Enhancement of DSSC by Using Gold Nanoparticles

Ghufran S. Jaber
Applied Sciences Department, University of Technology/ Baghdad
Email: Gufransattar184@yahoo.com،
Dr. Abdulrahman K. Ali
Applied Sciences Department, University of Technology/ Baghdad
Dr. Mukhlis M. Ismail
Applied Sciences Department, University of Technology/ Baghdad

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ABSTRACT

In this research, AuNPs prepared by laser ablation in liquid (PLAL) at 750 mJ energy and 90 pulses. They have been added to N719-dye to form (Au-N719) mixture. TiO_2 paste was deposited on FTO substrates and immersion in a mixture dye and AuNPs. DSSC was fabricated and enhancement of the DSSC conversion efficiency was achieved. Scanning electron microscope, X-ray diffraction and UV-Visible spectrophotometer were used to characterize and study the DSSC components. The UV-Vis data show high absorbance of AuNPs+N719 dye compared to N719 dye only; that means the immersion of AuNPs in the N719-dye solution tend to increase the total absorbance of the dye. The XRD pattern of AuNPs has diffraction peaks at 38.2° and 44.4° which can be indexed by (111), (200) plane of Au in the cubic phase. The shape and size distribution shows spherical AuNPs with particle size about (50-60) nm. The relative increase of short circuit current density after the adding gold nanoparticles was about 76%. In the same way the relative increase of open circuit voltage after adding gold nanoparticles was about 6.7%. The total photon-to-current energy conversion efficiency for the standard DSSC is 1.75 while its 2.8 of the enhanced DSSC with gold NPs.The maximum enhancement is about 60 % under illumination (105 mW/cm^2, (AM1.5).

Keywords: PLAL, DSSC, AuNps, N719-dye

تحسين خليه الصبغه باستخدام جسيمات الذهب النانويه

الخلاصة

في هذاالبحث، تمت إضافة جزيئات الذهب التي تم تحضيرها باستخدام الليزر(٧٥٠ملي جول وعدد نبضات ٩٠نبضه) للصبغة ليكون خليط. معجون التيتانيوم المرسب على قاعده فلورين اوكسيد القصديرغمس في الخليط المكون من الصبغه وجسيمات الذهب النانويه. بعد ذلك تم تصنيع خليه الصبغه وتحسين كفائتها. مجهر الماسح الالكتروني تشتت الاشعه السينيه ومطياف المرئي- فوق البنفسجي استخدم لتشخيص ودراسه خصائص خليه الصبغه. وجد ان امتصاص خليط الصبغه وجسيمات الذهب النانويه اعلى من الصبغه لوحدها مما ادى الى زياده الامتصاصيه الكليه للصبغه بعد اضافه جسيمات الذهب النانويه. تشخيص الاشعه السينيه لجسيمات الذهب النانويه كشفت عن مستووين (٢٠٠) و (١١١) لزاوايا الحيود وهي (٣٨.٢ و٤٤.٤) وبطور المكعب. توزيع جسيمات الذهب النانويه كرويه الشكل وذات حجم يترواح بين (٥٠ -٦٠) نانوميتر . الزياده النسبيه في تيار الدائره القصيره بعد اضافه جسيمات الذهب النانويه كانت ٧٦%. بنفس الطريقه فولطيه الدائره المفتوحه بعد اضافه جسيمات الذهب النانويه كانت ٦.٧%. الكفاءه لخليه الصبغه

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

النموذجيه هي ١.٥٧ لكن خليه الصبغه المحسنه كانت ٢.٨ باستخدام ضوء الشمس كمصدر اضاءه بقدره ١٠٥ملي واط \سم^{٢} وكتله هواء ١.٥ وحققت تحسين بلكفاءه بمقدار ٦٠%.

