Facile metallization of dielectric coatings for plasmonic solar cells

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ABSTRACT

Electroless deposition of Ag nanoparticles on PECVD SiNₓ:H dielectric layers is a new straightforward chemical bath process well adapted to the realization of plasmonic solar cells. Depending on the stoichiometry, SiNₓ:H contains a certain number of Si nanoclusters embedded in the silicon nitride matrix, that act as reducing agents for Ag ions in solution and thus allows the deposition of Ag nanoparticles directly on the surface. We investigate the influence of the layer stoichiometry and deposition parameters on the nucleation and growth of Ag nanoparticles, and show how they can be adjusted to control the nanoparticle size and density. We also demonstrate that this facile metallization process can be extended to PECVD SiOₓ layers, another dielectric coating of interest in photovoltaics.

1. Introduction

In the past few years, plasmonic nano-structures have appeared as a promising tool to enhance the optical properties of photovoltaic devices [1–3]. For thin film solar cells, scattering of incident light by metal (e.g. Ag and Au) nanoparticles (NPs) on the front or rear side, can strongly improve light trapping and hence absorption [4,5] due to their localized surface plasmon resonance (LSPR) properties. Fig. 1 shows the architecture of a plasmonic solar cell using light scattering from metal NPs deposited at the front side. Thanks to the angular spread, not only light has an increased optical path length in the substrate, but also the fraction scattered at an angle above the critical angle for reflection at the Si/dielectric rear interface is totally reflected. A metal reflector at the rear allows to reflect the rest of the light (below the critical angle) towards the front interface where it is again scattered by the metal NPs [3]. Recent studies have reported on problems with locating the metal NPs at the front such as absorption losses at wavelength below the surface plasmon resonance due to destructive interference between scattered and incident light [4,6,7]. Putting the scattering NPs on the rear side of the solar cell is currently seen as the best way to solve this problem since light trapping is mostly required for those long wavelength photons that reach the rear side. It also allows to optimize separately the front antireflection coating and the back scattering layer, i.e. the characteristics of the metal NP (size, shape and coverage) and of the underlying dielectric layer (refractive index and thickness) [8,9].

The metal nanoparticles can be deposited by different techniques, the most commonly used being thermal evaporation of metal layers with a subsequent annealing step [10], deposition from colloids and through porous templates. However, these methods are cost and time expensive and cannot be applied for large scale device production.

We have recently reported on a new and facile technique for producing Ag nanoparticles on SiNₓ:H dielectric films used in photovoltaic devices [11]. Ag can be deposited by dipping the SiNₓ:H coatings in a solution of HF and a Ag salt. The extent of Ag deposition depends on the stoichiometry of the films. We have determined that the driving force for this process is the presence of Si nanoclusters that play the role of sacrificial anode in presence of HF for the reduction of the Ag salt. If we consider the dissolution regime where 2 electrons per Si atom are involved [12], the overall electroless reaction can be summarized by:

\[ \text{Si} + 6\text{H}^+ + 2\text{Ag}^+ \rightarrow \text{H}_2\text{SiF}_6 + 2\text{Ag} + 2\text{H}^+ + \text{H}_2 \]

This metal-assisted etching of silicon is known as a deposition method of noble metals on Si and has been studied extensively for etching Si nanostructures, especially Si nanowires [13,14].

In this work, we go further in the investigation of the electroless deposition of Ag by examining the influence of the SiNₓ:H stoichiometry and chemical conditions on the NP features. Based on our previous findings, it was also logical to envision the possibility of depositing Ag with the same electroless process on other dielectrics containing a fraction of a Si phase. Here, we show for the first time that PECVD SiOₓ, a standard dielectric material used in solar cells, can indeed be metallized using the same electroless plating method.