

# Improved Efficiency of Thin Film a-Si:H Solar Cells with Au Nanoparticles

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**Abstract** — In this work, the effect of Au nanoparticles on the performance of a-Si:H solar cells is investigated experimentally. Au nanoparticles of 10, 20, 50, 80, 100, 200 and 400 nm are spin coated on ITO before metallization. The results show an increase in the  $J_{sc}$  and efficiency with increasing nanoparticle size. The  $J_{sc}$  increases from 9.34 mA/cm<sup>2</sup> to 10.1 mA/cm<sup>2</sup>. In addition, the efficiency increases from 4.28% to 5.01%.

**Index Terms** —nanoparticles, photovoltaics, plasmonics, thin film, solar cells, amorphous Si

## I. INTRODUCTION AND MOTIVATION

Effective light trapping mechanisms are important for the improved performance of thin film solar cells. For enhanced absorption in thin film solar cells, different approaches such as surface texturing and back reflectors have been described in [1-2]. More recently, nanotechnology has been used with plasmonic light trapping of metal nanoparticles (NP) like gold (Au) or silver (Ag) [3-5]. For incorporating metal NPs into solar cells, different methods have been established that includes island annealing and colloidal metal particles [6-7]. Also, some numerical models have been developed to understand the plasmonic effect [8]. In this work, the effect of Au nanoparticles on the performance of thin film a-Si:H n-i-p solar cells is studied.

## II. PLASMONIC ENHANCEMENT

Surface plasmons are collective oscillations of the free charges at a metal boundary. Metals support surface plasmons, either localized as for metal nanoparticles or propagating in case of planar metal surfaces. By controlling the size and shape of the metallic nanostructures, the surface plasmon resonance or plasmon propagating properties can be varied. Since the surface resonances of metals are mostly in the visible or in the infrared region of the electromagnetic spectrum, they are of particular interest for photovoltaic application. Two prominent mechanisms can explain the contribution of metallic nanoparticles based on application: scattering mechanism and the near-field localization effect [9].

Photocurrent enhancement by metal nanoparticles on the top surface of solar cells can be explained by the light scattering mechanism. Metal nanoparticles are strong

scatterers of light at wavelengths near their resonant frequency [10].

A point dipole model can describe the absorption and scattering of the incoming light by the nanoparticles for particles with diameters well below the wavelength the incoming light. The scattering and absorption cross-sections are given by the following equations [10]:

$$C_{scat} = \frac{1}{6\pi} \left( \frac{2\pi}{\lambda} \right)^4 |\alpha|^2 \quad (1)$$

$$C_{abs} = \frac{2\pi}{\lambda} \text{Im}[\alpha] \quad (2)$$

where

$$\alpha = 3V \left[ \frac{\epsilon_p/\epsilon_m - 1}{\epsilon_p/\epsilon_m + 2} \right] \quad (3)$$

is the polarizability of the particle. Here  $V$  is the particle volume,  $\epsilon_p$  is the dielectric function of the particle and  $\epsilon_m$  is the dielectric function of the embedding medium. From (3), its quite obvious that at  $\epsilon_p = -2\epsilon_m$  the particle polarizability will become very large. This very concept is termed as the surface plasmon resonance.

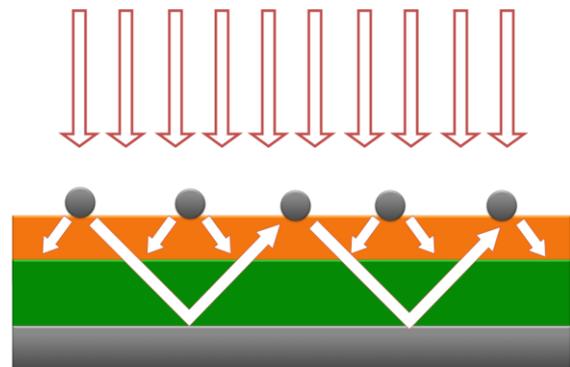


Fig. 1. Scattering of incoming light due to nanoparticles on top of ITO. (Figure not to scale)

At the surface plasmon resonance, the scattering cross-section exceeds the geometrical cross section of the nanoparticles e.g. silver nanoparticles in air has a scattering cross-section that is approximately ten times the cross-sectional area of the particle at the resonant frequency[11]. In such a case, a substrate covered with a 10 % areal density of

nanoparticles can fully absorb and scatter the incoming light, to first-order [11][12]. For light trapping it is important that scattering is more efficient than absorption, a condition that is met for comparatively larger nanoparticles as can be seen from (1) and (2) [4].

