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The Effect of Laser Heating and Overcasting Deposition on the Efficiency of Plasmonic Solar Cell with Noble Metallic Nanostructures

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Abstract

Surface plasmon resonance could increase the efficiency of solar cells , when light is trapped by the noble metallic nanoparticles arrangement at and into the silicon solar cell (SSC) surface. Pure noble metal (silver and gold) nanoparticles (NPs) have been synthesized as colloids in de-ionized water (DW) by pulsed laser ablation (PLA) process at optimum laser fluence. Silicon solar cell with low efficiency was converted to plasmonic silicon solar cell by overcasting deposition method of silver nanoparticles on the front side of the SSC. The performance of plasmonic solar cell (PSC) was increased due to light trapping. Two mechanisms were involved : inserting silver nanoparticles (Ag NPs) inside the silicon layer by the heating effect of pulsed laser and depositing gold nanoparticles (Au NPs) on the surface of the SSC by overcasting method. The optical properties of silver and gold colloidal solutions were studied with UV- Visible spectrophotometer with a range from 190 nm to 1100 nm. The absorption spectra showed single absorption peak located at about the characteristic value for silver and gold nanoparticles due to the surface plasmon resonance. Atomic Force Microscope (AFM) images were studied , the ablated noble NPs by pulsed laser have an average diameter less than 100 nm. AFM images showed the morphology of SSC surface without and with nanoparticles before and after overcasting and heating by laser methods. Electrical measurements for SSC namely current – voltage (I-V)characteristics and responsivity (Rλ) displayed higher efficiency after these procedures. The efficiency rise to(5.2%) due to the localized surface plasmons excitation of (Ag NPs) that were embedded into the silicon layer by the heating effect of pulsed laser. The deposition of AuNPs on the silicon surface of the plasmonic SC additionally increased the efficiency to (7.28%), due to light trapping by scattering from Au NPs towards the plasmonic solar cell depth .

Keywords: Silicon solar cell, Nanoparticles, Silver, Gold, Laser heating

تأثير التسخين الليزري و الترسيب بالغمر على كفاءة الخلية الشمسية البلازمونية تبعآ للتوزيع النانوي للمعادن النبيلة

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الخلاصة

أستطاع رنين سطح البلازمون الى حد كبير من زيادة الكفاءة للخلية الشمسية عند حصر الضوء بواسطة توزيع الجسيمات النانوية المعدنية النبيلة على و في سطح الخلية الشمسية السيليكونية. حضرت جسيمات

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معدن الفضة و الذهب النانوية النقية غروياً في ماء لاآيوني بواسطة عملية الاقتلاع بالليزر النبضي بكثافة طاقة ليزر محددة. تم تحويل الخلية الشمسية السيليكونية ذات الكفاءة الواطئة الى خلية شمسية سيليكونية بلازمونية بطريقة الترسيب بالغمر لجسيمات الفضة النانوية على الوجه الامامي للخلية الشمسية. آداء الخلية الشمسية البلازمونية زادت نتيجة حصر الضوء بآليتين تتضمن: آدخال جسيمات الفضة النانوية داخل طبقة السيليكون بواسطة التآثير الحراري لليزر النبضي ، وترسيب جسيمات الذهب النانوية على سطح الخلية الشمسية السيليكونية بواسطة طريقة الغمر. تم دراسة الخصائص البصرية لمحاليل الفضة و الذهب الغروية بواسطة جهاز مطياف الأشعة فوق البنفسجية–المرئية للمدى (190 – 1100 نانومتر). آظهرت قياسات طيف الآمتصاص قمة آمتصاص منفردة تقع ضمن حدود القمة المثلى لجسيمات الفضة و الذهب النانوية نتيجة رنين سطح البلازمون. آوضح مجهر القوة الذري آن الجسيمات النانوية المقتلعة بواسطة الليزر النبضي لها معدل آقطار آقل من (100 نانومتر) وآظهرت صور مجهر القوة الذري طبوغرافية سطح الخلية الشمسية بدون ومع الجسيمات النانوية قبل و بعد عمليات (الغمر و التسخين بالليزر). وبالمثل ، آظهرت القياسات الكهربائية للخلية الشمسية مثل (فولتية– تيار) و الآستجابية كفاءة عالية بعد تلك الطرق. وصلت الكفاءة الى (5.2%) نتيجة آثارة سطح البلازمون الموقعي (لجسيمات الفضة النانوية) التي آدخلت في طبقة السيليكون بواسطة تآثير التسخين لليزر النبضي . ترسيب جسيمات الذهب النانوية على سطح السيليكون للخلية الشمسية البلازمونية آستطاع زيادة آضافية للكفاءة الى (7.28%) عند حصر الضوء بواسطة الآنكسار من جسيمات الذهب النانوية بآتجاه عمق الخلية الشمسية البلازمونية.

