Photochemical synthesized NiO nanoparticles based dye-sensitized solar cells: a comparative study on the counter electrodes and dye-sensitized concentrations

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In this project, we report on the prepare of nickel oxide nanoparticles (NiO NPs) via a photolysis method using UV lamb followed by calcination at 400 C for 3 h. the synthesized Nano-powder were investigated field emission scanning electron microscope (FE-SEM), photoluminescence spectroscopy (PL) and X-ray diffraction (XRD). The SEM image confirmed the crystal structure of the synthesized NiO nanoparticles with an average particle size of 23 nm, and the XRD analysis revealed the absence of impurity peaks. The optical properties were analyzed using photoluminescence spectroscopy (PL), and the bandgap was determined to be 3.4 eV. The semiconductor property, which can be exploited for solar cell applications, is responsible for the broad bandgap. To make dyesensitized solar cells (DSSC), we used photo-chemically synthesized NiO NPs as a photoanode. Two counter electrode were used in this study: Graphene oxide Nano-Sheets and Graphene oxide/silver nanocomposite. cibacron brilliant red B is one of the dyes that are used in the textile factory of Wasit Governorate, and the rest of it is often discarded as waste water Which we used in our study as a photosensitizer. The open-circuit voltage (Voc), short t current density (Jsc), fill factor (FF), and efficiency (h) were determined from the J-V curves, where efficiency was between 0.231 to 1.47 %, at 100 mW/cm2. Finally, it can be confirmed that the presence of nickel oxide nanoparticles with a cibacron brilliant red B dye can improve the performance of dye-sensitized solar cells.

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1. Introduction

In technological applications, oxides are used in the fabrication of sensors. microelectronic circuits, fuel cells, piezoelectric devices, as catalysts and corrosion inhibitors. In the growing field of nanotechnology, one of the objectives is to produce nanostructures with special features regarding bulk or individual particles. Oxide nanoparticles may have unique chemical and physical properties due to its small size and high density. There are basically two types of semiconductors, (Intrinsic semiconductors) which are semiconductors in the pure form without doping and (Extrinsic semiconductors) which are semiconductors doped with some impurities and have two types (N-type) as a pentavalent impurity for doping so that the n-type semiconductor has electrons. The pentavalent impurities like arsenic or phosphorus and (P-type) when trivalent impurities used for doping p-type semiconductor it has holes[1-5]. P-type semiconductors (p-sc) have reawakened interest in the application of light-emitting diodes, transistors, and solar cells over the last decade [1]. Since the first dye-sensitized solar cell (DSSC) was realized in 1991, Gratzel suggested the creation of a new generation of solar cells. The p-type SC takes the place of the n-type [2,3]. This form of equipment is based on It is realized in the external circuit by light injection of holes rather than electrons [4]. Nickel oxide (NiO) has been the standard p-type semiconductor for p-DSSC applications so far.[5]. Nickel oxide is a compound

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with the chemical formula NiO, and its poly face-centered cubic crystal structure (CFC) structure is similar to NaCl. The valence ions of nickel (+2) and oxygen (-2) are octahedral [5,6]. The energy gap of the nickel oxide film is between (3.2 - 4 eV) [5]. This interval varies (bandgap) with the different precipitation methods used, and nickel oxide is considered a P-type semiconductor [7]. It is also an anti-ferromagnetic material, when an electric field flows on it and the resistance value exceeds 1000 Ω , it will change color [8]. It is an electronic material. Due to its characteristics, it is considered to be one of the most important transparent oxides in optical applications; the refractive index is 33.2 and (40%-80%) transmittance [9-12]. In industrial and commercial applications, nickel oxide films have several advantages over other transparent carrier oxide films [13]. These advantages are its electrical, optical, physical and chemical properties [14]. We mentioned its applications: in the manufacture of thermistors, in the electrodes of optoelectronic devices, in iron-nickel batteries (also called Edison batteries), making batteries rechargeable nickel oxide used in smart windows, rearview mirrors Electronic paper in highresolution mobile display devices, while nickel(II) oxide is used as an electrical colorant in catalysts and gas sensors [15-18]. In this work, an irradiation technique (ultraviolet radiation using mercury lamp 125 watt) was used to prepare nickel oxide nanoparticles. These prepared Nanoparticles were applied as photo-anode to fabrication of dye-sensitized solar cells using two

2. Experimental part

Nickel nitrate Ni(NO3)2, urea (CH4N2O), sodium hydroxide (NaOH) and deionized water was used to prepare the nanoparticles. All chemical was used purchased from (BDH) and without any purification.

counter electrodes: graphene oxide nano-sheets and graphene oxide/silver nanocomposite.