Nanoparticle size, shape and distribution over the surface will determine the effect of the nanoparticles on the performance of the photovoltaic device [13].

### III. STRUCTURE AND FABRICATION PROCESS

Fig. 2 shows the structure of the fabricated a-Si:H n-i-p solar cell. The structure is a stack of 80 nm ITO, 20 nm heavily doped n-type a-Si, 500 nm undoped a-Si and finally 20 nm heavily doped p-type a-Si on a p<sup>+</sup>-type Si wafer. The p<sup>+</sup> Si substrate serves as the back contact, and does not contribute significantly to the carrier generation. After the ITO etch, Au NP of various sizes in solution were spin-coated.

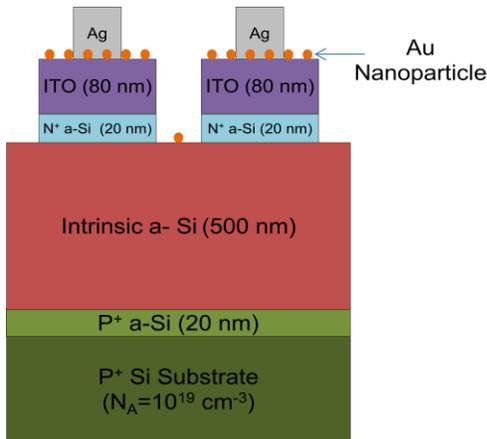


Fig. 2. Cross-section of the fabricated ITO/a-Si:H solar cell with Au nanoparticles deposited on the top surface. (Figure not to scale)

Seven different diameter-size, 10 nm, 20 nm, 50 nm, 80 nm, 100 nm, 200 nm and 400 nm particle sizes were investigated. The spin coating recipe was optimized to obtain uniform distribution and high concentration of particles on the surface, simultaneously and was set to 2000 rpm, 1000 acceleration and spinning for 60 seconds. Fig. 4 is an SEM image of the top surface showing the Au NP on the ITO.

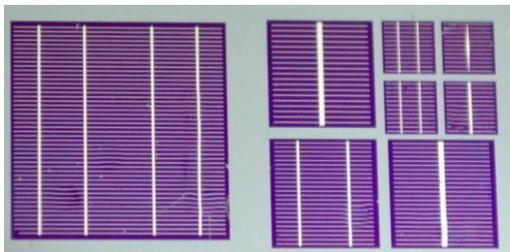


Fig. 3. Top view photograph of the fabricated solar cell.

After the NP coating, 100 nm of silver was deposited using Thermal Physical Vapor Deposition (PVD) tools. Three different cell area-sizes were fabricated i.e. 1 cm x 1cm, 0.5 cm x 0.5 cm and 0.25 cm x 0.25 cm. Fig. 3 shows the top view of final solar cell structure fabricated. Unless otherwise stated, solar cells of size 0.25 cm x 0.25 cm are presented in this work.

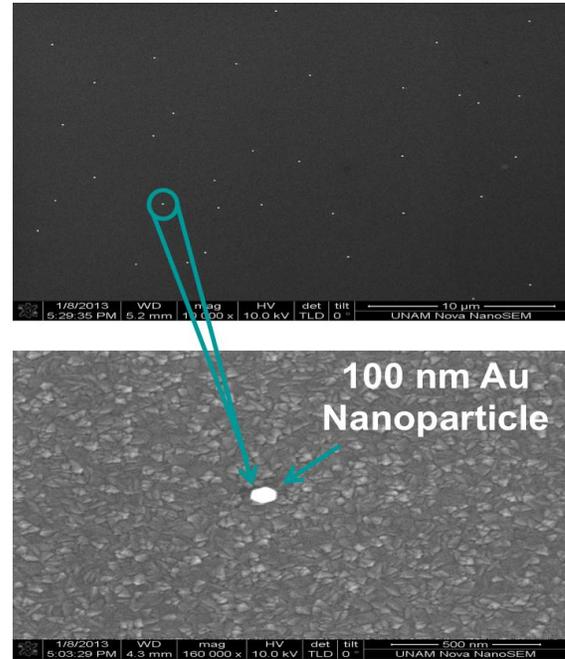


Fig. 4. SEM image of the top surface of the fabricated n-i-p a-Si:H solar cell with 100 nm Au nanoparticles on the ITO surface.