Introduction

Photovoltaic solar cells are used to generate electricity by converting the incident light into electric energy [1,2]. This field involves the use of solar cells (SCs) with heavy silicon layer [3], as the optical path in absorber dish was lengthier. That heavy film knowledge produced a rise in the SCs expense [4]. Though, presenting the knowledge of tinny film assisted in this duty [5,6]. However, the light riveted in the tinny film skill is fewer in relationship with heavy film knowledge. Therefore, the SC efficiency of tinny film is fewer than normal SC [3]. Novel methods of absorption and tricking were used to expand the state. The plasmonic structures confirm various motion to transmit or increase light that is incident on its surface. Noble metals coating or nanoparticles were start affecting for this drive. The plasmonic structures proved significant tools in submissions similar photovoltaic devices [4,7]. The inadequacies in the requests could be explained by presenting the right explanations that support the plasmon resonance and position of light to effect in efficient SCs [8]. The small resistivity of silver and gold completed them appropriate for plasmonic tinny film SCs [9], in a calculation to their connections with light in the visible area. Plasmonic nanostructure configurations in three positions have been used to improve the light trapping: (1) metal NPs on the surface of the solar cell,(2) metal NPs embedded in the silicon solar cell,(3) metal NPs at the bottom of the silicon solar cell [10]. Laser-dispensation procedures are presently existence examined for the manufacture of new kinds of great recital SSCs [11]. A novel metal nanopatterns embedded within ultrathin silicon films was described by *Ye et al.* [12] . They reported many fold enhancement in absorption when embedding novel metal nanostructures inside tinny Si-films, thus, causing an increase in the overall efficiency of SCs. *Santbergen et al.* [13] demonstrated up to a fourteen-fold enhancement in the driving electrical field intesity and extra effective light trapping via the scattering of embedded plasmonic silver nanoparticles in thin-film of SSC. *Abdulhameed, et al.* [14] used overcasting deposition of the ablated silver nanoparticles by pulsed laser at the SSC surface and reported significant development of SSC performance due to plasmon resonance of Ag NPs. *Kamal et al.* [15] used the plasmonic nanostructures of different particle sizes and materials to improve the absorption in the SCs that increased the density of short current circuit to 71%. *Hyder, et al.* [16] proved that embedding plasmonic silver nanoparticles inside the SSC layer by pulsed laser heating could extra enhance SSC efficiency compared to spray deposition method. In

this work, the role of noble metallic nanostructures at and inside the silicon layer in order to enhance the efficiency of plasmonic SSC using overcasting deposition and laser heating methods was studied.

Experimental Part

SSC sample of area [19.4 cm^2] was immersed in 0.5:5 hydrofluoric acid : de-ionized water for 2 minutes to remove the Titanium Dioxide coating [TiO_2] on the SSC surface. The sample was then dipped in ethanol and lastly cleaned by DW to remove the residual hydrofluoric acid, and it was left to dry. Silver and gold NPs (of average sizes **[~** 81, ~ 79 nm]) colloidal solutions (of concentricity [0.001, 0.002 g/ml]) were ablated by pulsed laser on Ag and Au plates in the DW at room temperature. Plates (of about 99.999 % purity) were positioned at the bottom of a glass beaker filled with 2.5 mL DW, which is sited in an ultrasonic device at [12 cm] space of the laser fountain. The pulsed laser used was Nd:YAG (of wavelength [1.064 μm] working at [1 Hz] repetition rate, of pulse width [0.01 μs], pulse energy [340 m Joule] and fluence of [1.73 Joule/cm²]). The number of pulses shots on Ag and Au targets were [100]. Figure 1 shows the experimental set-up..