INTRODUCTION

In 1991, Oregan and Gratzel built the first dye sensitized nanocrystalline solar cells[1]. Dye-sensitized solar cells have been considered as one of the most promising photovoltaic technologies because they are generally made from cheap and nontoxic compounds, and can be designed in a diversity of colors and transparencies [2]. The scientists try to improve its performance. Several properties, including novel sensitizers, electrolytes, thickness of TiO_2 and semiconducting behavior, have been utilized to enhance the power conversion efficiency of DSSCs [3]. Also, there is another way to increase the efficiency of DSSC represented by the enhancement the absorption of photons [4]. In simple terms, plasmonic nanostructures are equivalent to optical antennas of nanometer scale which essentially aid to harvest free space propagating photon energy and convert it into surface plasmon polarization of electrical energy in spatially compact form. These antenna effects include far-field scattering with prolonged optical path thus increase photon absorption probability [5]. Laser ablation in liquid (PLAL) is one of the useful techniques to produce new materials. Recently, it has been reported that ablation of metal targets in water prepared colloidal solutions such as gold nanoparticles [6]. Nanomaterials display unique, superior and indispensable properties and distinct characteristics that are unavailable in conventional macroscopic materials [7]. In this paper, we improve the conversion efficiency by adding AuNPs (high surface Plasmon resonance) to sensitizer (dye) to improving the scattering that's lead to increasing the efficiency.

Experimental

Gold nanoparticles were prepared by laser ablation using Nd:Yag laser(type HUAFEI), energy=750mJ, no. of pulses=90 ,then adding to N719-dye (RuL2(NCS)2, 2TBA(L=2, 2'bipyridyl4,4' dicarboxylic, acid TBA = tetrabutylammonium solution with ethanol) to form mixture of (Au-N719dye) 1:1Vol . After that Put Scotch tape on the conducting side of FTO glass then apply TiO_2 paste (average nanoparticle Size (active): ~20nm) and flatten it with a razor on the FTO glass (thickness about 2.3mm), entered the TiO_2 /FTO after dried at a furnace. The film was annealed at 450 °C for 30 min and cooled down to room temperature before immersing in the dye solution. Prepare two TiO_2/FTO films by same way. Dip the TiO_2 electrode into the dye solutions (AuNPs-N719dye and dye only) for 24 hour. The sensitized film is also known as photo anode or working electrodes. Prepare platinum use one drop of platinum gel (oil-based) on FTO then use blade to spread it. After drying, this paste must be fired at 450˚C.These results were uniformly distributed platinum providing good transparency and high catalytic activity. Take out the TiO_2/FTO/dye electrode from the dye solutions and wash it with fresh ethanol. Small diamond drill (DC12v/0.8A, Pros kit PK-500) to make two holes on counter electrode to injected the electrolyte (Iodine and triiodide as a redox couple, Additives (Inorganic iodide salt (I^-\\$I3^{-}$), organic iodide salt, imidazole compound and 3methoxypropionitrile the solvent). Place the (hot melt tape) on the TiO_2/dye electrode to paste with platinum electrode by using heater to 10 minute at 150Cº. Put some drops of iodide salt, organic iodide salt, imidazole compound and 3methoxypropionitrile the solvent) solution into one of hole and bubbles get out from other hole. The next step should be done quickly to prevent the solvent from drying out the electrolyte using epoxy (bostiik) to fill out holes. Measure DSSC properties by using UV-Vis beam spectrophotometer, SP-3000 puls, optima Tokyo, Japan, X-ray analysis measured in (lab XRD-6000, ADVANCEX-RAYSOLUTIONS-D8) and Scannig Electron Microscopy images were obtained using the JEOL (JSM-7000F) filed emission scanning electron microscope located at AUBURN university/America.

