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Synthesis, Characterization, Photo-Luminescence and Antibacterial Activities of Silica-Graphene Oxide Composites

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Abstract

In this research, a novel thin film Si-GO10 and nano-powders Si-GO30 of silica-graphene oxide composite were prepared via sol-gel method and deposited on glass substrates using spray pyrolysis. XRD results showed a relatively strong peak in graphite layer that corresponds to the plane of (002). TEM images displayed that SiO₂ nano-particles were randomly distributed on the surface of GO plates, and the particle size in these nano-powders was below 50 nm. FESEM analysis demonstrated that silica nano-particles on the surface of GO plates exhibited almost a spherical and rod-like nanoparticles shapes, which in turn confirmed the formation of SiO₂-GO nano-hybrids. Photocatalytic investigations revealed the composite materials exhibit high activity for dye adsorption and decomposition. Si-GO10 thin film did not undergo degradation after 120 minutes, however, for Si-GO30 nano-powder, the adsorption peak intensity was reduced to 665 nm, indicating a decrease in the dye concentration in the solution. FTIR analysis demonstrated that carboxylic functional groups are decreased by increasing silica particles. Photo-Luminescence (PL) spectrum in Si-GO10 thin film disclosed a severe emission peak at about 675 nm. This spectrum was completely disappeared in Si-GO30 nano-powders. Results of the antibacterial properties emphasized that Si-GO30 nano-particle would prevent Escherichia. coli growth after 20 hours. The presented methodology allows for the synthesis

of graphene oxide supported silicon dioxide nano-particles for promising applications in photocatalytic and antibacterial fields.

Keywords: Graphene Oxide Nano-Powder, Silica, Nano-Composite, Sol-gel, Photocatalytic decomposition, Antibacterial activities

1.Introduction

In recent years, special attention has been paid to graphene oxide (GO), a monolayer of graphite with various oxygen containing functionalities, as one of the most interesting materials due to the high specific surface area and the exceptional thermal and mechanical properties [1-3]. In particular, it has good hydrophilic properties due to the existence of oxygen-dependent hydrophilic groups, such as hydroxyl, carbonyl and carboxyl groups, which not only scatters GO easily in the water in the form of a stable colloidal solution [4], but also facilitates the preparation of GO-based composites in solution [5, 6]. In addition, GO sheets show unique chemical and physical properties when combining in composite materials, this in turn has opened up the opportunity to use this material in number of potential industrial applications, such as solar cell [7], catalysts [8], sensors [9], supercapacitors [10, 11] and electronic components [12] [13]. Correspondingly, the physicochemical properties of GO contribute significantly in bacterial killing by triggering a cascade of toxic events [14]. Moreover, nanocomposites of graphene oxides have been utilized in the biomedical applications as a component in the anti-cancer drug delivery systems [15, 16]. It also has been demonstrated that nano antibacterial agents including GO displays inactivation and elimination ability from bacterial growth on the surfaces such as paper, water filtration membrane, and skin [17]. Nanocomposites

graphene can be harnessed for photocatalysis based waste water remediation, biomedicine and nano drug delivery [18].

An extensive literature survey on the synthesis procedures of graphene material, its properties, and smart applications has been performed [19-21]. On the other hand, silicon (Si) has widely been utilized as an important material in the industries of semiconductor, photovoltaic (PV) and microelectronics [22-24]. The high chemical sensitivity and large internal surface adsorption of porous silicon are actively used in touch sensing electronics and biomedical technologies[25]. However, more than 40% of Si material goes to waste through rolling to wafer, causing serious loss of valued resources as well as environmental pollution [26, 27]. Recycling Si particles from waste silicon have recently been a big concern due to the demand for valuable high purity silicon recycling, for better environmental protection and for many potential applications as value added materials [28]. Porous silicon possesses number of valuable properties. For instance, a severe visible photoluminescence of porous silicon increases its anti-reflective and band gap properties, providing the prospect of using the porous silicon in optoelectronics and photonics due to the quantum confinement effect in silicon nano-crystals [29, 30]. Silicon dioxide is a well-established support or additive to graphene oxide. In this view, Bakhsheshi-Rad et al. [31] reported that nano-SiO₂/GO coating exhibits an effective antibacterial activity and high corrosion resistance of the Mg alloy. Very recently, our group [32] has successfully synthesized silica-graphene oxide nano-composites via sol-gel method and deposited on glass substrate by spray pyrolysis for both optical and wetting purposes.

