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Enhanced electrode-contact property of silicon nano-textured solar cells via selective etching

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Abstract

The electrode contact property of silicon nano-textured solar cell was investigated. An industrial feasible technique was introduced to enhance the electrode contact. The electrical performance of nano-textured cells with this contact enhancement was measured and compared with the ones without. The series resistance was reduced significantly from 1.5 Ω to 0.3 Ω and the short-circuit current was increased from 27 mA cm^{-2} to 29 mA cm^{-2}. The cell efficiency was improved from 6% to 10%. These data indicate that the contact enhancement is effective.

Keywords: Silicon solar cell; Nanostructures; Electrode-contact

1. Introduction

Silicon (Si) – nanostructure (NS) has attracted intensive attentions in solar cell application due to their ultra-low reflectance and excellent enhancement in light trapping (Oelhafen and Schüler, 2005; Ben and Bessaïs, 2010; Wu et al., 2009; Hochbaum et al., 2005; Ben et al., 2012; Hamilton, 1995). Appling the nano-textures to the silicon solar cell can dramatically reduce the optical reflection and transmission losses (Tsakalakos et al., 2007; Peng et al., 2008; Lee et al., 2013; Yae et al., 2006). Therefore, the silicon nanostructures exhibit a promising prospect in improving the performance of silicon solar cell. Ag-catalyzed chemical wet etching technique has been reported so far to produce vertical-aligned NS array with average reflectance less than 3% (Nositschka et al., 2003; Hsu et al., 2012; Peng et al., 2005; Dou et al., 2013). This technique can fabricate NS array of large scale rapidly in room temperature and atmosphere. It is simple and low-cost, and promisingly suitable for industrial application.

However, such nano-textured c-Si solar cell has not shown advantage in efficiency. One shortage that impacts the nano-textured cell's performance was believed as the poor front electrode contact (Li et al., 2011; Garnett and Yang, 2008). Since the nano-textured surface is highly fluctuated and the space size is very small, the electrode can only be printed on the tips of NS array. The contact area shrinkage increases the contact resistance. There were several reports concerning the electrode contact enhancement for nano-textured solar cell (Kumar et al., 2011; Chen et al., 2011; Dou et al., 2012). The contact property was enhanced by different techniques: protected the contact area from etching (Kumar et al., 2011); heavy doping facilitated Ohmic-contact formation (Chen et al., 2011) or fulfilled the voids between electrode and nano-textured surface (Dou et al., 2012). After the enhancements, the cells performances were improved as expected.

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In this paper, a low-cost technique based on screen-printing and normal diffusion was demonstrated to enhance the electrode contact for nano-textured solar cell. The contact area was protected from etching and heavily doped. The series resistance (R_s) of the cells was significantly reduced and short-circuit current (J_{sc}) was improved. This technique is effective and also feasible in industrial fabrication.

2. Experimental details

The 4 in. *p*-type ⟨1 0 0⟩ CZ wafers with resistivity of 1–5 Ω/cm and thickness of 280 μm were used in this work. All the wafers were well cleaned and then divided into three groups.

Full-textured (FT) group: nanostructures were fabricated via Ag catalyzed chemical etching (HF (5.0 M), and $AgNO_3$ (0.02 M) at 25 °C for 10 min). The wafers were fully nano-textured.

Selective-textured A (ST-A) group: firstly etching-resist was screen-printed to protect the electrode region, and then the nanostructures were fabricated via Ag catalyzed chemical etching. After etching, the etching resists were removed. In this way, the electrode region was protected from etching.

Selective-textured B (ST-B) group: wafers were diffused using liquid $POCl_3$ to form N^+ region firstly. Then screen-printed etching resists was prepared to protect the electrode region, and nanostructures were fabricated via Ag catalyzed etching. After etching, the etching resists were removed. In this way, the electrode region remained flat and also was heavily doped.