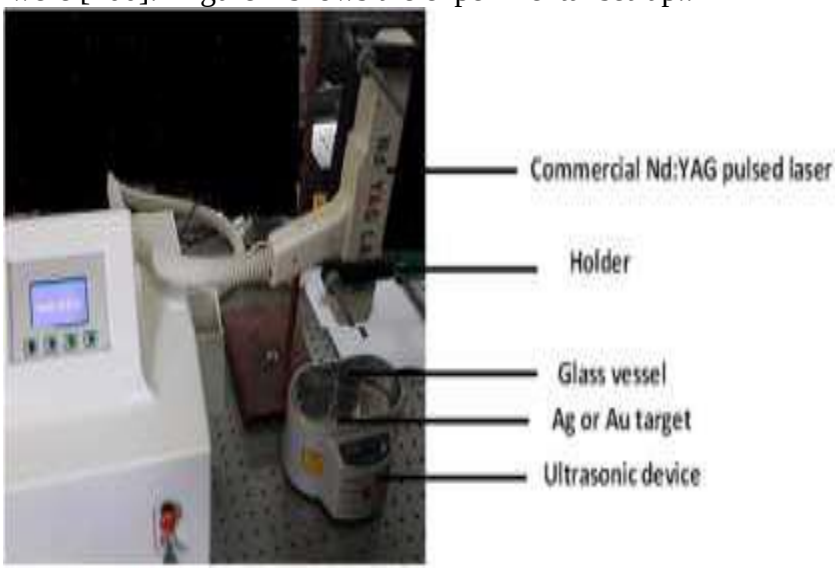


Figure 1- Experiential setup for nanoparticles designed for PLAL technique.

Silver nanoparticles (of average size [~ 81nm]) solution (of concentricity [0.001 g/ml]) was deposited on the front side of the SSC via overcasting method, as shown in Figure 2.The deposited SSC substrate was dried using a halogen lamp.

Plasmonic SSC was prepared via embedding Ag NPs in the silicon layer, by treating it with a commercial Nd:YAG pulsed laser (of wavelength [1.064 μm], repetition rate[1 Hz], pulse width [0.01 μs], and pulse energy [480 m Joule]) so as to heat up the silicon layer. This heat will cause the Ag NPs to embed inside the Si- layer, as that the pulse fluency does not spread the verge damage of the Silicon material. The pulsed laser fluence was [1.45 Joule/cm²] at a space of [0.65 cm], and also employ [x-y] scanning stage to make an overlay circles between laser pulse spots on the plasmonic SC surface to shield all its region, as displayed in Figure 2.

