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Effect of surface texturing processes on the performance of crystalline silicon solar cell

Khaldun A. Salman

Solar Energy Researches Department, Al-Nahrain Nanorenewable Energy Researches Center, Al-Nahrain University, Baghdad, Iraq

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ABSTRACT

Two texturing methods using porous silicon (PS) and pyramids were performed to investigate the effect of them on the performance of crystalline silicon (c-Si) solar cell. Surface morphology and structural properties of samples have been studied using scanning electron microscopy (SEM) and atomic forces microscopy (AFM). Optical reflectance was obtained using optical reflectometer. I-V characterization of fabricated solar cells was investigated. The results showed the highest conversion efficiency of 13.23% for PS layer compared with 11.36% and 3.70% efficiencies for the solar cells devices with pyramids texturing and as-grown Si, respectively. PS texturing exhibited an excellent reduction in the reflection of incident light compared with pyramids texturing process, with a good light-trapping of wide wavelength spectrum, which could produce high efficiency solar cells.

1. Introduction

The suitable tools for enhancing the conversion efficiency of crystalline silicon (c-Si) solar cells is the surface texturing processes which used to reduce light reflection and leads to changes in the optical transitions. c-Si solar cells currently lack efficiency due to electrical and optical losses, such as reflection, shadowing, non-absorbed radiation, and recombination (Ackermann et al., 2002). Porous silicon (PS) is a nanostructured material that has been much attracted to enhance the optical properties of c-Si. The formation of PS layers on c-Si wafers using electrochemical etching (ECE) were exhibits photoluminescent and electroluminescent properties similar to those properties of a semiconductors with a direct energy gap (Canham, 1990). The PS is becomes an attractive material in the field of solar cells due to the broadening band gap, wide optical transmission range (700–1000 nm), wide absorption spectrum, surface roughening and a good anti-reflection coating (ARC) (Koshida and Koyama, 1992). The main performance improving factor of PS layer is the rough surface and lower effective refractive index compared with c-Si which can decrease the reflection losses of the sunlight radiation (Vitanov et al., 1997).

Many researchers have started their research in c-Si solar cells using c-Si substrates. However, the situation differs significantly on textured substrates where pyramids a few microns high, have to be covered by conformal thin films only some tens of nanometer thick. Moreover, the c-Si (100) in textured substrates instead of the usual (111) of flat substrates can also have significant influence in interface passivation. Actually, special attention to wet-chemical pre-treatments is required to assure a low interface defect density on textured substrates (Angermann, 2008). Si texturization is an important topic of modern science and technology, particularly appealing in photovoltaics (PV) (Moreno et al., 2010; Huynh et al., 2002; Law et al., 2005). Random pyramid arrays with a reduced reflectivity of 10% can be readily obtained via anisotropic etching of c-Si in alkaline solutions (Seidel et al., 1990), which is widely used in c-Si solar cell manufacturing (Singh et al., 2001; Campbell and Green, 1987; Vazsonyi et al., 1999). c-Si wafer random texturing is usually achieved in commercial solar cells by an anisotropic etching of the **c-Si** network. Although dry etching techniques are currently under investigation, wet etching by an alkaline solution is the standard process for industrial solar cell texturing. In fact, wet chemical etching is also routinely used in c-Si cell processing to remove sawing damage. The most widely used anisotropic etching is a low concentration potassium hydroxide (KOH) solution in water with the addition of isopropyl alcohol (IPA) (Muñoz et al., 2009).

This work investigated the increase of the efficiency in the c-Si solar cell using two methods of texturing designing (PS and pyramids). The objective of this work was to study the performance of c-Si solar cells with different texturing processes. The author suggests using texturing processes with PS layer to increase the light conversion efficiency of solar cells.

E-mail address: khaldunphysics@gmail.com

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2. Experimental

N-type c-Si wafer, ⟨1 0 0⟩ orientation, 0.75 Ω cm resistivity and 283 μm thickness has been used as a substrate for surface texturing using PS and pyramids methods. Before the texturization process, **c-Si** wafers were cleaned in a H_2SO_4:H_2O_2 (2:1) solution. For PS performing, the wafer was placed in electrolyte solution (HF: ethanol, 1:5) with current density of 40 mA/cm^2 and 25 min. etching time using photoelectrochemical (PECE) cell, which is made of Teflon and has a circular aperture at the bottom that was sealed by the c-Si sample. The cell has a two-electrode system connected to the c-Si sample as the anode and platinum (Pt) as the cathode (Fig. 1) (Salman et al., 2011a,b).

The synthesis was carried out at RT and the samples were rinsed in ethanol and dried in air after etching process. In this case, the illumination was positioned over the c-Si n-type samples for the maximum possible illumination and to generate the required holes for dissolution (Bisi et al., 2000; Salman et al., 2011a,b). The pyramidal texturisation of c-Si wafers after c-Si dioxidion made square patterned windows which were exposed to UV source. Through the open window in oxide, c-Si was symmetrically etched in 48% KOH concentration at a temperature about 80 °C to synthesis the pyramids texturing. After the etching process, the samples was rinsed in distil water and dried in nitrogen source until they become hydrophobic.