Then all the wafers were normally diffused to form *p*–*n* junctions. After the deposition of 80 nm SiN_x passivation layer via plasmon-enhanced chemical vapor deposition (PECVD), the samples were cut off into cells with an area of 20 × 20 mm^2. Then the back and front sides of each cell were screen printed with Al and Ag pastes to form Al-BSF and front electrode, in which front electrode Groups B and C were printed by align-screen-printing. The silver electrode was printed on the location reserved in advance. Finally, dried cells were co-fired in belt furnace for metallization. The schematic graphs of cells are depicted in Fig. 1. For FT group cells (Fig. 1(a)), the surface was fully textured and the silver electrode was directly printed on the tips of silicon NS array. While for ST-A and -B group cells (Fig. 1(b) and (c)), the surface area for electrode was reserved as smooth and the silver paste contacted well. Especially, the electrode contact area of ST-B group cell (Fig. 1(c)) was heavily doped, which facilitated the Ohmic contact formation.

The surface morphology of nano-textured solar cells was investigated via field-emission scanning electron microscopy (SEM) in a HITACHI S4800 device, as Fig. 2 shows. And then, in order to verify the quality of the silver–silicon contact, the electrical properties of the three groups' cells were measured.

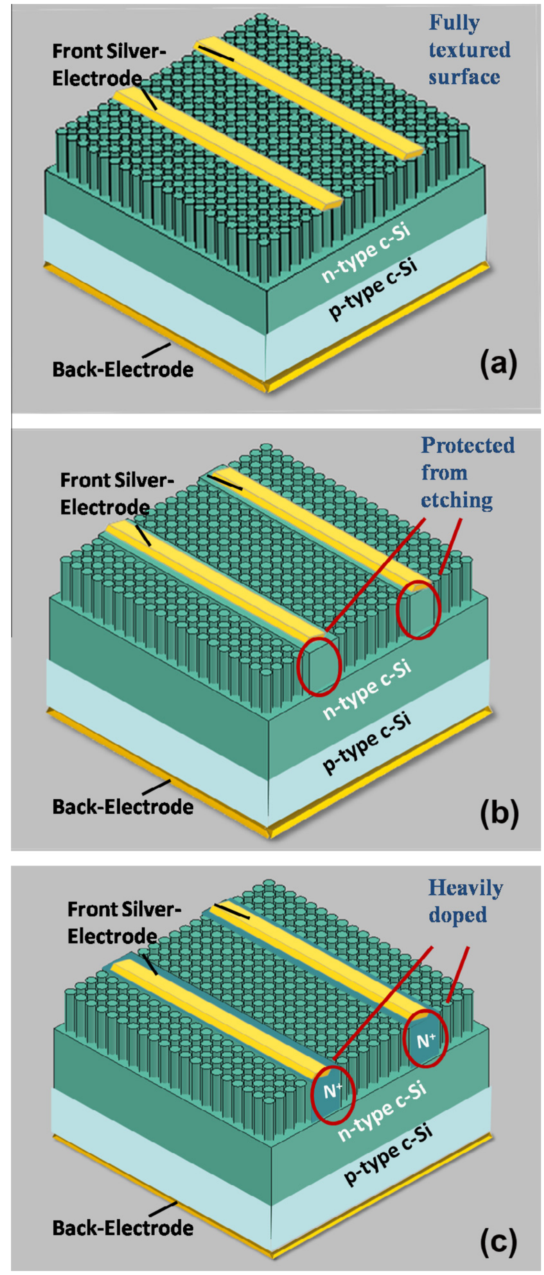

Fig. 1. The schematic structures for (a) the full-textured (FT) solar cell; (b) the selective-textured A (ST-A) solar cell, the surface area where for electrode contact was protected from etching; and (c) the selective-textured B (ST-B) solar cell, the surface area where for electrode contact was protect from etching and heavily doped.

3. Results and discussion

For the full-textured nanostructures solar cells, the screen-printed front silver electrode lay on nano-arrays, according to Fig. 2. The diameter of silver particles of silver paste is about 1–5 μm, while the width between silicon nano-wires is about 50–200 nm. Therefore, the screen-printed silver paste cannot be filled in the spaces. In this circumstance, only tips of nanowire contacts with the electrode and thus a lot of voids existed. Which means the