomposite depicts the peak shift toward lower temperature, which suggested the possible use of the nanocomposite in medical dosimetry purposes as well as in radiation dosimetry after certain optimizations. Comparative studies of GO and GO-Ag nanocomposite will provide insight into the doping of metal nanoparticles in the graphene moiety to enhance its practicability in many fields.

4. MATERIAL AND METHODS

All chemicals were purchased from Merck, India. Concentrated H\(_2\)SO\(_4\) (97%, v/v) was purchased from Fisher Scientific.

4.1. Synthesis of Graphene Oxide (GO). Graphene oxide was synthesized using the modified Hummers method in which graphite was oxidized on treatment with KMnO\(_4\) and NaNO\(_3\) in concentrated H\(_2\)SO\(_4\).\(^{35}\) Graphite powder (1.2 g), to increase the interlayer spacing of the carbon source, and sodium nitrate (2 g; all chemicals purchased from Merck, India) were taken in a beaker containing 50 mL of concentrated H\(_2\)SO\(_4\) (97%, v/v; Fisher Scientific).\(^{36}\) At the outset, we implemented a precooling protocol (PCP) to control the highly exothermic nature of the involved reactions, which appeared as the primary reason for its explosive nature.\(^1\) The reaction mixture was stirred for 2 h in ice-cold water, maintaining its temperature (0–6 °C), and then 6 g of K\(_2\)MnO\(_4\) was slowly added to the reaction mixture. This mixture was controlled carefully to maintain the reaction temperature lower than 14 °C as per PCP to eliminate any possibility of explosion. After 2 h of continuous stirring, the ice bath was removed, and the sample mixture was stirred at 30 °C until it turns into a brownish paste and continued stirring for another 2 h for every half an hour increase in temperature.\(^{37}\) The reaction was weakened with the addition of 100 mL of water, and the temperature was increased quickly with effervescence with the change in color from purple to brownish. The solution mixture was finally treated with 8 mL of H\(_2\)O\(_2\) to terminate the reaction. Upon addition of H\(_2\)O\(_2\), a sudden change in color from dark brown to golden yellow was observed, which is a visual marker for the formation of GO.\(^{38}\) Finally, the mixture was centrifuged and rinsed with 8% HCl followed by DI water for multiple times. The obtained precipitates were filtered, dried, and ground in fine powder form.

4.2. Synthesis of Silver Nanoparticles (AgNPs).

Solution A of silver nitrate was prepared by adding 3.4 g of AgNO\(_3\) in 20 mL of distilled water. Solution B of polyvinylpyrrolidone (PVP) was prepared by dissolving PVP (1 g), glucose (1 g), and NaOH (1 g) in 60 mL of distilled water together.\(^{39}\) Solution B was heated to 60 °C with continuous stirring, and solution A was dropwise added to it. After that, the obtained mixture was stirred for 10 min. Finally, the mixture was centrifuged, washed with distilled water, and dried to get AgNPs.

4.3. Synthesis of GO-Ag Nanocomposite. The coupled nanosystem of GO-Ag was synthesized by mixing GO and Ag in a 2:1 ratio in 50 mL of methanol. The mixture was sonicated for 2 days followed by thermal annealing at 400 °C and subsequent cold freezing at −20 °C; the whole process was repeated twice. The powder was dried and homogenized.

4.4. Photocatalytic Dye Degradation. Photocatalytic degradation is one of the methods for the removal of environmental carcinogenic pollutant from wastewater. Here, we have reported application of the GO-Ag nanocomposite as a photocatalyst under UV–Vis irradiation for degradation of methylene blue dye solution.\(^{40}\)

Batch experiments were performed for both GO and GO-Ag nanocomposite using 30 mL of methylene blue (MB) solution (30 mg/L). In a dye solution, the catalyst was added (1 mg/L) and kept in the dark for 30 min to establish adsorption–desorption equilibrium. Subsequently, these solutions were exposed to UV–visible radiations producing UV light of 254 nm. Aliquots (3 mL) were taken out at fixed time intervals and...
centrifuged, and the absorbance was recorded at 664 nm using a UV–Vis spectrophotometer.