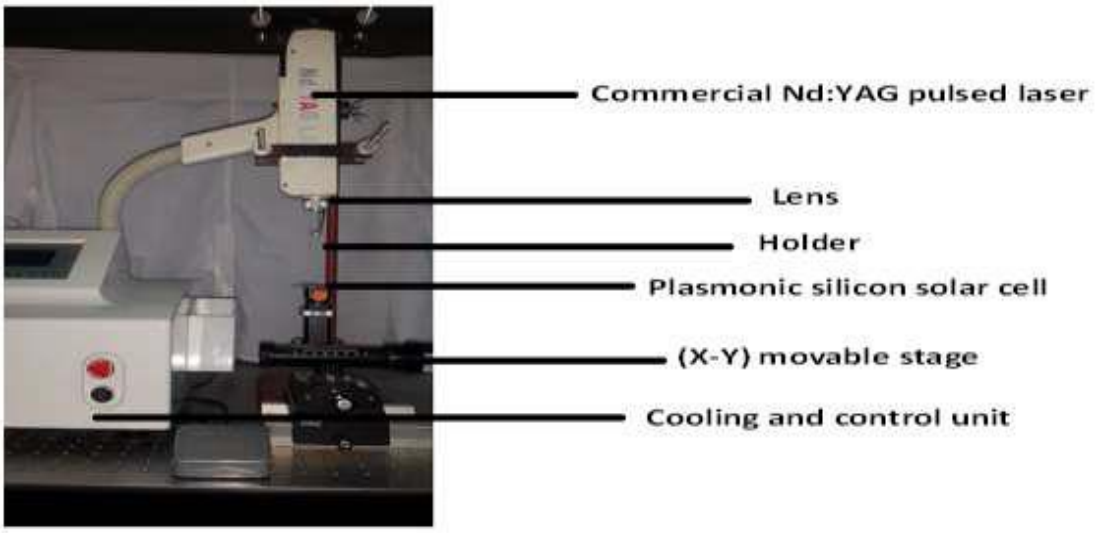


Figure 2 - Irradiating the plasmonic SSC surface by pulsed laser system.

Then, the ablated Au NPs (of average size [~79 nm]) solution (of concentricity [0.002 g/ml]) were deposited on the plasmonic SSC surface by overcasting method.

Finally, the [I-V] measurements and competence for SSC with region [19.4 cm^2] were done with cell tester device [MODEL # CT 100AAA], as displayed in Figure 3.

Figure 3- Cell tester device for SSC measurements.

Results and Discussion

Pulsed laser ablation in DW is a simple and purity technique [17] to synthesis silver and gold nanoparticles of sizes [~ 81, ~ 79 nm]. Size of metal nanoparticles plays an important role in the properties of plasmonic structure. Small NPs [< 50 nm] have high absorption. While, large NPs cause significant light scattering, which is more suitable for photovoltaic applications [18]. Figure 4 displays the colour of the silver and gold nanoparticles [of sizes ~81, ~ 79 nm, respectively] solutions, that were generated by pulse fluence [1.73 Joule/cm^2] in DW. The opaqueness is relative to the same mass concentricity of silver and gold nanoparticles [0.001, 0.002 g/ml] in DW. The color of the solutions were light yellow for the Ag NPs colloid and light pink for Au NPs colloid. The color of silver and gold nanoparticles solutions are related to the surface plasmon resonance SPR wavelength of the individual noble metallic NPs [19].

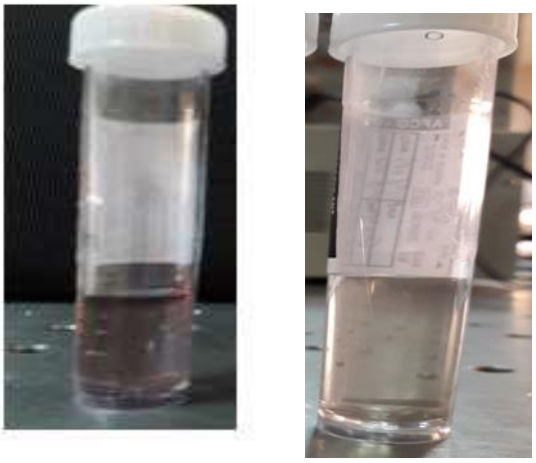


Figure 4-A light yellow color of Ag NPs colloid and the light pink color of Au NPs colloid, next ablated by pulsed laser in DW.

Using UV-Visible spectrophotometer, the absorbance spectra of silver and gold nanoparticles were obtained (as shown in Figure 5). These spectra display the typical absorption groups with a peak at about [400 nm] and about [525 nm] for Ag and Au, respectively.This agrees with the surface plasmon resonance signatures of Ag and Au nanoparticles [20, 21].