Results and Discussion

Gold Nanoparticles the absorption spectra of nanoparticles gold solutions, synthesized by pulsed laser ablation of piece gold plate placed on the bottom of plastic vessel containing 1ml of ultra-pure ethanol this shown in fig.1. The piece of metal was irradiated by Nd: YAG laser (energy of 750 mJ/pulses and wavelength of 1064 nm. The color of solution was changed and the intensity of AuNPs was around (530-550) nm. The presence of the single surface plasmon peak implied that was formed nanoparticles were nearly spherical. The gold nanoparticles, was faint pink in color, due to plasmon absorption [8] [9]. The position of the plasmonic peak of gold 540 nm is systematically shifted to the red region; usually the red shift of the plasmon resonance of spherical AuNPs is attributed to the increase of the average size of NPs [10].

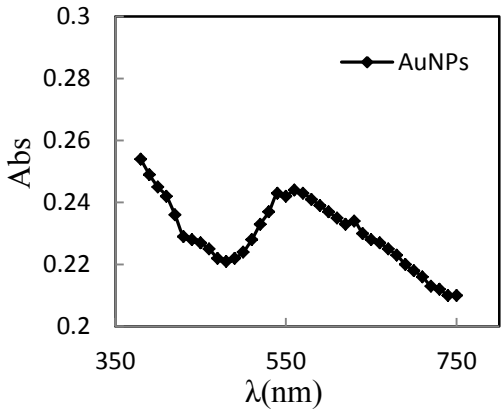
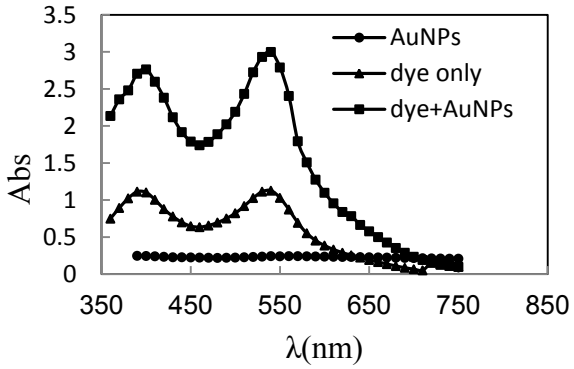


Figure (1) Gold nanoparticles spectrum prepared by laser ablation in ethanol.

Sensitized Dye Enhancement

Optical absorption spectra of N719-dye and gold nanoparticles respectively are shown in Fig 2. The N719 dye absorbs visible light in the wavelength range from (350 to 700) nm. Adding gold nanoparticles to dye (1ml of dye + 1ml of AuNPs in ethanol =dye + AuNPs). The UV data show that the absorption of N719-dye only and AuNPs + dye have two peaks occur in the visible region (380 and 550) nm that means the immersion of AuNP increases the total absorbance of the dye.



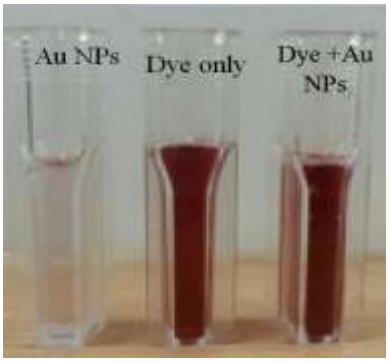


Figure (2) Absorption spectra of gold nanoparticles, N719-dye and N719-dye + gold nanoparticles.

TiO_2 Colloidal

50µg of anatase TiO_2 powder (P25) was submerged in 1ml of ethanol with the submerging depth 3 mm, which putted at ultra- sonic to remove all aggregated particles and get homogenous colloidal. As shown in Fig. 3 absorption spectra of the obtained nano-TiO_2 colloids. It is found that anatase TiO_2 nanocrystals display a strong and wide band in the range of (200–600) nm [11].