4.5. Characterization Techniques. For the X-ray diffraction measurement, the GO-Ag nanocomposite was sonicated using a probe-type sonicator for 15 min to avoid any possible agglomeration. XRD measurements were carried out using a Rigaku Ultima IV with a 10 mm Cu target slit and using a Cu Kα radiation of 1.54 Å wavelengths. Raman spectral measurements were carried out with 514 nm excitation wavelength (argon ion laser source) using a Renishaw PLC Raman spectrometer. For FTIR analysis, the samples were dried, ground with KBr pellets, and analyzed on a Bruker Tensor 37. For SEM (Carl Zeiss, Germany) analysis, a droplet of solution of nanoparticles was transferred on a clean glass slide (1 cm × 1 cm), and micrographs were taken randomly at various locations with the help of an accelerating voltage of 15 kV. TEM images were obtained using a FEI Philips Morgagni 268D at 100 kV acceleration voltages. Electrochemical measurements of the nanocomposite were performed on a computer-controlled CH-Instrument electrochemical workstation (model no. CHI 600D (SPL)) using three-electrode system (Ag/AgCl (1 M) as a reference electrode, platinum as a counter electrode, and glassy carbon as a working electrode) in dimethylformamide (DMF) and tetrabutylammonium perchlorate (TBAP) as a supporting electrolyte. The dielectric properties of the nanocomposite were studied using an Agilent 4284-A precision LCR meter at room temperature in the frequency range from 75 kHz to 5 MHz. The electrodes on the pellets surfaces were made by polishing and then coating with silver paste. The thermoluminescence (TL) property of the synthesized nanocomposite was studied by irradiating with gamma radiation of 365 nm wavelength. After the desired exposure, TL curves were recorded on a Harshaw TLD reader (model 3500), taking 5 mg of the sample each time at a fixed heating rate of 5 K/s. Photocatalytic dye degradation was executed on a Systronics UV–Visible double beam spectrophotometer operated at 1 nm resolution from 200 to 900 nm at room temperature.

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REFERENCES
(1) Ranjan, P.; Agrawal, S.; Sinha, A.; Rao, T. R.; Balakrishnan, J.; Thakur, A. D. A Low-Cost Non-explosive Synthesis of Graphene Oxide for Scalable Applications. Sci. Rep. 2018, 8, 12007.
(2) Smith, A. T.; LaChance, A. M.; Zeng, S.; Liu, B.; Sun, L. Synthesis, properties, and applications of graphene oxide/reduced graphene oxide and their nanocomposites. Nano Mater. Sci. 2019, 1, 31–47.
(3) Ban, F. Y.; Majid, S. R.; Huang, N. M.; Lim, H. N. Graphene Oxide and Its Electrochemical Performance. Int. J. Electrochem. Sci. 2012, 7, 4345–4351.
(4) Ramakrishnan, M. C.; Thangavelu, R. R. Synthesis and Characterization of Reduced Graphene Oxide. Adv. Mater. Res. 2013, 678, 56–60.
(5) Liu, Y.; Dong, X.; Chen, P. Biological and chemical sensors based on graphene materials. Chem. Soc. Rev. 2011, 41, 2283–2307.
(6) Kavinkumar, T.; Varunkumar, K.; Ravikumar, V.; Manivannan, S. Anticancer activity of graphene oxide-reduced graphene oxide-silver nanoparticle composites. J. Colloid Interface Sci. 2017, 505, 1125–1133.
(7) Chen, Y.; Xu, P.; Shu, Z.; Wu, M.; Wang, L.; Zhang, S.; Zheng, Y.; Chen, H.; Wang, J.; Li, Y.; Shi, J. Multifunctional graphene oxide-based triple stimuli-responsive nanotheranostics. Adv. Funct. Mater. 2014, 24, 4386–4396.
(8) Hu, W.; Peng, C.; Luo, W.; Lv, M.; Li, X.; Li, D.; Huang, Q.; Fan, C. Graphene-based antibacterial paper. ACS Nano 2010, 4, 4317–4323.
(9) Ghosh, D.; Dhabar, S.; Dey, A.; Mukherjee, S.; Joardar, N.; Babu, S. S. P.; Dey, B. Graphene oxide dispersed supramolecular hydrogel capped benign green silver nanoparticles for anticancer, antimicrobial,
cell attachment and intracellular imaging applications. J. Mol. Liq. 2019, 282, 1–12.

(10) Singh, P.; Shandilya, P.; Raizada, P.; Sudhaik, A.; Rahmani-Sani, A.; Hosseini-Bandegharaei, A. Review on various strategies for enhancing photocatalytic activity of graphene based nanocomposites for water purification. Arab. J. Chem. 2020, 13, 3498–3520.

(11) Safarpour, M.; Khataee, A. Graphene-Based Materials for Water Purification. Nanoscale Mater. Water Purif. 2019, 383–430.

