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The low cost multicrystalline silicon solar cells

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ABSTRACT

This paper presents a new solar-cell structure obtained by the front-surface texturization of multicrystalline silicon substrate by laboratory technology and main equipments used in characterization of such devices. The structure consists of an antireflection coating, a silicon active layer, front and back wafer contacts. The main objective was the minimizing the production cost maintaining the device performances. For these reasons the general technology cycle consists of maximum seven steps, a multicrystalline silicon substrate was used, the doping profile was optimized by simulations, the front-surface solar cell was texturized in order to reduce the light reflectivity and the wafer back-side was p+-diffused in order to get low series resistance. The performed measurements were in good agreement with simulations and expected results.

1. Introduction

Solar-cell technologies are an attractive option for clean and renewable energy generation in the form of electricity. Several technologies have been developed since 1950s and many of them reached the commercialization stage [1]. The main research activities in the photovoltaic field are related to material development, which can be obtained at relatively low cost, focusing on improving the energy conversion efficiency [2–4]. Si solar cells, which contribute 94% to the world market [5], are made from single-crystalline and multi-crystalline silicon (Si-sc and Si-mc). Because of the high electronic quality of Si-sc and Si-mc (diffusion lengths in the range of 100 s of micrometer) photovoltaic cells with stable and reasonably high efficiencies (ranging from 14 to 25%) can be made from these materials [6]. The substrates used in this work were "as cut" p-type, CZ multicrystalline silicon (Si-mc) wafers. The thickness of the wafers was 450 μm and area 5 cm × 5 cm.

One of the aims of this paper is to present the optimization of the textured surface fabrication process in order to obtain the lowest possible reflectance. A surface-texturing etching process in KOH and acid is presented. The obtained textured structures were studied by SEM and by optical techniques.

2. Design optimization

Multicrystalline silicon consists of several smaller crystals or grains, which generate boundaries. These boundaries engender a gap-stated distribution and impede the flow of electrons and encourage them to recombine with holes to reduce the power output of the solar cell. Multicrystalline silicon is much less expensive than single-crystalline silicon [7]. The methods of increasing silicon solar-cell efficiency are focused on the doping profile, structure of the illumination window, gap-state distribution and the back surface electrode. The structure of the illumination window refers in our case to the oxide thickness (antireflective layer) and the light trapping by the solar-cell front surface. The thickness of the oxide antireflective layer, doping profile and the back surface electrode were optimized by simulations using the Medici optical device advanced application module. For oxide antireflective layer optimization the solar spectrum was approximated by the black-body radiation spectrum, which is nearly identical to Air Mass Zero (AM0) spectrum and the energy was approximately 100 mW over the 0.2–1.0 μm wavelength range. The number of sampled wavelengths and the ray width were set so that the whole device was illuminated. For each wavelength a monochrome component of the light intensity was calculated by the software package. The simulation result for transmittance of the oxide film with thickness of 0.12 μm is presented in Fig. 1.

For greater silicon oxide thickness the maximum of transmittance characteristic is shifted toward greater wavelengths and for lower silicon oxide thickness the characteristic is shifted toward lower wavelengths. The optimum oxide thickness is 0.12 μm because its transmission maximum lays is situated in the range of 0.4–0.7 μm where the most of the solar energy is concentrated. The simulated short-circuit current through the solar cell is presented in Fig. 2.

The cell with 0.12 μm oxide thickness reaches the peak of generated current for the wavelength approximately 0.58 μm, very close

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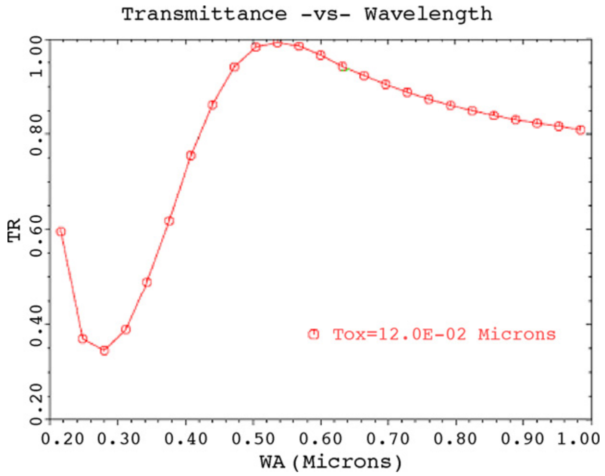

Fig. 1. Transmittance of 0.12 μm oxide thickness functions of wavelength.

