



# Effect of gold nanoparticles size on light scattering for thin film amorphous-silicon solar cells

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Received 3 October 2013; received in revised form 8 February 2014; accepted 11 February 2014  
Available online 5 March 2014

Communicated by: Associate Editor Frank Nuesch

## Abstract

In this work, the effect of gold (Au) nanoparticles on the performance of a-Si:H solar cells is investigated experimentally. The solar cell stack is grown on a highly doped p-type Si wafer and consists of 20 nm heavily doped p-type a-Si, 500 nm undoped a-Si, 20 nm heavily doped n-type a-Si and finally 80 nm Indium Tin Oxide (ITO) on the top. Au nanoparticles of 10, 20, 50, 80, 100, 200 and 400 nm are spin coated on top of the ITO before metallization. The plasmonic effect of the Au nanoparticles allows for additional scattering at the surface thus reducing the overall reflectivity. The larger the nanoparticle size the more scattering is obtained and the median reflectivity drops from about 23% to 18%. The results show an increase in the short-circuit current density ( $J_{sc}$ ) and efficiency with increasing nanoparticle size. The  $J_{sc}$  increases from 9.34 to 10.1 mA/cm<sup>2</sup>. In addition, the efficiency increases from 4.28% to 5.01%.  
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**Keywords:** Nanoparticles; Photovoltaics; Plasmonics; Thin film; Solar cells; Amorphous Si

## 1. 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 (Berginski et al., 2008; Ferry et al., 2009). More recently, nanotechnology has been used with plasmonic light trapping of metal nanoparticles like gold (Au) and silver (Ag) (Atwater and Polman, 2010; Catchpole and Polman, 2008; Akimov et al., 2009). For incorporating metal nanoparticles into solar cells, different methods have been

established that includes island annealing and colloidal metal particles (Beck et al., 2009; Derkacs et al., 2006). Also, some numerical models have been developed to understand the plasmonic effect (Akimov et al., 2009). Plasmonic nanoparticles have been explored extensively for dye-sensitized solar cells (DSSC) (Lin et al., 2012) and a nanoparticle-size dependent study similar study to ours but for DSSC has been published in Deepa et al. (2012). Though most of the publications in this field have presented data for back-scattering by implementing the nanoparticles in the back side of the solar cells, a recent study showed insightful results of placing Ag nanoparticles on the top surface of solar cells (Lenzmann et al., 2013).

Surface plasmons are collective oscillations of the free charges at a metal boundary. Metals support surface

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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 (Bohren and Huffman, 2008). Two prominent mechanisms can explain the contribution of metallic nanoparticles based on application: scattering mechanism and the near-field localization effect (Temple et al., 2009). 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 (Lenzmann et al., 2013).

## 2. Structure and fabrication process: spin-coating gold nanoparticles

Typically nanoparticles are placed on the bottom of the solar cell to enhance back scattering as well as back reflection. In this work, the effect of gold nanoparticles size placed on the top surface of thin film a-Si:H solar cells is studied.

In order to study the effect of the gold nanoparticles, an a-Si:H solar cell is fabricated. Fig. 1 shows the structure of the fabricated a-Si:H solar cell. The solar cell stack is grown on a p+ type Si wafer and consists of 20 nm heavily doped p-type a-Si, 500 nm undoped a-Si, 20 nm heavily doped n-type a-Si and finally 80 nm Indium Tin Oxide (ITO) on the top. The p+ Si substrate serves as the back contact, and does not contribute significantly to the carrier generation. The n+, intrinsic and p+ layers of aSi:H were grown using Plasma Enhanced Chemical Vapor Deposition (PECVD) tool in a single run on the P + Si substrate. Then 80 nm of ITO was sputtered on the top layer using RF sputtering tool (<http://www.mvsystemsinc.com/research-and-development-services>, 2013). More details of the solar cell fabrication process flow can be found in Hadi et al.

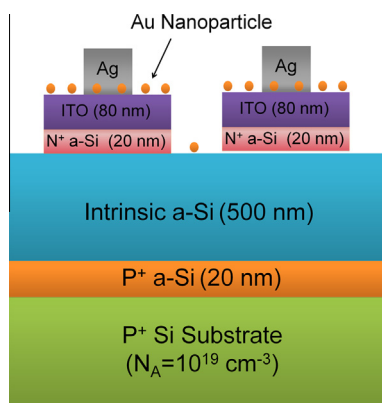


Fig. 1. Schematic cross-section of the fabricated ITO/a-Si:H solar cell with Au nanoparticles deposited on the top surface. (Figure not to scale).

(2011, 2012), Alnuaimi et al. (2013). The gold nanoparticles were spin-coated on top of the ITO.

There are various ways to deposit the nanoparticles as mentioned earlier including island forming by annealing, drop-casting, dip coating and spin coating. In this work, colloidal gold nanoparticles dispersed in Phosphate Buffered Saline (PBS) solution were used (<http://www.sigmaaldrich.com/materials-science/nanomaterials/gold-nanoparticles>, 2013). In order to study the effect of the gold nanoparticles size, seven different diameter-size i.e., 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 as well as optimum concentration of particles on the surface. Several spin-coating recipes are investigated and the most optimized spin-coating recipe is found to be 2000 rpm speed, 1000 rpm acceleration and spinning for 60 s. Fig. 2 is an SEM image of the top surface showing the gold nanoparticles on the ITO. The surface coverage by the nanoparticles is approximately calculated from the SEM images and is found to be 0.07854% for the 100 nm nanoparticles with a variance of 0.016% based on different locations of the cell surface. We assume the surface coverage percentage remains in close vicinity for different nanoparticle sizes since number of nanoparticles per unit volume of the solution decreases with increasing nanoparticle sizes, as mentioned in the supplier's data sheet. For example, there are  $5.98 \times 10^{12}$  nanoparticles/ml of solution for 10 nm Au particles whereas the number of nanoparticles for 100 nm Au particles is  $3.84 \times 10^9$  per ml of the PBS

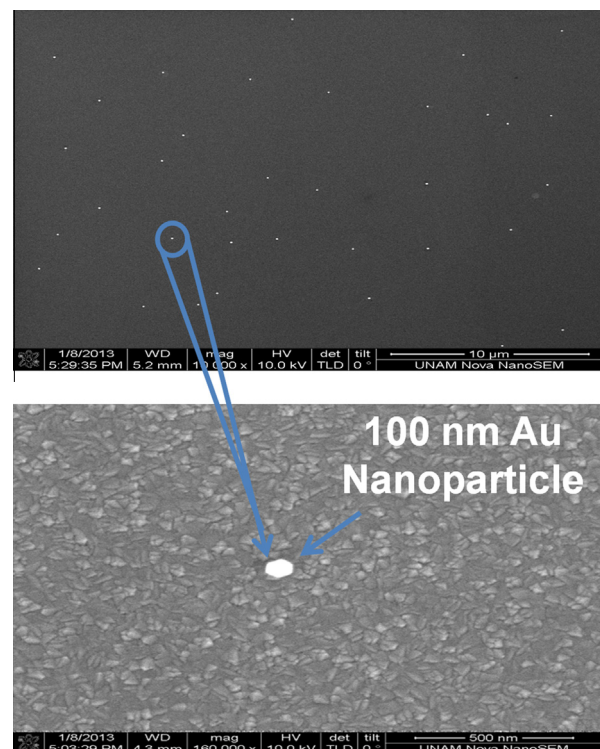


Fig. 2. SEM image of the top surface of the fabricated n-i-p a-Si:H solar cell with 100 nm Au nanoparticles on the ITO surface.

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