To date, sol gel synthesis of nano-SiO₂/GO coating on glass substrates for the photocatalytic and antibacterial applications is rarely reviewed in the literature. Hence, the present study reports for the first time novel experimental results on Si decorated graphene oxide nanocomposites and their efficiency in decomposing

methylene blue dye in addition to their antimicrobial efficiency toward E.coli strain growth. Furthermore, the crystalline structures, textural, morphological, and topological properties of the synthesized thin film and nano-powder were characterized via X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), atomic force microscopy (AFM) and transmission electron microscope (TEM). Fourier transform infrared scan (FTIR) and the particle size distribution measurements were also carried out.

2. Experimental Procedure

2.1. Sample Preparation

Tetraethyl orthosilicate abbreviated (TEOS) (Merck), graphene oxide colloid (Borhan Nanomeghyas Company, Iran) and deionized water were used as the precursors. Two graphene oxide solutions at a 1mg/ml concentration (10, 30ml) were firstly prepared and mixed with ethanol under stirring. 2ml of TEOS was added to each of the above solutions and stirred briefly. The concentrations of silica-graphene oxide composite were 20 and 6.67 % (v/v), respectively. The final solutions were diluted by adding deionized water and left at room temperature for one night and termed as Si-GO10 and Si-GO30. To prepare nano-powder sample of Si-GO30, the solution was dried in oven at 100°C then calcined at 400°C for one hour.

Concerning the synthesis of Si-GO10 thin film, 35ml of the above solution was sprayed using the spray pyrolysis method and compressed air as carrier gas. A simplified schematic illustration of the spray procedure is presented in Figure 1. For the growth of nano-materials, glass substrates were cleaned using ultrasonic bath for 30 minutes. Deposition conditions include the distance of the nozzle, deposition rate, and plate temperature are listed in Table 1.

2.2. Material Characterization

X-ray diffraction (XRD) instrument, D8 Advance Bruker YT model were used to confirm the structure of the thin films and nano-powders synthesized using $\text{CuK}\alpha$ radiation at $\lambda = 1.5418 \text{ \AA}$ at 2θ ranges from 5° to 80° . To investigate the surface morphology and chemical analysis of the layers, field emission scanning electron microscope (FESEM), MIRA3 TESCAN-XMU model equipped with EDX analysis was utilized. Atomic Force Microscopes (AFM) (manufactured by Ara-research Company) was employed to examine the surface topology of the layers. Fourier transform infrared (FTIR) spectrometer, Nicolet AVATAR 370 equipment model was operated in the wavenumber extending from $400\text{-}4000 \text{ cm}^{-1}$ to inspect the chemical bonds in the obtained layers and powders. To measure the porosity rate and effective surfaces, surface area measurements were attained using the Brunauer–Emmett–Teller (BET) (BEL model BELSORP MINI II) device based on the measurement of N_2 gas adsorbed and desorbed by the material surface at constant temperature of liquid nitrogen (77 K). The pressure range of our device was set from 0 to 85 kPa. The degassing process of the samples was carried out at 200°C for 4 hours. The photo-luminescence properties were inspected using the PL device (Perkin Elmer LS 45 model). Transmission electron microscopy (TEM), EM 208S model (100 kV) was used to probe the size and shape of the grains in nano-powders. The antibacterial activity of the samples against *Escherichia coli* DH5 alpha (Standard gram-negative bacterium) (ATCC 25922) (1399PTCC) was examined. These bacteria were purchased from the Iranian Scientific-Industrial Research Center.

3. Results and Discussion

3.1 Structural and Morphology Analysis

The crystalline structures of Si-GO10 and Si-GO30 thin films deposited at 400°C were investigated using x-ray diffraction (XRD) with CuK α radiation (1.5406 Å) and the obtained patterns are depicted in Figure 2. The amplitude (range) of 2 θ angle is from 5° to 80°. GO structure has been reported to have a broad diffraction peak of about 11° with a base space of 0.86 nm [33]. Following the ultrasonication of the GO colloidal with TEOS and their mixing, GO diffraction peak is sharply reduced and almost disappears, indicating the large distance of GO layers due to amorphous SiO₂ bonding [32, 34]. In the thin film as well as nano-powders of Si-GO10 and Si-GO30, a relatively strong peak is observed at an angle of 25° with an interlayer distance of 3.35 Å [35]. This peak corresponds to the plane of (002) of graphite layer [36], showing the complete reduction of GO to graphene [37]. This broad peak implies the disordered accumulation of different graphene layers to the graphite structure [38]. Furthermore, the peak at 2 θ =31.50 resembles (102) plane that is corresponding to cristobalite (i.e, polymorph of silica). The existence of this peak is ascribed to loading silica to the material. However, the peak disappeared when the ratio of graphene increases due to reducing oxygen contents of graphene oxide as a consequence of graphitization phenomenon [32].