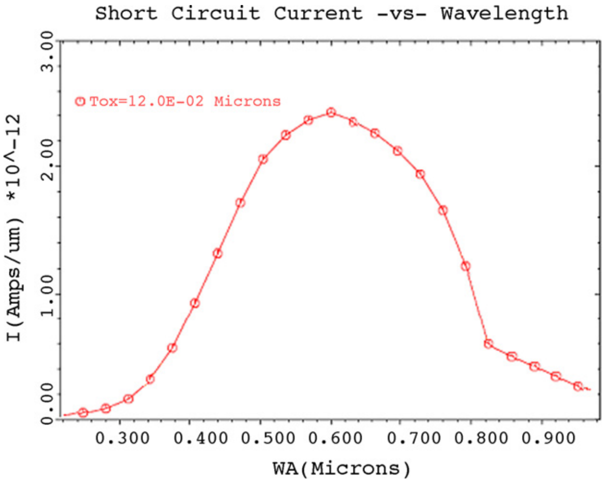

Fig. 2. The short-circuit current through the solar-cell functions of wavelength.

to the $\lambda = 0.51\ \mu m$ corresponding to the maximum spectral power density of the source. Therefore this cell can absorb more photons than all the others, the transmittance peaks of which are far from the solar power density peak. The external collection efficiency is defined as the total photocurrent density at given wavelength $J(\lambda)$ divided by the number of photons incident on the cell surface multiplied with the electronic charge q. The graphical simulation result of the external collection efficiency has the same shape as the graphic of short-circuit current and includes a small peak by 0.2 μm because the influence of transmittance.

The maximization of light trapping in the structure refers to rear-surface preparation to assure the reflection of unabsorbed light at the first path through the structure, or front-surface texturing for maximum reduction of the surface reflection. The front-surface texturing of Si-mc cells depends on the etching solution.

3. Experimental

In performed experiments p-type multicrystalline silicon wafers were used, with resistivity 0.5–1 Ω cm, thickness 450 μm and area 5 cm × 5 cm. The multicrystalline silicon wafers were processed using the planar technology of integrated circuits fabrication to obtain solar-cell structures of 1 cm × 1 cm. The surface texturization of solar cells was made using the MEMS technology.

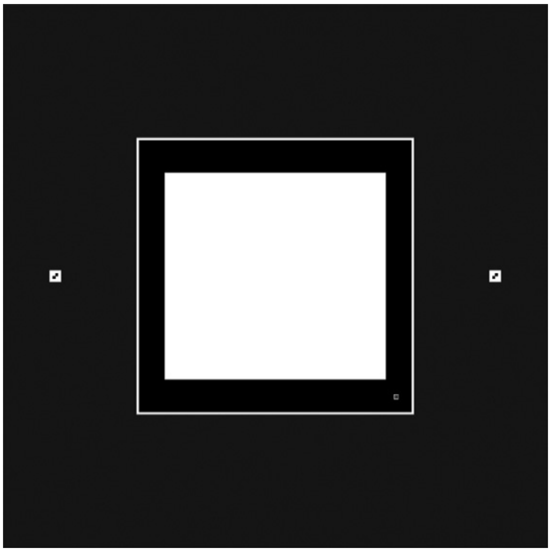

Fig. 3. The active area chromium mask.

For patterns configuration of the processed substrate on Si-mc wafers, 4 inch. chromium work masks were used in order to perform the lithography with positive resist.

The 1 cm × 1 cm solar cells were processed in five versions, with and without surface texturization, the texturization being processed in acid and alkaline solutions. The obtained solar cells devices were then compared to evaluate the contributions of texturization and substrate doping in the final device parameters.

The technological flux of solar-cell fabrication on multicrystalline silicon substrate (Si-mc) contains the next steps:

1. Thermal oxidation by water vapors at $T = 1100\,^{\circ}C$ in order to create a masking layer which was etched on the back-side of the wafers.
2. To improve the back-side wafer contacts these were highly doped with boron by prediffusion from solid source B^+ at $T = 1050\,^{\circ}C/N_2$ [8]. The prediffused layer characteristics are: the deep $x_j = 0.6\ \mu m$ and $V/I = 4–5\ \Omega$. In the next step, an oxide layer with thickness of 6200 Å was created by wet oxidation at $T = 1000\,^{\circ}C$, which was used as a masking layer in the next technological step. During thermal oxidation boron diffusion in the wafers was also performed.
3. The windows opening in the diffusion oxide (the active area of the cell) was performed by photolithographic process using the mask M1 (Fig. 3) and the silicon oxide has been etched using a $NH_4F:HF = 6:1$ solution with an etching rate of 1000 Å/min. In the active cell area the silicon surface was texturized with the solution $HNO_3:HF:CH_3COOH = 25:1:10$, at room temperature (Fig. 4a, b) and with solution KOH25% at 80 °C (Fig. 4c) [9]. Texturization results in an increased surface roughness, enabling a longer optical path for light entering into the cell, thus increasing light absorption and solar-cell efficiency [10].
4. The emitter n^+ region from solar-cell active area was realized by the prediffusion from $POCl_3$ liquid source at $T = 1050\,^{\circ}C$. The prediffusion layer characteristics are: $x_j = 0.6\ \mu m$ and $V/I = 1.5–2.5\ \Omega$. V/I was measured with a four point probe. The formed phosphoric pentoxide creates a layer of phosphorus–silica glass ($SiO_2 + P$) on the wafer, from which phosphorus atoms will prediffuse into the upper part of the wafer. After prediffusion completion the remaining phosphorus–silica–glass layer is removed by etching with flu-