### IV. EXPERIMENTAL RESULTS AND ANALYSIS

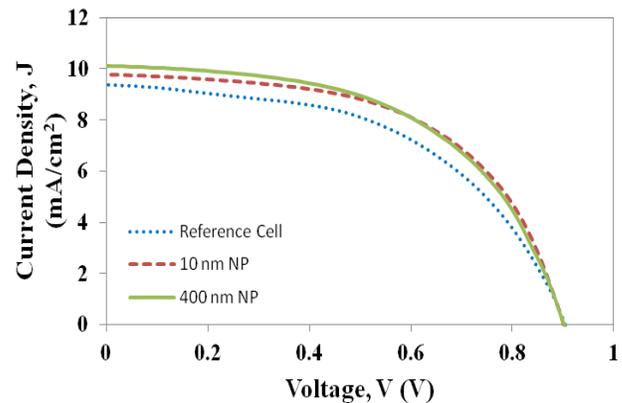


Fig. 5. Measured J-V characteristics of n-i-p a-Si:H reference cell without nanoparticles and cells with 10 nm and 400 nm Au nanoparticles.

Fig. 5 shows the J-V curve for the reference cell without NP and cells with 10 nm and 400 nm NP. The  $V_{oc}$  is constant at 0.89 V while the  $J_{sc}$  improves with larger NP size. Fig. 6 plots  $J_{sc}$  vs. NP size. The  $J_{sc}$  increases from 9.34 mA/cm<sup>2</sup> to 10.1 mA/cm<sup>2</sup>. Fig. 7 plots the median reflectance across all wavelengths vs. NP size. The reflectance drops from 23.19% with no Au NP to less than 20% for all NP sizes. The drop shows the improved surface scattering due to the Au nanoparticles.

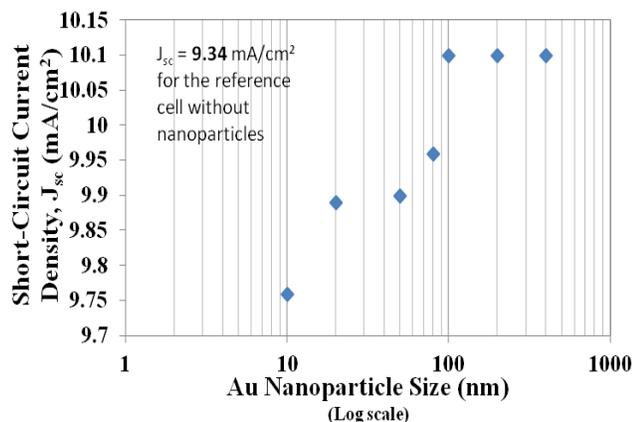


Fig. 6.  $J_{sc}$  vs. Au nanoparticle size (plotted in log scale) for Au nanoparticle enhanced plasmonic n-i-p a-Si:H solar cells.

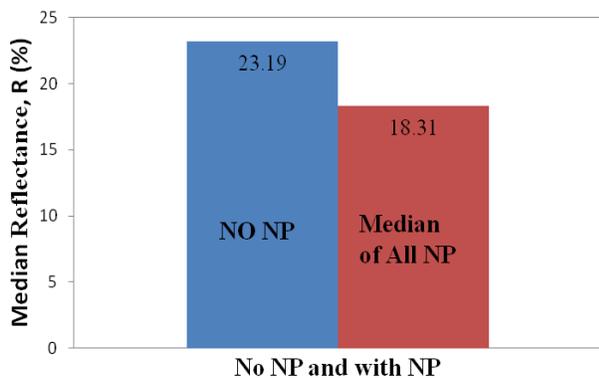


Fig. 7. Median reflectance vs. Au nanoparticle size (plotted in log scale) for Au nanoparticle enhanced plasmonic n-i-p a-Si:H solar cells.