Figure 3 shows the TEM images of Si-GO30 nano-powder at two scales of 100 nm and 300 nm to study the morphology of the nano-composite. As can be seen from the figure, graphene oxide plates have dimensions in the nanometer range. SiO₂ nano-particles are randomly scattered on the surface of GO plates and the particle size is below 50 nm. These images confirm the coverage of graphene oxide plates with SiO₂ nano-particles. Field emission scanning electron microscope (FESEM) images of Si-GO10, Si-GO30 samples are shown in Figure 4. The FESEM images demonstrate quite different morphology, the former is so rough and crumble, while the latter is relatively smooth on the surface. This can

be ascribed to the functional groups (hydroxyl and carboxyl groups) attached to the graphene surface. Therefore, the surface of the graphene oxide in Si-GO30 was relatively smooth [39]. Moreover, the surface of GO plates is smooth, and they slightly overlap each other, which is randomly crumpled by the drying process. Silica nano-particles appear on the surface of Si-GO30 sample as demonstrated in Figure 3 in a nearly spherical and rod-like nanoparticle shapes, confirming the formation of SiO_2/GO nano-hybrids. This difference in the shape of the silica particles is ascribed to that the calcination process by the thermal treatment (i.e. at 100°C and 400°C for one hour) occurring during the sample preparation is behind the emergence of rod-like nano-shape in the Si-GO30 sample [40]. For the spherical silica nano-shape, it is very well known that any thermodynamic system tends to minimize the change in its Gibbs free energy and the lowest free energy has been assigned to the spherical geometry structures.

Further, the nano-particles are randomly distributed on the surface and the particle size is less than 50 nm. The number of silica nano-particles in Si-GO30 sample is lower than that of Si-GO10 sample and the particle size is smaller.

In Figure 5, 2D and 3D images of atomic force microscope of Si-GO10 and Si-GO30 samples are compared. According to the figure, graphene oxide plates have coated the surface, and silica nano-particles are scattered in the form of prominent peaks on the surface, and SiGO nano-hybrids have a rough and heterogeneous morphology. Moreover, Graphene oxide plates have the lateral dimensions up to a few micrometers. The mean surface roughness of the samples was examined by AFM microscope. Root Mean Square Roughness (RMS) is assessed by determining the deviation of elevation between peaks and troughs in a particular region. The more deviation indicates the higher surface roughness. According to AFM results, the RMS values of Si-GO10 and Si-GO30 structures record 75.76 nm and 31.18 nm, respectively. These results indicate that the level of surface roughness of Si-GO10 sample is higher than that of Si-GO30 sample due to the

more presence of silica nano-particles in Si-GO10 sample as illustrated in FESEM images.

3.2 BET Analysis

The diagrams of adsorption-desorption isotherm of Si-GO10 and Si-GO30 samples are shown in Figure 6. The isotherm of Si-GO10 sample did not show the hysteresis loop. Implying the non-porosity nature of these sample, and meso-holes were not formed. To this end, one can expect that holes have the cylindrical shape. Concerning the isotherm of Si-GO30 sample, there is a difference between adsorption and desorption branches of the diagram where a relatively large hysteresis loop is formed in this range. The existence of the hysteresis loop in the isotherm diagram indicates the presence of meso-holes in the samples, which may confirm the small-angle FTIR and XRD results based on the formation of meso-holes resulting from the complete removal of micelle pattern. BET measurement indicating that the size of specific surface area of these samples was $469.24 \text{ m}^2/\text{g}$ for Si-GO10 and $127.22 \text{ m}^2/\text{g}$ for Si-GO30. It is observed from these findings that the specific surface area is decreased after loading graphene oxide to the samples. This decrease in specific surface area may be due to the filling and destruction of these holes as a result of ordering the atoms in new sites and the crystalline growth of the sample.

