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Effect of texturing process involving saw-damage etching on crystalline silicon solar cells

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For high efficiency silicon solar cells, surface texturing is used to increase the short circuit current by reducing the surface reflection loss. Surface texturing is an anisotropic wet chemical etching process commonly used to form random pyramids. We investigated how the process is affected by surface conditions. We also compared the texturing behavior and cell performances of as-cut, polished and saw-damage etched wafers. Textured samples with different processing times were analyzed to detect pyramids and determine weighted reflectances. After the texturing process, conventional screen-printed solar cells were fabricated to observe the cell performance. The pseudo *I–V* curves and quantum efficiency for the samples were analyzed. Performance of samples with different surface conditions makes no difference. Thus, the processing-cost of solar cells can be reduced by omitting the saw-damage etching process.

1. Introduction

There are two major issues that reduce the conversion efficiency of silicon solar cells: optical loss and electrical loss. Optical losses, encountered by surface reflection, can be prevented by the use of an anti-reflective coating or by the technique of surface texturing. It is well known that polished wafers reflect 30% of the incident light. In contrast, textured surfaces and anti-reflection-coated surfaces only reflect 10 and 3% of the incident light, respectively. Reducing the extent of surface reflection can increase the short circuit current of the solar cell panels, and thereby increase their conversion efficiency [1].

For the surface texturing of crystalline silicon wafers, alkali hydroxide etchants, such as potassium hydroxide (KOH) and tetramethyl ammonium hydroxide (TMAH), have been widely used. Such etchants are mixed with alcohol additives in order to control the etching rates and to preferentially etch the different crystalline planes. The reaction usually results in the formation of random pyramids on the surface that are about 10 μm in size [2–5].

Generally, before the texturing process, saw-damage etching is performed to remove any wafer damage caused by wire-sawing. In this work, we describe our investigation into texturing and the effects observed with the saw-damage etching process with the aim of reducing the fabrication costs associated with solar cells.

2. Experiments

We used p-type (100) mono-crystalline silicon wafers with a resistivity of 0.5–3.0 Ω cm and thickness of 200 μm. To witness the texturing behavior, we prepared three different surface wafers, namely saw-damage etched (SDE), polished, and as-cut wafers. Fig. 1 shows scanning electron microscopy (SEM) images of the different surface conditions. The saw-damage etching process was performed with potassium hydroxide (KOH) for 10 min, at 80 °C. The polished wafer was prepared by using chemical mechanical polishing (CMP). After preparing the different surface wafers, the texturing process was carried out using a 20 wt% tetra-methyl ammonium hydroxide (TMAH) solution with isopropyl alcohol (IPA) at 80 °C. Analysis of the process was performed after 2, 5, 10, 20, 30, and 60 min.

Conventional screen-printed solar cells (Ag/c-Si(n)/c-Si(p)/Al) were fabricated in order to observe the cell performance. According to the processing sequence described below (see Fig. 2), we fabricated $4 \times 4\ cm^2$-sized conventional screen-printed solar cells with wafer surface conditions of SDE (Process 1), polished (Process 2), and as-cut (Process 3) wafers. The texturing process was carried out using a 20 wt% TMAH solution with IPA at 80 °C, for 60 min. After the texturing process, the wafers were cleaned using a process based on the standard RCA cleaning procedure [6]. In this way, a process involving a hydrochloric acid and peroxide mixture (HCl: H_2O_2: H_2O at 85 °C for 10 min) was performed

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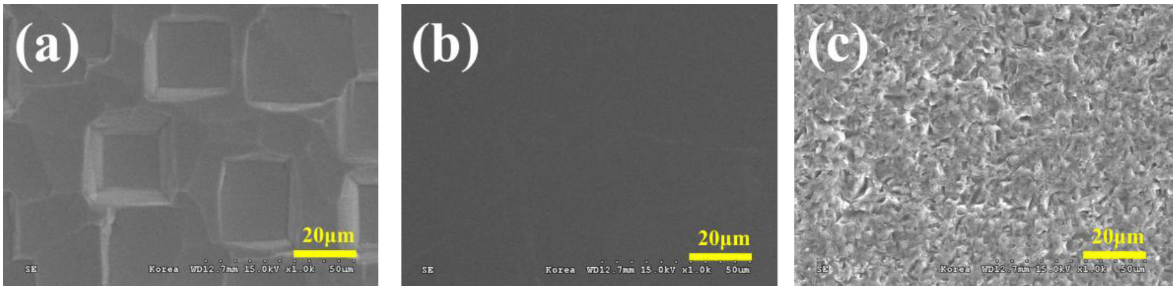

Fig. 1. Surface SEM images of different surface conditions: (a) saw-damaged etched wafer, (b) polished wafer, and (c) as-cut wafer.

