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Influence of silver nanoparticles on the photovoltaic parameters of silicon solar cells

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Abstract. Influence of Ag nanoparticles on optical and photovoltaic properties of, silicon substrates, silicon solar cells and glass have been investigated. Silver nanoparticles have been fabricated by evaporation of thin Ag layers followed by the thermal annealing. The surface plasmon resonance peak was observed in the absorbance spectrum at 470 nm of glass with deposited silver nanoparticles. It is demonstrated that deposition of silver nanoparticles on silicon substrates was accompanied with a significant decrease in reflectance at the wavelength 360-1100 nm and increase of the absorption at wavelengths close to the band gap for Si substrates. We studied influence of Ag nanoparticles on photovoltaic characteristics of silicon solar cells without and with common use antireflection coating (ARC). It is shown that silver nanoparticles deposited onto the front surface of the solar cells without ARC led to increase in the photocurrent density by 39% comparing to cells without Ag nanoparticles. Contrary to this, solar cells with Ag nanoparticles deposited on front surface with ARC discovered decrease in photocurrent density. The improved performance of investigated cells was attributed to Ag-plasmonic excitations that reduce the reflectance from the silicon surface and ultimately leads to the enhanced light absorption in the cell. This study showed possibility of application of Ag nanoparticles for the improvement of the conversion efficiency of wafer-based silicon solar cells instead of usual ARC.

Keywords: silver nanoparticles; plasmonic resonance; reflectance; silicon solar cells; efficiency

1. Introduction

Silicon solar cells are most widely used devices on photovoltaic energetic due to raw material abundance in nature, stability of the parameters and well established processing technologies. However manufacturing cost presents an issue for its wider applications. Simultaneous increase of efficiency and considerable reduction the cost of manufacturing are required for making photovoltaic sources of electricity competitive with other technologies. The main problem for solar cell is relatively low efficient of absorption of solar light.

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2. Experimental procedure

Monocrystalline p-type boron-doped silicon wafers with orientation of (100), resistivity about of 3 **Ω** cm and thickness of about 200 μm were used for fabrication of solar cells by screen printed process (Green 2007, Agnihotri and Gupta 1981, Dzhafarov *et al*. 2012). The wafers were cleaned in NaOH:H_2O (1:4 in volume) at 80°C for 10 min, in HCl at room temperature for 10min and then etched in HF: H_2O (1:1 in volume) for 1 min. Then samples were dried in deionized (DI) water. Containing phosphorus spin-on dopant (SOD) (KFK-50-10T type) was used as phosphor source. Cleaned surface of wafer was coated with SOD by spin-on technique at room temperature with 2000 rpm for 10 seconds. Then the coated samples were baked at 600℃ for 2 min for destructization of the coating.

The n^+-p junction was formed by phosphorus diffusion from SOD into p-type silicon substrate at 950°C in vacuum 1.33×10^{-1} Pa for 25 min in a tube furnace. The phosphor-silicate glass layer was removed from the silicon surface with hydrofluoric acid solution (HF: H_2O, 1:9). n^+-emitter layer with 0.5-1.0 μm thickness and 15-20 **Ω**/□ sheet resistance was formed as a result of phosphorus diffusion. The thickness and sheet resistance was found by four-point method.

The electrical contacts were made by screen printed process with a Du Ponte photovoltaic silver paste for front and silver with 3% aluminum paste for the back contact. Samples with silver contacts were baked at 200℃ for 10 min and then metallization at 800 ℃ for 10 min in the conventional annealing furnace was done. Two types of solar cells were prepared in this work: without and with traditional SiO_x antireflection coating (ARC) (A-type and B-type cells respectively). The thickness of the last one with SiO_x antireflection coating prepared was 80 nm (Kim 2007). Active area of the cells was about 1.1 cm^2.

Silver nanoparticles have been fabricated on top surfaces of silicon solar cells (of both A and B types), silicon substrates wafers and cleaned glass substrates by thermal evaporation of 10-15 nm Ag films followed by thermal annealing. Silver evaporation has been performed in vacuum of 1.3×10^{-3} Pa at room temperature. The thickness of the Ag film was measured during evaporation by using a Deposition controller (Inficon, Leybold). The solar cells, silicon wafers and glass substrates with silver films and the test samples without silver films were then annealed at nitrogen atmosphere in furnace at 500°C. It will be noted that best adhesion of silver nanoparticles to silicon surface was observed as result of thermal treatment at 500°C for 10-30 min. To investigate the surface morphology, the optical properties of silicon wafers and photovoltaic characteristics of the solar cells, we examined the size and density of the Ag nanoparticles by the atom-force microscopy (AFM, Solver NEXT, NT-MDT), the integrated reflectance and transmittance of the silicon wafers or glass substrates and the current-voltage (I-V) characteristics of the cells in each stage of processing. The silver nanoparticles have a surface coverage about 35-40%. The integrated reflectance and transmittance of the samples was measured at room temperature by UV-VI spectrometer ("Specord-210") in the wavelength range 300-1100 nm. The absorption spectra of samples were found from the reflectance and transmittance data of the samples. The absorption coefficient (α) is deduced from transmission spectra by solving α in the equation

$$T= (1-R)^2 \exp(-\alpha d) \tag{1}$$

Here R is reflectivity and d is the effective sample thickness. The absorption coefficient is determined from correlation

$$\alpha = \frac{1}{d} \ln\frac{(1-R)^2}{2} \tag{2}$$