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Crystalline silicon solar cells with micro/nano texture

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ABSTRACT

Crystalline silicon solar cells with two-scale texture consisting of random upright pyramids and surface nanotextured layer directly onto the pyramids are prepared and reflectance properties and *I–V* characteristics measured. Random pyramids texture is produced by etching in an alkaline solution. On top of the pyramids texture, a nanotexture is developed using an electroless oxidation/etching process. Solar cells with two-scale surface texturization are prepared following the standard screen-printing technology sequence. The micro/nano surface is found to lower considerably the light reflectance of silicon. The short wavelengths spectral response (blue response) improvement is observed in micro/nano textured solar cells compared to standard upright pyramids textured cells. An efficiency of 17.5% is measured for the best micro/nano textured c-Si solar cell. The efficiency improvement is found to be due to the gain in both J_{sc} and V_{oc}.

1. Introduction

The silicon surfaces functionality increasing is of high importance for various applications. One particular approach for implementing multifunctionality is the formation of two-scale structured surfaces, as for instance micron-scale structured surfaces that also possess nanoscale roughness. These surfaces have superhydrophobic self-cleaning (after an additional surface fluorination), photoluminescence and antireflection properties. There are several methods for preparation of two scale micro/nano surface structures, the metal-assisted etching [1] being one of the simplest and effective. Superhydrophobic surface was obtained by two-scale roughness prepared by this simple silicon etching techniques as described in [2]. Micron-scaled pyramid structure was obtained by anisotropic KOH etching and nanostructure onto these pyramids by metal-assisted etching in HF/H_2O_2 aqueous solution. Furthermore [3] the potential application of these two-scale rough surfaces formed by the metal-assisted etching of micron-sizes pyramid texture in antireflection and light-trapping properties was highlighted. Silicon solar cells texturization is important for the reflection losses reduction, increased light absorption as well as for an overall conversion efficiency improvement. Moreover, surface texture with nano-dimensions [4,5] is proven to be effective for broadband reflection suppression. The nanotextures could be also incorporated on microtextured silicon surfaces (for example, pyramids etched mono crystalline silicon) to improve even further the solar cell devices functionality [6]. Indeed on the micro/nanostructured two scale surfaces a weighted light reflectance of 3.8% in the 300–1000 nm wavelength was measured [3]. Electroless stain etching in HF/HNO_3 [7] and $HF/Fe(NO_3)_3$ [8] solutions, as well as electrochemical etching [9,10] was further employed for formation of nanoporous layer on pyramids pretextured wafers. The prepared solar cells using these methods as well as metal-assisted electroless etching however possess rather low conversion efficiency [11].

In this paper a relatively simple method for producing a hierarchical (micro/nano) structure on the crystalline silicon surface is presented. The preparation method is using only electroless wet chemistry processes at room temperature. Solar cells with this multi-scale surface structure incorporated were prepared, by using the standard screen-printing process, and their performance measured.

2. Experimental

The p-type CZ c-Si (1 0 0) wafers with thickness of 180–240 μm and resistivity 3–6 Ω cm were fabricated to solar cells using the processing sequence shown in Fig. 1. A texturization with micron-sized random pyramids was performed in KOH-IPA solution at a temperature 80 °C for 45 min. The textured wafers were cleaned in $HCl:H_2O_2:H_2O$ (HPM) mixture at 80 °C for 10 min and then wafer surfaces H-terminated in diluted HF. The nanotexture onto the random pyramids was formed by two-step process consisting of an electroless treatment in an acidic aqueous solution of $Na_2S_2O_8$ and

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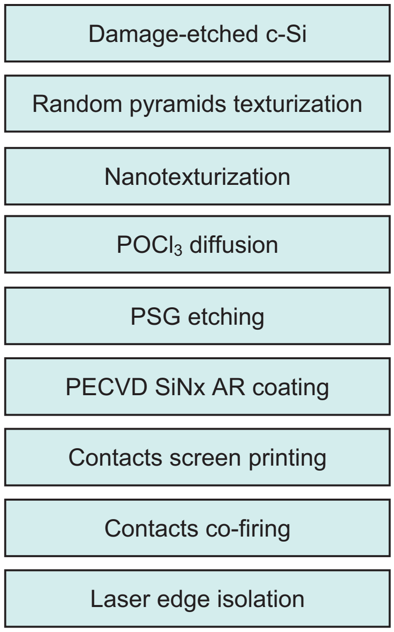

Fig. 1. Processing sequence for the preparation of crystalline silicon solar cells with micro/nano surface texturing.