3.3 Photocatalytic Activity

Among all water pollutants, organic pollutants are one of the most persistent pollutants in purification processes, and in most cases, it is difficult to completely remove them from water sources. Dyes for instance, represent one of the main organic pollutants [41]. Environmentally, dye-containing wastewater would prevent sunlight from penetrating the water and impair the photosynthesis performance of aquatic plants as well as increases the chemical oxygen demand of water [42]. Some compounds and products resulting from the decomposition

of dyes are toxic and carcinogenic. In addition, the dyes are problematic due to their inappropriate appearance and low degradability and must be removed prior to discharge [43, 44]. Therefore, due to the importance of removal of organic pollutants, this research compares the photocatalytic properties of Si-GO10 thin film and Si-GO30 nano-powder in the presence of Methylene Blue (MB) [45].

In an oxidizing environment, the color of the solution of MB dye displays a blue color, whereas, it becomes colorless when exposing to a reducing agent [46]. Furthermore, MB is a type of cationic dye that has broad applications, especially in textiles, especially, in dyeing cotton, wool and silk. On the other hand, inhalation of this material can impair breathing, causing nausea, and vomiting. Direct exposure to MB may also cause burning sensation at the contact site and permanent eye damages may be resulted when contacting eyes. In this work, the photocatalytic activities of the attained composites were considered via the degradation of MB in solution. UV-Vis adsorption spectrum of this dye has reported a maximum adsorption peak at the wavelength of $\lambda_{\text{max}} = 659 \text{ nm}$. One shoulder and another peak also exist at $\lambda = 612 \text{ nm}$ and $\lambda = 290 \text{ nm}$, respectively [47].

Two MB solutions at a concentration of 1 ppm were firstly prepared to investigate the photocatalytic properties of graphene oxide-silica nano-composites. In one of the solutions, Si-GO30 nano-powders were placed and Si-GO10 thin films were put in the other one. The solutions were stirred in the dark for 30 minutes to achieve the adsorption-desorption equilibrium, 5ml of each solution was then taken and their adsorption rate was investigated by UV-Vis spectroscopy (A_0). The solutions were then irradiated by two types of UV radiation namely, UVC and UVB of 18W for 120 minutes. 5ml of each final solution was also taken and UV-Vis spectrum was investigated (A_t). The percentage of MB degradation was calculated by the equation below.

$$\text{The percentage of MB degradation} = \frac{A_0 - A_t}{A_0} \times 100$$

The absorption diagram in terms of wavelength for Si-GO10 thin film and Si-GO30 nano-powder under UV irradiation at 0 and 120 minutes is plotted in Figure 7. The investigation of results displays that in Si-GO10 thin film, no degradation occurred after 120 minutes but for Si-GO30 nano-powder, the adsorption peak intensity decreased at 665 nm, indicating a decrease in dye concentration in the solution and about 7% of MB was degraded. Analysis of the results showed that increasing the ratio of graphene oxide to silica nano-particles increased the rate of dye degradation of MB.

Semiconductor-based photocatalysts rely on the active absorption of photon from semiconductor to form an electron-hole pair, and this process depends on the size of the band gap [48]. The excited electron must be separated from the hole to avoid the recombination. GO is a chemically tunable 2-D material with a relatively large band gap [49]. Particularly, it can be utilized as a photocatalyst by doping of graphene oxide with metal oxides, owing to the large surface area [50, 51]. GO doping with metal oxides reduces its band gap, produces the electron-hole pair and prevents the recombination. It has been demonstrated that decreasing the band gap size would increase the degradation rate of MB in Si-GO30 sample as compared with Si-GO10 sample.

FTIR is an effective analytical tool mainly employed to explore the types of functional groups formed on silica-graphene oxide nano-hybrids. The adsorption and photocatalytic decomposition under UV irradiation of MB in solution were inspected via FTIR spectroscopy. Figure 8 demonstrates FTIR spectrum of Si-GO10 and Si-GO30 samples at a wavenumber ranging from 400-4000 cm^{-1} . For Si-GO10 sample, there is a strong broad peak at 3443.94 cm^{-1} related to the hydroxyl (-OH) group, whereas in Si-GO30 sample, this broad peak is seen at 3438.24 cm^{-1} . Furthermore, there are two very weak peaks in Si-GO30 sample at