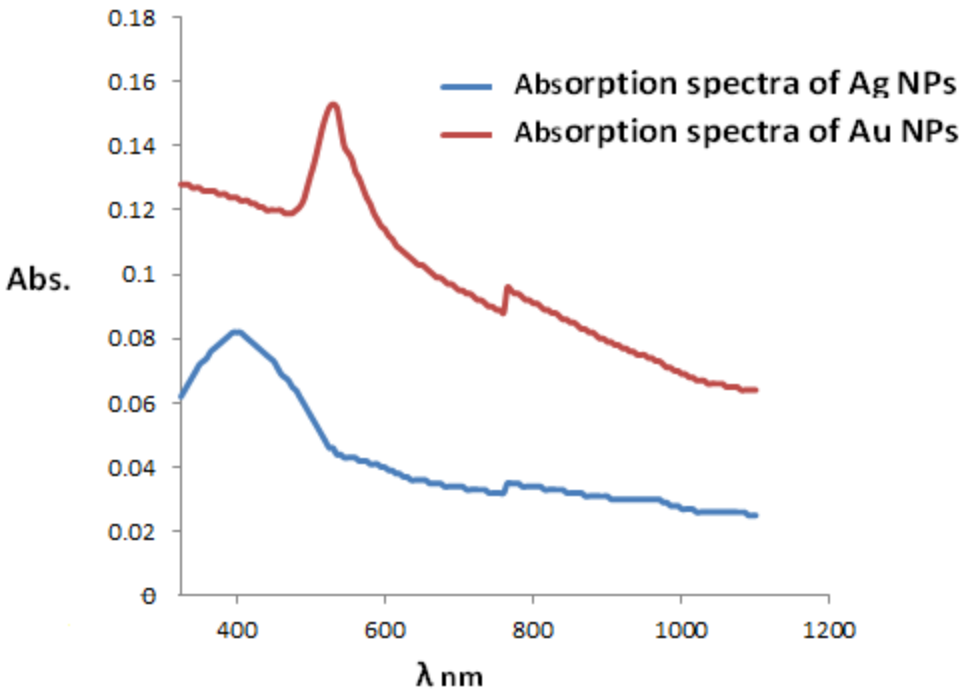
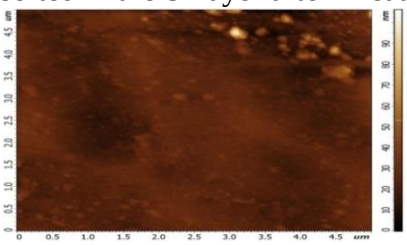


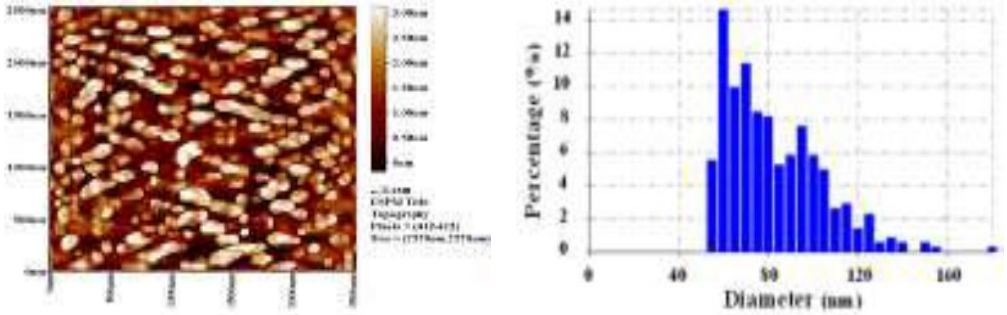
Figure 5-Absorbance spectra of Ag and Au nanoparticles solutions with pulse fluence of (1.73 Joule/cm^2).

The silicon surface was heated by the laser pulses so that no melting or evaporation of the heated area occured. Laser pulses induced a thermic growth due to the pulse energy strong absorption, causing shallow thermic pressure waves, that embedded the Ag NPs within the heated up Si- surface [17, 22]. The morphology images of the SSC surface with changed states were obtained with an atomic force microscope as shown as in Figure 6 (A, B, C and

D). Figure 6 (A) displays the SSC surface before nanoparticles embedding..It shows a flat surface absent of nanoparticles on it. The images of the embedded surface , (Figure 6 (B, D)) shows the Ag and Au Nps are of a spherical form (the figures also show the size distribution chart).The nanoparticles are seen as white dots which represent the conglomerate particles development growth . The topography of the SSC surface displayed in Figure 6 (C) designates that Ag NPs were inserted in the Si layer after heating with pulsed laser.