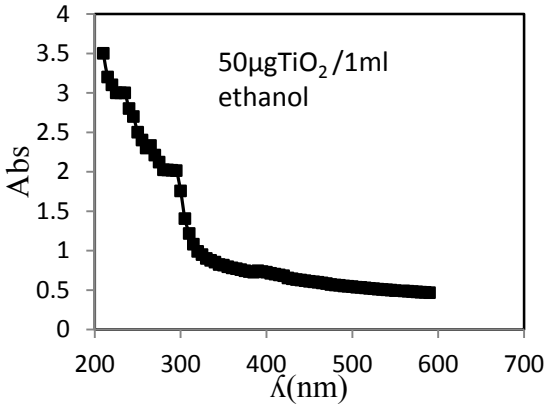


Figure (3) Absorption spectra of TiO_2 colloidal in ethanol.

Spectroscopy of DSSC

Fig (4) shows Absorption spectra of the DSSC before and after enhanced. Standard DSSC have peaks at (440 and 530) compared with (430-530) for enhanced cell. It was observed that there is slight change in peak position. There have been many studies on enhancing efficiency of DSSC by adding submicrometer-scale particles as light scatter, to get a significant advance in DSSCs. here, gold in sub nanometers sized aggregates consisting of nanosize crystallites have been utilized for efficient scatter, while the nanocrystallites provide the films with the necessary nonporous structure and large surface area.

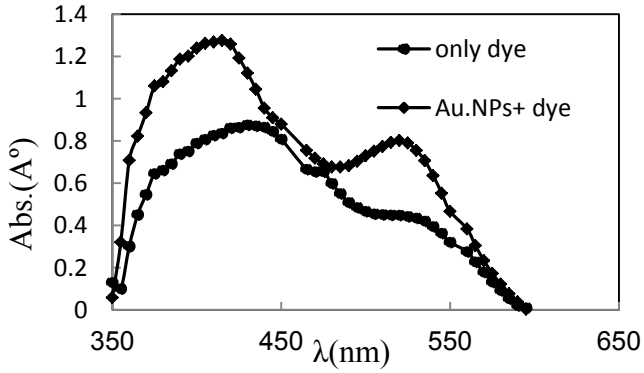


Figure (4) Absorption spectra of the DSSC before and after enhance.

X-ray Diffraction Analysis

The X-ray diffraction of TiO_2 crystalline is as shown in fig (5A). The figure shows two typical peaks (1 0 1) and (2 0 0) of anatase TiO_2 are observed (θ) at scattering angle of 25°and 45°, (JCPDS no. 01-0562) [10]. No characteristic peaks associated with other crystalline forms were detected in the XRD pattern, indicating the anatase phase-

pure nature of the product. Fig (5B) shows the XRD pattern of Au NPs prepared by PLAL having diffraction peaks at angle 38.2° and 44.4°which can be indexed to (111), (200) plane of Au in the cubic phase.

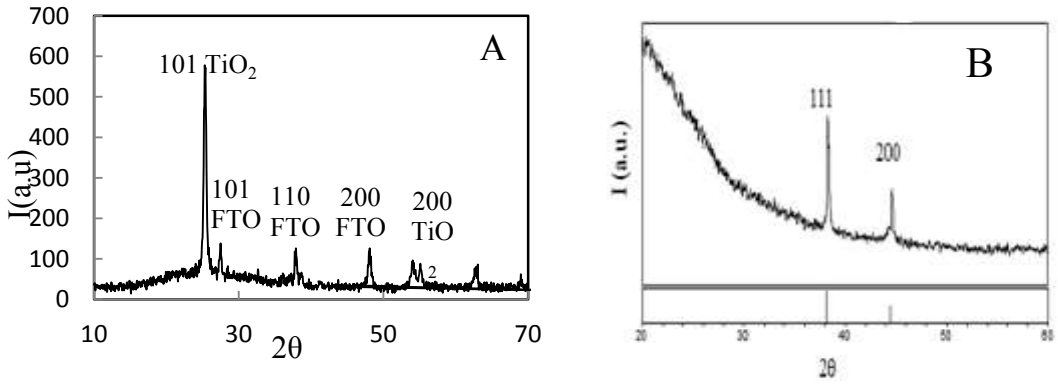


Figure (5) Shows the X-ray diffraction pattern of TiO_2 film on FTO substrate for (A) TiO_2 film sintered, (B) AuNPs prepared by PLAL.