(12) Li, X.; Zhu, B.; Zhu, J. Graphene oxide based materials for desalination. Carbon 2019, 146, 320–328.

(13) Zhang, L.; Xia, J.; Zhao, Q.; Liu, L.; Zhang, Z. Functional graphene oxide as a nanocarrier for controlled loading and targeted delivery of mixed anticancer drugs. Small 2010, 6, 537–544.

(14) Chen, D.; Zhuang, X.; Zhai, J.; Zheng, Y.; Lu, H.; Chen, L. Preparation of highly sensitive Pt nanoparticles-carbon quantum dots/ionic liquid functionalized graphene oxide nanocomposites and application for H2O2 detection. Sens. Actuators, B 2018, 255, 1500–1506.

(15) Lin, D.; Qin, T.; Wang, Y.; Sun, X.; Chen, L. Graphene Oxide Wrapped SEBS Tags: Multifunctional Platforms toward Optical Labeling, Photothermal Ablation of Bacteria, and the Monitoring of Killing Effect. ACS Appl. Mater. Interfaces 2014, 6, 1320–1329.

(16) Zhang, S.; Zhuang, X.; Chen, D.; Luan, F.; He, T.; Tian, C.; Chen, L. Simultaneous voltammetric determination of guanine and adenine using MnO2 nanosheets and ionic liquid-functionalized graphene combined with a permeation-selective polypyrrole membrane. Microchim. Acta 2019, 186, 450.

(17) Gurunathan, S.; Kim, J. H. Graphene Oxide-Silver Nanoparticles Nanocomposite Stimulates Differentiation in Human Neuroblastoma Cancer Cells (SH-SYSY). Int. J. Mol. Sci. 2017, 18, 2549.

(18) Zhuang, X.; Chen, D.; Wang, S.; Liu, H.; Chen, L. Manganese dioxide nanosheet-decorated ionic liquid-functionalized graphene for electrochemical theophylline biosensing. Sens. Actuators, B 2017, 251, 185–191.

(19) Sharma, S.; Prakash, V.; Mehta, S. K. Graphene/silver nanocomposites-potential electron mediators for proliferation in electrochemical sensing and SERS activity. TrAC, Trends Anal. Chem. 2017, 86, 155–171.

(20) Chen, J.; Sun, L.; Cheng, Y.; Lu, Z.; Shao, K.; Li, T.; Hu, C.; Han, H. Graphene Oxide-Silver Nanocomposite: Novel Agricultural Antimicrobial Agent against Fusarium graminearum for Crop Disease Prevention. ACS Appl. Mater. Interfaces 2016, 8, 24057–24070.

(21) Fu, X.; Wang, Y.; Liu, Y.; Liu, H.; Fu, L.; Wen, J.; Li, J.; Wei, P.; Chen, L. A graphene oxide/gold nanoparticle-based amplification method for SERS immunosassay of cardiac troponin I. Analyst 2019, 144, 1582–1589.

(22) Tran, M. H.; Jeong, H. K. Synthesis and Characterization of Silver Nanoparticles Doped Reduced Graphene Oxide. Chem. Phys. Lett. 2015, 630, 80–85.

(23) Marambio-Jones, C.; Hoek, E. M. V. A review of the antibacterial effects of silver nanomaterials and potential implications for human health and the environment. J. Nanopart. Res. 2010, 12, 1531–1551.

(24) Naz, S.; Mansoor, Q.; Nisar, A.; Karim, S.; Khan, M.; Ali, G.; Rahmani, A.; Ahmad, M. Silver Nanoparticles Embedded Graphene Oxide Nanocomposite with Enhanced Antibacterial and Photocatalytic Degradation Activities. ChemistrySelect 2019, 4, 8372–8377.

(25) Guzmán, G. G.; Jean Dille, S. G. Synthesis of Silver Nanoparticles by Chemical Reduction Method and their Antibacterial activity. Int. J. Mater. Metall. Eng. 2008, 2, 91–98.

(26) Gupta, V.; Sharma, N.; Singh, U.; Arif, M.; Singh, A. Higher oxidation level in graphene oxide. Optik 2017, 143, 115–124.

(27) Janardhanan, R.; Karuppaiah, M.; Hebalkar, N.; Rao, T. N. Synthesis and surface chemistry of nano silver particles. Polyhedron 2009, 28, 2522–2530.

(28) Kumar, R.; Singh, R.; Gurjar, A.; Kashyap, R.; Kumar, M.; Kumar, D. Study the thermal stabilization of functionalized graphene oxide. AIP Conf. Proc. 2019, 2142, No. 040015.