$AgNO_3$ (pH < 3) for 6 min followed by an etching in an aqueous solution of HF and H_2O_2 for 2 min. Both treatments were performed at room temperature on 125 cm × 125 cm pseudo square wafers. The electroless solution preparation details are described in [12]. The average sheet resistance after the phosphorous oxychloride ($POCl_3$) diffusion and phosphor-silicate glass (PSG) removal in diluted HF was measured to be approximately 80 Ω/sq. After PECVD deposition of a SiNx passivation and anti-reflection layer on the front side of the wafers, silver pattern contact and aluminum back surface field were formed by using screen-printing and co-firing in a belt IR furnace. The total reflectance of the texturized wafers and the solar cells was measured with a Hitachi U-3010 spectrophotometer equipped with an integrating sphere, in the wavelength range 300–900 nm. The wafers surface morphology was studied by using scanning electron microscopy (SEM) technique. For SEM (JEOL JSM-6500F) measurements square pieces of size 20 mm × 20 mm were prepared using laser cutting. The finished solar cells performance was analyzed by reflectance, quantum efficiency and *I–V* measurements. The solar cells current-voltage (*I–V*) parameters assessment was performed at 25 °C under AM 1.5 G solar spectrum using a solar simulator Wacom WXS-220S-L2 with power density of 1000 W/m^2.

3. Results and discussion

3.1. Surface structures

Micron-sized surface pyramids were formed by anisotropic etching of silicon wafers with (1 0 0) orientation in an aqueous KOH-IPA solution. The treatment in $Na_2S_2O_8$ activated by $AgNO_3$ electroless solution and following 2 min etching in $HF/H_2O_2/H_2O$ resulted in production of a nanostructure directly onto the pyramids covered silicon surface. The hierarchical (nanotexture on microtexture) structure prepared in the above described techniques is shown in Fig. 2 as plan-view as well as cross-sectional SEM images. The pyramids surface is covered uniformly with fine nanoporous layer. The pores lateral dimensions are less than

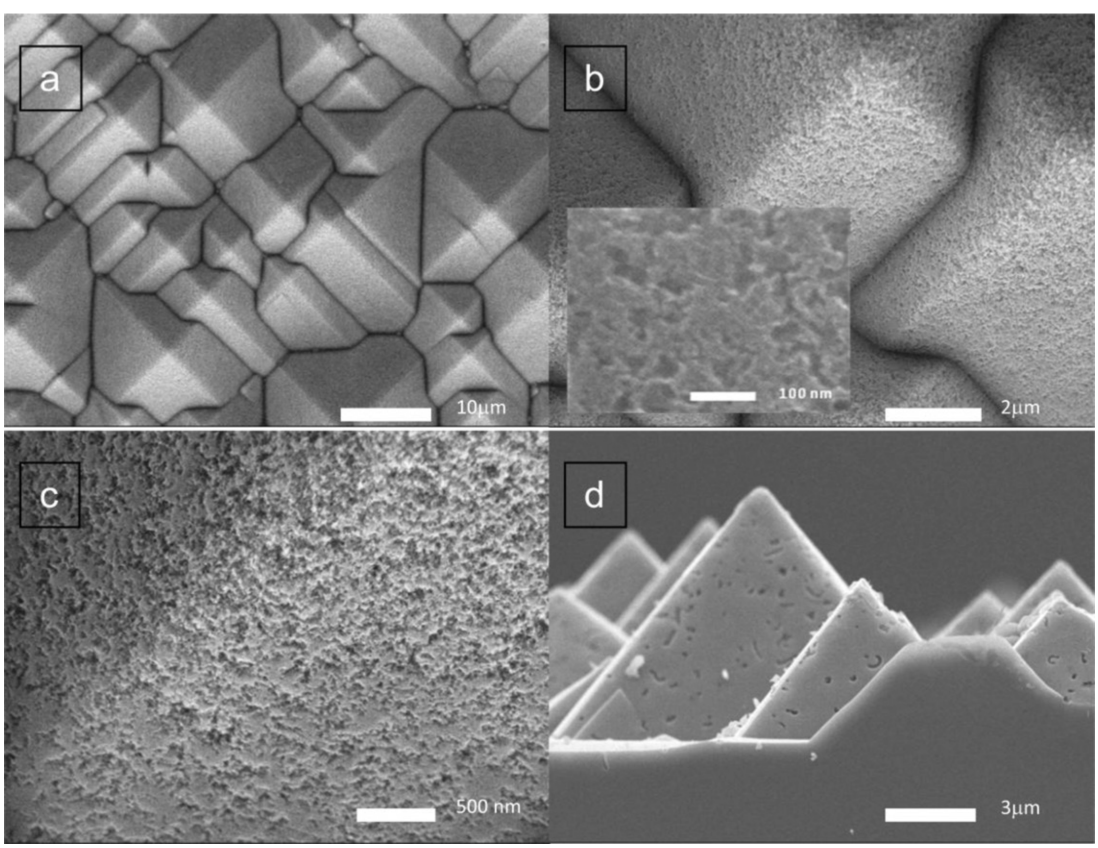

Fig. 2. (a and b) Plan-view SEM images with different magnification of Si pyramid surfaces covered with nano-texture, (c) nano-texture on pyramid surface (high magnification), (d) cross-sectional SEM image, of the multi-scale surface texture. The inset in (b) shows higher magnification (100,000×) image of the nano-texture (scale bar – 100 nm).