Scanning Electron Microscpe Of Gold Nanoparticle

The surface morphology and size distribution was shown in Fig 6 (A and B) respectively. The size and shape of individual particles of gold were characterized as well as the size distribution of the particles. The size distribution of gold nanoparticles shows spherical shape and particle size about (50-60) nm. The different shapes will result to different intensities of the surface plasma resonance (SPR).

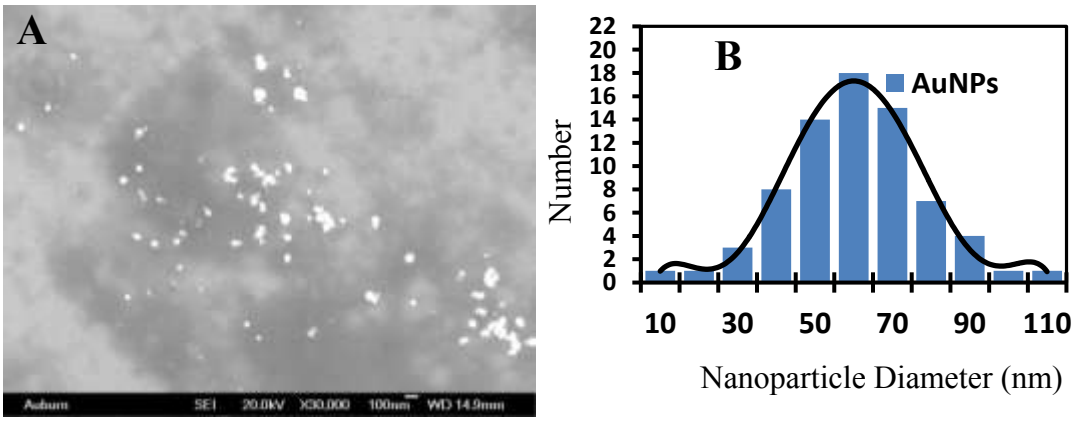


Figure (6) SEM image for AuNPs (A) at 100nm and (B) size distribution for AuNPs.

Scanning Electron Microscope of TiO_2 Film

SEM photographs for TiO_2 thin film was shown in Fig 7 (A and B) at different magnification prepared by doctor-blade method. The porosity structure of the TiO_2 film should favor the DSSC application because dye molecules would deeply penetrate into the TiO_2 film resulting in more dye absorbed on the TiO_2 film [12].

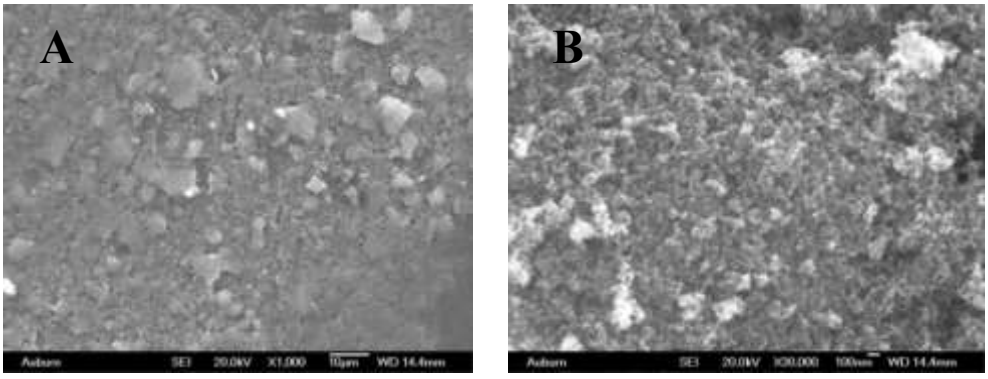


Figure (7) SEM image for TiO_2/Si for (A)10 µm and (B)100nm prepared by doctor-blade.