wavenumbers of 2953.92 cm^{-1} and 2880.36 cm^{-1} that are related to the stretching mode of the carboxylic group. The peaks at 1642.22 cm^{-1} and 1638.14 cm^{-1} are related to Si-GO30 and Si-GO10 samples, respectively, which represent the C = C aromatic group. A very strong peak is seen at 1087.25 cm^{-1} in Si-GO10 sample and at 1080.79 cm^{-1} in Si-GO30 sample, which appears after the reaction of GO with TEOS and corresponds to the asymmetric C-O-Si stretching modes. The band observed at 947.68 cm^{-1} could be assigned to the Si-OH stretching vibration. The significant new band around $790\text{--}800\text{ cm}^{-1}$ could be attributed to the SiO_4 tetrahedron ring, which confirms that the nanoparticles anchored on the layers of GO are silica nanoparticles. The peaks in the range of $550\text{--}1000\text{ cm}^{-1}$ are related to Si-OH stretching mode, which confirms the presence of silica nano-particles on the graphene oxide plates. The peaks of 465.95 cm^{-1} and 461.64 cm^{-1} are related to Si-GO30 and Si-GO10 samples, respectively, which show Si-O-Si bending vibrations. Comparing the FTIR spectrum of the two samples shows that the intensity of IR bands in Si-GO10 sample is higher than that of Si-GO30 sample because the presence of carboxylic functional groups is decreased by increasing silica particles. This change coincides with an increase in relative intensity in the 1087.25 cm^{-1} band, which is related to the stretching fluctuations of C-O bonds of the alkoxide groups [52-56].

3.4 Photo – Luminescence (PL)

GO layers have a high optical transmission in the visible region of the spectrum. This optical transmission allows them to be used as a protective coating and a window for luminescence radiations created in silicon [57]. Figure 9 shows the Photo – Luminescence (PL) spectrum of the structures of thin film and nano-powder of Si-GO10 and Si-GO30, respectively. PL spectrum in Si-GO10 thin film shows a strong (severe) emission peak at about 675 nm. A visible photoluminescence band of silicon is a good position of the radiative process induced by the recombination of electron-hole pairs exited in silicon nano-

crystals at different sizes. The electronic spectrum of such nano-crystals has been modified due to the quantum confinement effect. Therefore, the optical radiation band is broad and can be adjusted by changing the peak location by means of modifying the silicon preparation path technology. This intensity of PL spectrum in Si-GO10 films reflects the good quality of the silicon matrix. The effect of GO on PL peak position is ascribed to shifting the emission peak of silicon from 625 nm to 675 nm. One possible reason for changing the spectral range is the reaction of GO layer with the radiative recombination centers in silicon nano-crystals. This peak is almost completely disappeared in Si-GO30 nano-powders. Given the increased amount of graphene oxide in nano-powders, this decrease and disappearance of PL peak in Si-GO30 structure may be due to the absorption of electromagnetic radiations by GO layers. Another possible reason for the peak disappearance is maybe attributed to the peak - shifting towards the longer wavelengths located in the infrared range (IR).

3.5 Antibacterial Properties

Prevailing investigations have revealed that the antibacterial activity of GO is size dependent. Liu et al.[58] proposed that GO with larger lateral size displayed a stronger antibacterial activity as compared with smaller sized GO. They showed that larger sized GO sheets strongly wrapped bacterial cells, whereas smaller sized GO tends to only adhere the surfaces of *E. coli* and did not fully cover the cells.

In this section, bacterial growth inhibition studies were performed. The standard gram-negative bacterium of *Escherichia coli* DH5 alpha (ATCC 25922) (1399PTCC) was purchased from Iran's Scientific-Industrial Research Center. Growth medium of Muller Hinton Broth (Merck) was used. The sample of *Escherichia coli* was cultured in Muller Hinton Broth medium for 24 hours at 37°C. The rate of adsorption of cell density of bacterium at 630 nm was investigated by spectrophotometer. Bacterium was prepared according to the