Fig. 8 plots the efficiency vs. NP size. The efficiency increases with increasing NP size due to the increase in the  $J_{sc}$ . The efficiency increases from 4.28% to 5.1%. The  $V_{oc}$  does not change with NP size. The fill factor (FF) increases from 51% for the reference cell up to 56% for the Au NP based cell. For the most part the FF does not change with NP size.

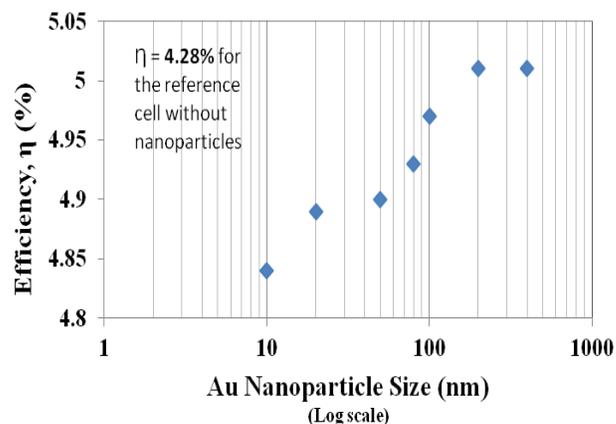


Fig. 8. Efficiency vs. Au nanoparticle size (plotted in log scale) for Au nanoparticle enhanced plasmonic n-i-p a-Si:H solar cells.

Fig. 9 plots the External Quantum Efficiency (EQE) of the reference cell, 10nm and 400nm Au NPs. The results show an improved spectral response with increasing NP size. The peak EQE is 59% for the cell with 400 nm NP while the reference cell has 43% peak EQE. The EQE predicts that there should be a 41.6% increase in the  $J_{sc}$  for the 400 nm NP cell with respect to the no NP cell. From the actual measurement, the  $J_{sc}$  increases from 9.34 mA/cm<sup>2</sup> for the no NP cell to 10.13 mA/cm<sup>2</sup> for the 400 nm NP cell, which is 8.46% increment. More investigations are required to further explain this mismatch.

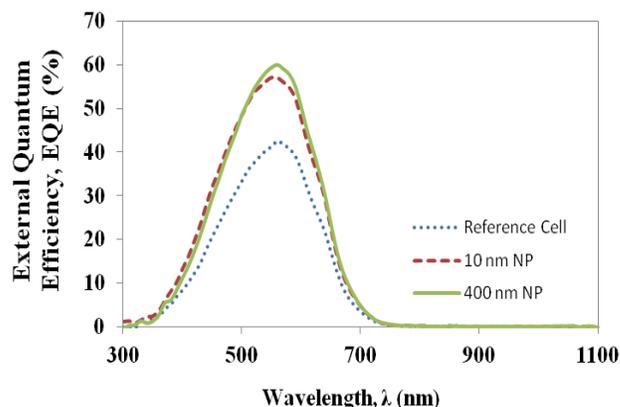


Fig. 9. Measured external quantum efficiency of n-i-p a-Si:H reference cell without nanoparticles and cells with 10 nm and 400 nm Au nanoparticles.

Table I summarizes the main findings of this work, listing the  $J_{sc}$  and efficiency of the solar cells with respect to the Au NP size. The  $J_{sc}$  increases by 8.46% with the introduction of NP for the best case and the efficiency improves by 17.06% with NP for the best case as well. Both the  $J_{sc}$  and efficiency tend to improve with larger NP sizes.

TABLE I  
SUMMARY OF RESULTS

Au NP Size (nm)	$J_{sc}$ (mA/cm <sup>2</sup> )	$\eta$ (%)
0	9.34	4.28
10	9.76	4.84
20	9.89	4.89
50	9.9	4.9
80	9.96	4.93
100	10.1	4.97
200	10.11	5.01
400	10.13	5.01

### V. CONCLUSIONS

In summary, the effect of Au nanoparticles on the performance of a-Si:H thin film solar cells was studied. The results show an increase in  $J_{sc}$ , efficiency and spectral response with the Au nanoparticles. The results highlight a promising and simple enhancement for future thin film solar cells using nanoparticles.

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