2.1. Synthesis of NiO nanoparticles

NiO Nanoparticles have been prepared by photo irradiation method, irradiation cell, as in Fig. 1 was used to irradiate Nickel nitrate as sources of Nickel oxide nanoparticles. Immersed UV source (125 W mercury medium pressure lamp) is used with maximum light intensity at 365 nm. The cell contains a quartz tube as a jacket for immersion UV source in the solution of Nickel nitrate. Pyrex tube is used as a reactor. The reactor is cooled by ice bath to avoid the temperature rising as a result of the UV irradiation [19-24]. Accordingly, 30 ml of 0.02 mole of urea is added slowly (one drop per second) to 30 ml, 0.01 mole Ni(NO₃)₂ with magnetic stirrer at 30 C°. then, the solution is irradiated by photo cell for 30 min. light green powder is precipitate, it is separated and washed several time with deionize water. The precipitate has dried for one hours at 110°C and calcined at 400°C for 3h. A black- gray precipitate of Nickel oxide nanoparticle is obtained.



Fig. 1. Photo-chemical Immersed UV cell.

2.2. Fabrication of dye-sensitized solar cell

Glass-coated indium doped tin oxide (ITO, 8 ohm resistant, 83% transmitted) was washed many times in an ultrasonic bath with ethanol, and distilled water to eliminate impurities before being dried with a blower. A dye-sensitized solar cell (15 * 20 * 1 mm) was used to carry out the following procedure: Nano oxides powder (0.3 g) was mixed with ethanol (10 ml) to make a colloidal solution of NiO nanoparticles. The photo anode was created by using a dropper to cover the conductive side of the glass with colloid solution for half an hour in the cold, then annealing at 150 °C for 30 minutes. The Nano-oxides electrode was immersed in 0.5 M dye (cibacron brilliant red B) for 60 min after cooling. A counter electrode with a conductive glass side covers the graphene oxide Nano-sheets [25]. By capillary action, the electrolyte solution (I-/I-3) was lowered between the photo anode and the counter electrode into the working space. Both electrodes were kept together with binder clips, as shown in Fig. 2, and same steps again but used graphene oxide/ sliver nanocomposite as the cathode electrode [25-27].



Fig. 2. Design of dye sensitizer solar cell.

3. Results and discussions

Some techniques have been used to Characterization of powder before and after calcination at 400°C. X-ray diffraction (XRD) Model D-5000 was used to investigate the composition of the specimens by using Cu-K α radiation (λ =0.154nm) source in 20. Fig. 3 (A) shows the XRD patterns of the sample Before calcination, which are in good agreement with Ni(OH)₂. The pure hexagonal phase of Ni(OH)₂ can be indexed to all diffraction peaks (JCPDS, file No. 14-0117). There were no peaks from impurities, suggesting that the product was pure phase. Fig. 3 (B) shows the XRD patterns of the sample after calcination at 400°C. The peaks were positioned at 37.2, 43.5, 63.0, 75.3, and 79.5 degrees, respectively, in the (111), (200), (220), (311), and (222) planes of NiO NPs cubic structure (JCPDS 78-0423). According to equation 1, the Scherrer formula was used to measure the crystallite size of NiO NPs. [28-33].

$$\mathbf{D} = \mathbf{K} \,\lambda/\beta \,\mathrm{COS}\,\,\theta \tag{1}$$

where, D is the crystallite size, K constant equal 0.9, λ is a wavelength of Cu-K α radiations (0.154 nm), β is the full width of the diffraction peak at half maximum (FWHM) and, θ is the angle of Bragg diffraction. The crystallite size of NiO nanoparticles was 7.84 nm.



Fig. 3. X-ray diffraction of sample A) Before calcination B) After calcination at 400 °C.

Field emission scanning electron microscope (FE-SEM) model Jeol JSM-6010LV A total of 20 µL was used to investigated morphology the NiO nanoparticles. Figure 4 shows the SEM of NiO NPs synthesized by photolysis method. In the SEM, the crystal nature of the synthesized nanoparticles of equal sizes is shown. NiO nanoparticles were discovered to have an average size of 23 nm. NiO NPs are homogeneous in nature, with little agglomeration, due to their small size.



Fig. 4. FE-SEM of NiO nanoparticles.