(A)



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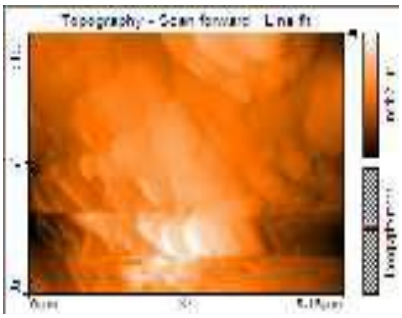
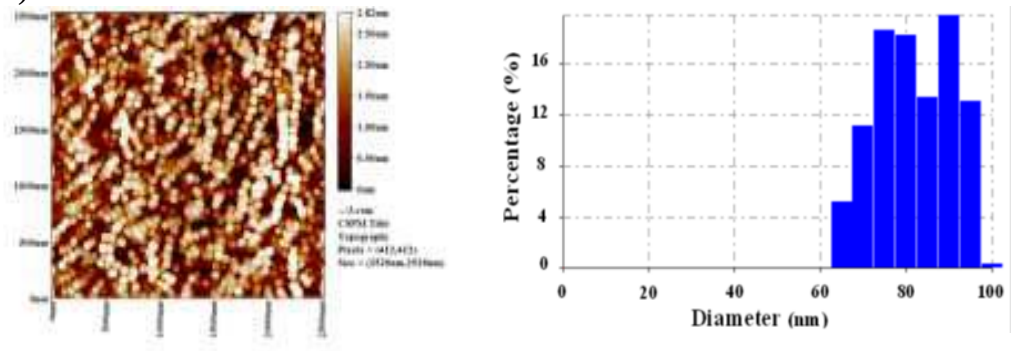


(C)



(D)

Figure 6- (A) The topography of SSC surface without NPs deposition, (B) Silver nanoparticles deposited on the upper SSC surface with their size distribution chart. (C) Silver nanoparticles embedded in the SSC layer by heating with pulsed laser . (D) Gold nanoparticles deposited on the plasmonic SC surface with their size distribution chart.

The typical [I-V] characteristics of SSC: without NPs, with silver nanoparticles colloidal deposited on SSC surface by overcasting deposition; with Ag NPs embedded inside the

plasmonic SSC by laser heating; , and with Au NPs colloidal deposited on the plasmonic SSC surface by overcasting method are presented in Figure 7. The enhancement of the short circuit current density Jsc and the efficiency ɳ was attributed to the higher plasmonic absorption influence of noble metallic NPs resonance. The position of nanostructures has major influence on the plasmonic SC performance. The noble metallic NPs deposited on the upper SC will produce great electric field causing strong absorption and great scattering cross section which redirects the extra incident light inside the silicon layer causing great light absorption in it. The embedded NPs into SSC will achieve broadband and polarization impervious absorption enhancement as light gets trapped inside the silicon layer. [23].

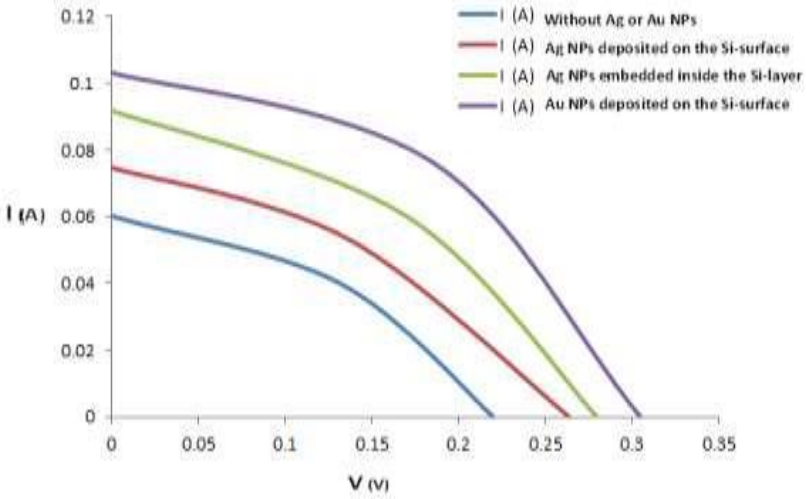


Figure 7- [I-V] characteristics of the SSC: without NPs, with silver nanoparticles deposited on Si-surface, with silver nanoparticles imbedded inside the silicon layer by heating with pulsed laser, and with Au NPs deposited on the plasmonic solar cell surface by overcasting deposition.