Characteristics

The photovoltaic parameters of the cells can be obtained from the analysis of the J–V curves shown in fig.8 (A and B). The detailed results of the photovoltaic parameters of DSSCs are listed in table.1. One of them was prepared by adding gold nanoparticles to dye then immersed TiO_2 thin film but the other staining in dye only. The total photon-to-current energy conversion efficiency for the standard, FTO /TiO_2/ dye and FTO/TiO_2/AuNPs, with TiO_2 past from dysol (A=0.4mm^2, thickness=11±1) and TiO_2 fabricated with our lab is 1.75, 2.8, 1.07 and 2.009 respectively.

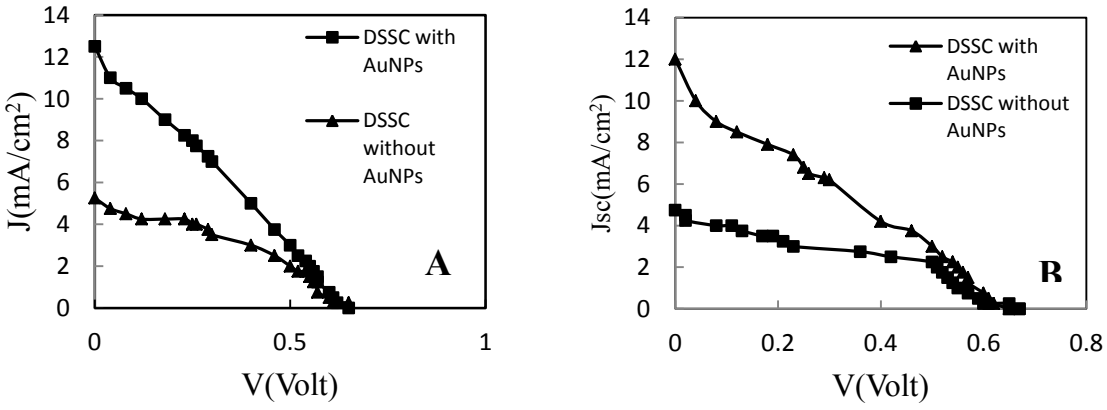


Figure (8) Comparison of J–V characteristic curves of DSSCs with and without AuNPs under sun illumination fabricated (A) The TiO_2 layer fabricated by dysol and (B) in our lab.

Cell type	*Voc*(Volt)	J*sc*(*mA*/cm^2)	Fill Factor	Efficiency (η)	Enhanced efficiency
DSSC without AuNPs(dysol)	0.59	5.25	0.395	1.75	60%

DSSC with AuNPs(dysol)	0.63	9.25	0.504	2.8	
DSSC without AuNPs(our lab)	0.67	4.75	0.359	1.07	87%
DSSC with AuNPs(our lab)	0.65	12.5	0.258	2.009	

Table (1) DSSC parameters under sun illumination.

The maximum enhancement after adding AuNPs is 60% and 87% for TiO_2 paste prepared by dyesol and our lap respectively. This enhancement is due to the intense local electromagnetic fields produced by the plasmonic nanoparticles, which couple light very effectively from the far-field to the nearfield of the dye molecule monolayer. Under these intense local fields, the exciton generation rate in the dye molecule monolayer increases significantly, thereby improving the photocurrent [13].

CONCLUSIONS

Adding gold nanoparticles to N719-dye to get homogenous solution have to high absorption peak about twice peak of N719-dye due the high SPR of gold nanoparticles lead to increase the total absorption. The particle size and size distribution of gold nanoparticles show spherical shape. Gold nanoparticles have range of size lead to different intensities of the surface plasma resonance (SPR). A significant increase in the efficiency of DSSC is observed when adding gold nanoparticles.

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