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Improvement of the efficiency and power output of solar cells using nanoparticles and annealing

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Abstract

Silver nanoparticles have been deposited on crystalline Si solar cell surfaces using direct-current (DC) magnetron sputtering. The influence of localized surface plasmons in Ag nanoparticles (NPs) on the performance of annealed solar cells has been investigated. We find that the localized surface plasmons can improve the thermal stability of annealed solar cells. When the cell with 8% Ag nanoparticle coverage is annealed at 600 °C for 10 min, approximately 40% increase in short-circuit current (I_{sc}) and approximately 50% increase in maximum power (P_m) are observed.
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Keywords: Silver nanoparticle; Localized surface plasmon; Solar cell; Thermal stability

1. Introduction

In recent years, photovoltaics have become a most pursued renewable energy technology due to rising concerns about petroleum extinction and greenhouse effects (Chen et al., 2012). Currently, crystalline silicon solar cells still dominate the photovoltaic market because of the non-toxic and abundant material resources used. However, silicon solar cells are already near their potential peak for converting solar energy to electricity and thus are unlikely to improve much more (Service, 2008). To enhance the efficiency, a variety of approaches for increasing optical absorption of photovoltaic devices based on surface plasmon polariton resonances in nanoparticles have been explored. Surface plasmon resonance is a light-induced collective oscillation of conducting electrons on the surface of a metal. Sunlight excites the surface plasmon resonance of metallic nanoparticles leading to extraordinary scattering, in which light is trapped to confine light, and strong electromagnetic field greatly strengthens the absorption of dye (Atwater and Polman, 2010; Oelhafen and Schuler, 2005). By engineering the size (Fahr et al., 2009; Lim et al., 2007; Liu et al., 2012; Muduli et al., 2012; Schaadt et al., 2005; Sundarajan et al., 2008), shape (Hägglund et al., 2008; Rockstuhl et al., 2008), and concentration (Derkacs et al., 2006; Lee et al., 2013; Matheu et al., 2008) of nanoparticles, transmission of light into the semiconductor can be enhanced via scattering that occurs preferentially in the forward direction. Scattering by nanoparticles is strongly influenced by localized surface plasmon resonances.

So far, there is a great deal of work about the effect of large nanoparticles on the photoelectric performance of solar cell. Little work is investigated on the effect of small nanoparticles on the photoelectric performance. According to above ideas, in this paper, small Ag nanoparticles are

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deposited on the surface of crystalline Si solar cells by magnetron sputtering, and the effect of the coverage of small Ag nanoparticles on the electrical performance of solar cell is investigated. In addition, the thermal stability of optimized solar cell is also investigated.

2. Experimental

All the cell samples used in our experiment were commercial cell panels with pyramid textured surface, their fill factor (*FF*) was 70% and efficiency (η) was 17%. To meet the size requirement of magnetron sputtering, panels were cut into square pieces with the size 2 cm × 2 cm, the performance of which decreased due to the damage during cutting process. The solar cells were first cleaned in ethanol and then blown dry in a stream of cold-blast air. Ag nanoparticles were deposited on cell surfaces using ultra high vacuum magnetron sputtering system (Model: JGP600). The base pressure of vacuum chamber was better than 5×10^{-5} Pa. The working pressure was 0.3 Pa. The deposition rate was 0.5 Å/s. The 5%, 8%, 14% and 23% surface coverages were obtained respectively by controlling the deposition time. The cells were annealed for 10 min at 400 °C and 600 °C. Fig. 1 shows the schematic diagram of device structure with Ag nanoparticles.

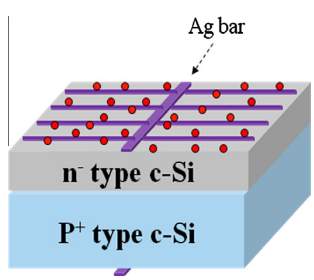

Fig. 1. Schematic diagram of solar cell structure with Ag nanoparticles.

Current–voltage (*I–V*) characteristics were measured using a Keithley 2400 under a 500 W solar simulator in standard test conditions (25 °C, AM1.5g spectrum, and 1000 W/m^2). Scanning electron microscopy (SEM) was used to study the size of Ag nanoparticles.

3. Results and discussion

Fig. 2 shows the scanning electron microscope images of cells with Ag surface coverages of 5%, 8%, 14%, and 23%. The Ag surface coverage increases by extending the deposition time. However, the variety of average particle size is very small. This is attributed to the similar speeds of nucleation and particle growth. In our experiment, supposedly, the Ag nanoparticles are spherical and distributed homogeneously. The size of the Ag nanoparticles is obtained from SEM graph by comparing the every image of Ag nanoparticles with the scale bars one by one and then the average size is worked out by averaging statistically the size obtained from several SEM graphs. The average particle size is approximately 9 nm and the Ag nanoparticles are present predominantly as isolated single particles.

Fig. 3(a) shows the current–voltage and corresponding power output curves of cells with the different silver nanoparticle surface coverages. The cell without nanoparticles is used as a reference. Light incident perpendicular to the cell surface. The fill factor and the efficiency as functions of

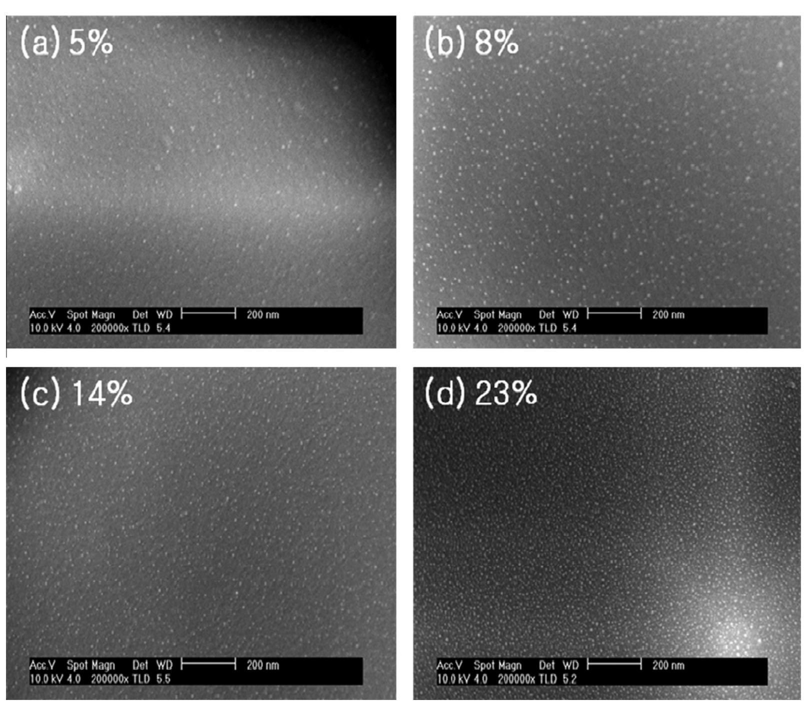

Fig. 2. Scanning electron micrographs of cells with Ag surface coverages of (a) 5%, (b) 8%, (c) 14%, and (d) 23%.

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