The exhaustive electric factors of SSC without NPs, with silver nanoparticles colloidal deposited on the front side of SSC by overcasting method, with embedded silver nanoparticles into the SSC layer using laser heating, and with gold nanoparticles colloidal deposited on the plasmonic SSC by overcasting process are briefed in Table 1**.**

Table 1- Electric factors of SSC without NPs, with Ag NPs colloidal deposited on the SSC surface by overcasting method, with embedded Ag NPs into silicon layer by laser heating, and with Au NPs colloidal deposited on the plasmonic solar cell surface by overcasting method.

SSC	Metal NPs Location	I sc (mA)	Voc (mV)	Jsc (mA/cm)	F.F	Improvement ofJsc	
Absent of NPs	_	60.21	220.26	3.1	0.39	2.7%	_
Ag NPs next overcasting	upper SSC	74.7	264	3.85	0.368	3.7%	24%
Ag NPs next heating by laser	into SSC	91.771	280	4.73	0.398	5.2%	52%
Au NPs next overcasting	upper plasmonic SSC	103.11	305	5.31	0.44	7.28%	71%

Figure-8 displays the SSC spectral response that increases progressively with various developments of overcasting sedimentation and laser heating. This high response is due to the plasmonic structures of Ag and Au nanoparticles that significantly trap the incident

sunlight in the active layer of SSC. The plasmon resonance causes light concentration onto small absorbance spectra regions over from ultraviolet (UV) up to near infrared (NIR).

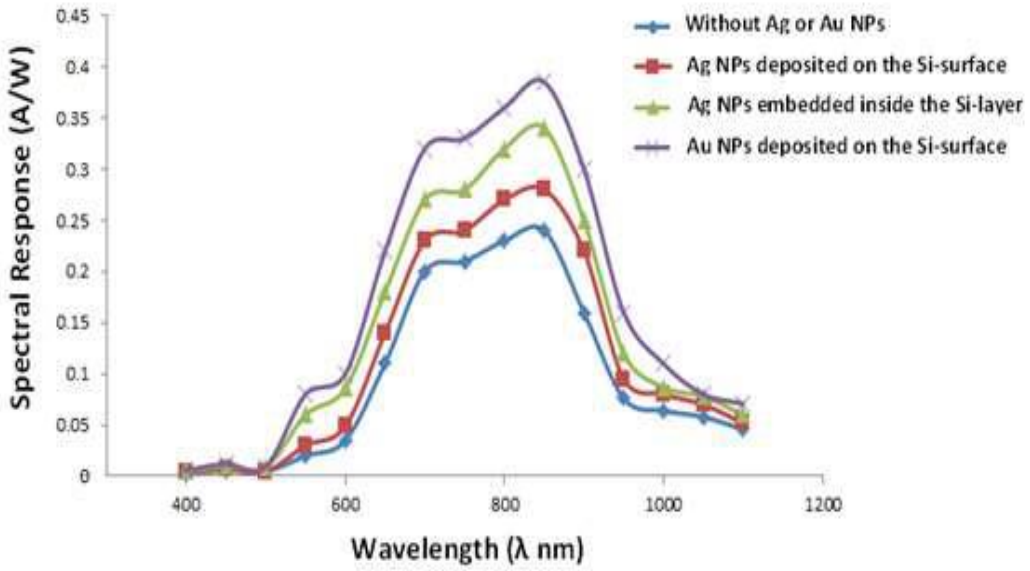


Figure 8- The spectral response of SSC without NPs, with silver nanoparticles colloidal deposited on SSC surface by overcasting method, with silver NPs embedded into Silicon layer by pulsed laser heating , and with gold nanoparticles deposited on the upper plasmonic solar cell surface by overcasting method.

Conclusion

Fast and simple ablation technique has been used to prepare pure metallic silver and gold nanoparticles in DW by pulsed laser ablation . The silicon solar cell performance was improved gradually by using two plasmonic nanostructure structures mechanisms on and inside the active layer of Silicon. The interaction between light and Ag, AuNPs caused light trapping resulting in better absorbance regions of solar spectrum owing to surface plasmon resonance.

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