McFarland 0.5 (equivalent to 10^8 CFU/ml) using dilution method for each sample in each iteration. Samples of Si-GO30 nano-powder and Si-GO10 thin film were placed in culture container and the bacterial environment was spilled onto them and placed in an incubator at 37°C . The antibacterial effect on the sample of standard gram-negative bacterium of *Escherichia coli* was performed according to Clinical & Laboratory Standards Institute (CLSI) international standard with three iterations using micro-dilution method. The adsorption rate of the samples at 630nm was read at 0, 2, 4 and 20 h of incubation at 37°C in ELISA Reader. The mean of the different iterations was calculated and plotted for each sample at different times. The adsorption rate of samples was compared with positive control (bacterium and Hinton Broth growth medium) and negative control (Muller Hinton Broth growth medium). Results demonstrate that Si-GO30 nano-powder could inhibit *E. coli* growth after 20 hours while Si-GO10 thin film could not inhibit *E. coli* growth. Besides, Si-GO30 sample had a higher GO/Si ratio than SG10 sample, and the more presence of graphene oxide plates causes the stronger antibacterial properties in Si-GO30 sample. These results are presented in Figure 10. The antibacterial properties of graphene oxide plates in the presence of different nano-particles and reported comparable findings [59]. The mechanism governed the antibacterial activity of GO plates is based on interacting GO plates with the cell membrane and accumulating of cell-GO that eventually results in disruption and degradation in cell membrane [60]. The particle size and the type of functional groups present on the surface of GO plates are the main factors that influence the antibacterial activity of GO. The main features of GO plates as an antibacterial material are structure stability, high ability in functionalization, high surface-to-volume ratio and the existence of sharp edges in the walls [3-6, 61, 62]. According to the above-mentioned cases, it seems that the higher number of graphene oxide plates in the nano-composite has a better effect on the antibacterial properties of the nano-composite.

4. Conclusions

Nano-composites of Si-GO10 thin film and Si-GO30 nano-powder have been successfully fabricated by spray pyrolysis and sol-gel methods, respectively. XRD results show that the relatively strong peak of the graphite layer that corresponds to the plane of (002). Morphological investigation revealed that SiO₂ nano-particles are randomly scattered on the surface of GO plates, and the particle size in these nano-powders was below 50 nm. Furthermore, FESEM analysis depicted silica nano-particles on the surface of GO plates in a nearly spherical and rod-like nanoparticles shapes, which confirmed the formation of SiO₂/GO nano-hybrids. Photocatalytic investigations revealed that Si-G10 thin film did not degrade after 120 minutes, however for Si-GO30 nano-powder, the adsorption peak intensity was reduced to 665 nm, indicating a decrease in the dye concentration in the solution. PL spectrum in Si-GO10 thin film shows a strong emission peak at about 675 nm. This spectrum was completely disappeared in Si-GO30 nano-powders. Furthermore, the performance of the prepared composites was investigated by the adsorption of dye methylene blue. Results from the antibacterial properties indicate that Si-GO30 nano-powder could inhibit E. coli growth after 20 hours. The established results confirmed the excellent performance played by GO/SiO₂ as photocatalytic and antibacterial agents and enabling this material to be served as a prospective adsorbent for the elimination of dye pollutant.

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Figure 1: Schematic illustration for the synthesis of Si-GO Nano-Composite.

Figure 2: XRD patterns of Si-GO10 thin film and Si-GO30 nano-powder.

Figure 3: TEM Images of Si-GO30 Nano-Powder at two scales of 100 nm and 300 nm.

Figure 4: Field Emission Scanning Electron Microscope (FESEM) images of a) Si-GO10 and b) Si-GO30 samples.

a) Si-GO10 **b) Si-GO30**

Figure 5: 2D and 3D Images of Atomic Force Microscope (AFM) of Samples of a) Si-GO10 and b) Si-GO30.

Figure 6: Diagram of Adsorption-Desorption Isotherm for Si-GO10 and Si-GO30 Samples.

Figure 7: Absorption diagram as a function of wavelength for a) Si-GO10 thin film. b) Si-GO30 nano-powder under UV irradiation at 0 and 120 mints.

Figure 8: FTIR spectra of Si-GO10 and Si-GO30 samples at a wavenumber extending from 400-4000 cm^{-1} .

Figure 9: PL spectra of the Si-GO10 and Si-GO30 structures.

Figure 10: Antibacterial activity of Si-GO10 thin film and Si-GO30 nanopowder against *E. Coli* growth.

Table 1: The preparation conditions of Si-GO10 thin film.

Spray parameters	Optimum value
Nozzle	Glass
Solution flow rate	3-4ml/min
Carrier gas	Compressed air
Substrate temperature	400°C
Nozzle-substrate distance	38cm