The following procedures were used to fabricate the solar cells: The etched samples of PS and pyramids texturing were coated with photoresist, and then, a masks were placed directly above the samples and exposed to UV radiation for 30 s to form a patterned coating. P-type doping was achieved using the spin coating method by placing boron liquid on the center of the samples, followed by spin coating at RT at a speed of 1100 rpm for 8 s. Then the layer was placed in a furnace at 80 °C for 10 min. to remove moisture. Dopant diffusion was carried out using a tube furnace at 800 °C for 50 min. under flowing (4 L min^{-1}) nitrogen gas. A p-n junction was fabricated and placed in a solution of NH_4F:H_2O in a weight ratio of 3:7 then mixed with HF in a mole ratio of 1:7 to remove the oxidation layer. Silver (Ag) evaporation was used on the front (n-type) side of the sample to form a metallisation grid pattern and aluminum (Al) evaporation was used on the back (p-type) side to form a reflector contact. Annealing was carried out at 250 °C for 30 min to insure optimal contact. The schematic diagram of the designed solar cell based-on PS and pyramids texturing samples are shown in Fig. 2.

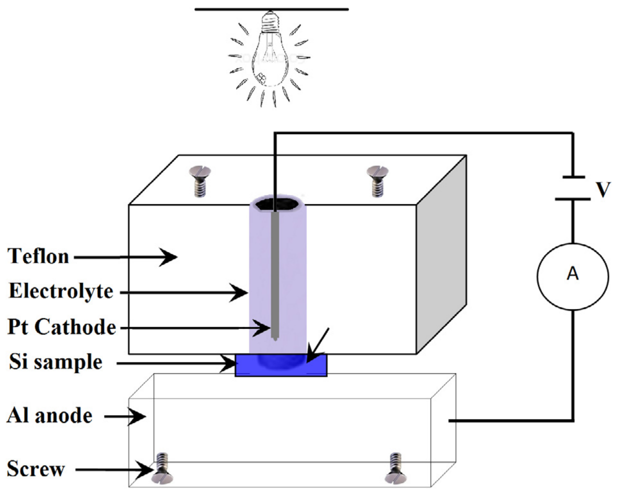

Fig. 1. The electrochemical etching set-up.

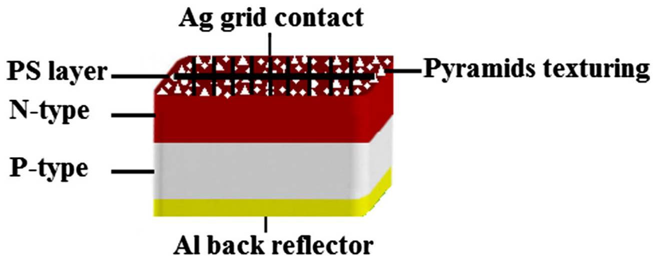

Fig. 2. Solar cells based-on PS and pyramids texturing samples.

The fabricated devices were examined by using current-voltage (I-V) characterization. Optical reflectance was characterized using optical reflectometer (Filmetrics F20). Surface morphology and structural properties of samples were characterized using scanning electron microscopy (SEM) and atomic forces microscopy (AFM).

3. Results and discussions

Fig. 3 demonstrates the SEM image of the PS layer formed on the n-type c-Si (100) sample. Many nano-sized pores were evidently randomly distributed on the Si surface. A highest density of pores and porosity was observed.

Much more homogeneous distribution of pores could be showed on this sample in comparison to other samples, which were prepared with different electrolyte composition (Omar et al., 2008). This distribution could be attributed to the ethanol which acts as an active surface agent, removes hydrogen bubbles during etching, reduces surface tension, and therefore the layers have higher porosity (Jakubowicz, 2007).

Fig. 4 shows the topography of pyramid texturing for n-type c-Si (100), it had seem that many nano-pyramids were evidently randomly distributed on the surface of the n-type c-Si (100). A lowest density of pyramids and porosity was observed in comparing with the PS sample. Also, the distribution is not statistical for pyramid heights. This histogram distribution is a key parameter in the information about the number of pyramids, and the texturing process which has created different size pyramid in non-textured regions.

Fig. 5 shows the AFM images of the PS layer and pyramids texturing compared to the as-grown Si (100). The images reveals the high value of root mean square of PS layer (330.64 nm) compared with low values of root mean square (2.65 nm) and (110.30 nm) of the as-grown Si and pyramids texturing, respectively. This is an advantage for using the PS layer as an anti-reflection coating (ARC) in solar cells because the PS layer reduces light reflection and leads to enhances in the optical transitions (increasing light absorption in the VIS region of the solar spectrum) and lead to light

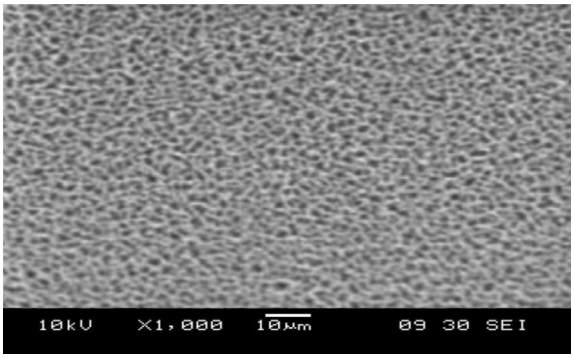

Fig. 3. SEM image of PS layer.