Nano-powder of Nickel oxide was analyzed by solid state photo-luminescent (PL) spectrum (Perkin– Elmer spectrometer design LS55 with photomultiplier tube) for prepared its emissions. The behavior of the PL spectrum is highly influenced by the size distribution of nanoparticles, which can be derived from various sources. To measure the emission energy gap, Figure 5 shows the fluorescence spectra of Nickel oxide nanoparticles with a maximum wavelength of 364 nm. The PL spectra have a single peak in this case, with a nearly wide full width at half limit (FWHM). According to the equation Eg (e.V) = 1240λ , the energy gab was 3.4 ev. In other words, as opposed to bulk Nickel Oxide, the blue change occurs due to the smaller size of Nickel Oxide.



Fig. 5. The PL analysis of Nickel oxide nanoparticle.

3.1. Dye-sensitized solar cells parameters

Fig. 6 shows the current density-voltage (J-V) curve of the NiO NPs-based DSSC. The parameters of dye-sensitized solar cells, like Isc, Voc, Imax, and Vmax, were calculated from the J-V curves, and the fill factor and cell efficiency were determined using the equations[34,35]:

$$\eta = \frac{pm}{pin} \rightarrow 100\% \tag{2}$$

$$F.F = \frac{Jm \ Vm}{Jsc \ V_0c}$$
(3)

Table 1 shows the Dye-sensitized solar cells parameters were determined. Because of the concentration sensitizing dye and small particles of synthesized Nickel oxide nanoparticles, it was stated to be critical for Nickel oxide nanoparticles-based Dye-sensitized solar cells parameters. Two counter electrodes were used in this study, Graphene Nano-sheets (GO) and Graphene\Ag nanocomposite (GO-Ag). With higher dye concentrations in each them (GO and GO\Ag), the cell's power conversion efficiency improved. The increased absorption may also justify the dye molecules' high efficiency on the Nickel oxide nanoparticles surface. As a result, Nickel oxide nanoparticles are promising for use in future photovoltaics because the process is simple and the materials can even be produced easily. The current density rating was relatively poor. For calculating the overall device efficiency limit, the photo-current is the most important parameter. As particle sizes reach the nanoscale, the parent materials behave differently due to its large surface area and surface energy. When comparing the Dye-sensitized solar cells prepared by GO Nano-sheets with GO\Ag nanocomposite, we note that the efficiency was high when the electrode had GO\Ag nanocomposite. The reason was due to the increase in the surface area and the high conductivity that silver gave when attached to graphene, which leads to greater freedom of movement of the electron and increased efficiency [36,37].



Fig. 6. J -V curves of NiO NPs-DSSC at different Concentrations dye and counter electrodes A) GO and, B) GO\Ag.

Table 1. DSSC parameters of NiO nanoparticles at different concentrations dye and counter electrodes.

counter	Conc.	Voc	J sc	V max	J max	P max	F.F	η%
electrodes	Dye	(V)	(A/cm2	(V)	(A/cm2)	(W/cm2)		-
	[M])					
	0.5	0.33	0.0026	0.21	0.0011	0.000231	0.269	0.231
GO	1	0.34	0.0032	0.22	0.0012	0.000264	0.242	0.264
	1.5	0.39	0.0042	0.23	0.0020	0.000460	0.280	0.460
	0.5	0.37	0.0032	0.28	0.0027	0.000756	0.638	0.756
GO\Ag								
	1	0.38	0.0040	0.30	0.0029	0.000870	0.572	0.870
	1.5	0.41	0.0061	0.32	0.0046	0.000147	0.588	1.470

4. Conclusions

Finally, the photolysis method was successful in producing NiO NPs. According to Scherrer's equation, the synthesized NiO NPs had a cubic structure with an average crystallite size of 7.84 nm. The spherical nature of the nanoparticles was reported by SEM, with little agglomeration. NiO NPs is found to have a mean particle size of 23 nm. The NiO NPs showed a broad surface Plasmon resonance absorption peak at $\lambda max = 364$ nm with energy gap of 3.4eV in PL spectroscopy.

The NiO NPs-based DSSC was experimentally verified, and its performance was investigated using current density-voltage behavior under simulated sunlight. The fabricated DSSC's high efficiency is due to a large increase in dye molecule absorption onto the surface of NiO NPs. The use of photo-chemically synthesized NiO NPs in the fabrication of DSSC at various concentrations dye and counter electrodes is a simple and promising process for our future wellbeing. Through, the use of dyes that are released into the water as waste from textile factories as photo-sensitizers for the DSSC.

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