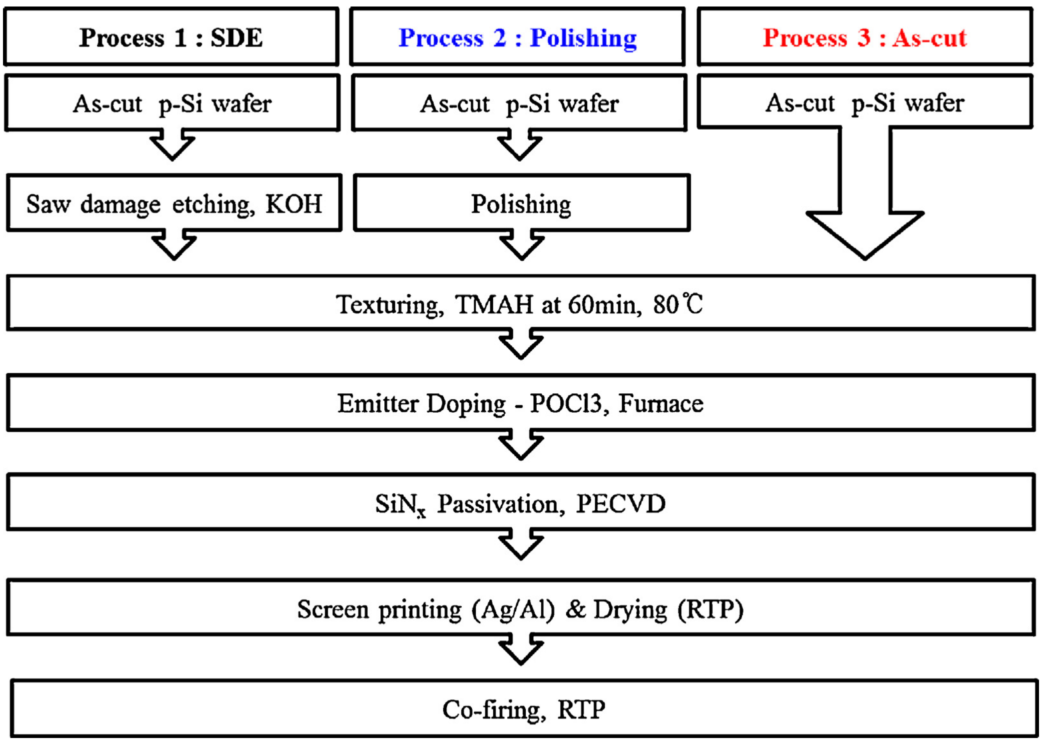

Fig. 2. Fabrication sequences of screen-printed silicon solar cells for different surface conditions in texturing process.

to remove metal particles from the surface. Then, the wafers were dipped in a solution of sulfuric acid and peroxide mixture (H_2SO_4:H_2O_2:H_2O at 85 °C for 10 min) in order to eliminate any organic contaminants. A $POCl_3$-diffusion furnace was then employed to form the emitter layer. To remove the phosphosilicate glass layers from the surface, the samples were dipped in buffered oxide etching solution for 1 min. A 100 nm-thick layer of silicon nitride (SiNx), which plays the dual role of passivation layer and anti-reflection coating layer, was deposited onto the surface by plasma-enhanced chemical vapor deposition. Finally, the metallization process was performed. Front and back side metal contacts were screen printed using standard Ag paste and Al paste, and then dried by a rapid thermal process (RTP) to evaporate all of the solvents in the paste. The RTP was used to fire-through both metals.

Analysis of the textured samples (with different processing times) was carried out by scanning electron microscopy (SEM) and UV–visible spectrophotometry in order to examine their surface morphology and reflectance. In addition, the pseudo *I*–*V* curves, measured using the Suns-V_{oc} method, and quantum efficiency measurements were analyzed by the performance of the respective cell.

3. Results and discussion

3.1. Effect of surface condition on texturing behavior

The wafers with different surface conditions prior to texturing are referred to as SDE (Process 1), polished (Process 2), and as-cut (Process 3). SEM images of the wafers are shown Fig. 3, and they serve to illustrate the extent of the change in the morphology of the textured surfaces over texturing time. After 30 min of texturing time, the SDE sample is completely covered by pyramids. On the other hand, the as-cut and polished samples take more than 60 min to be covered. Surface texturing is an anisotropic wet-chemical etching technique that is commonly used to form random pyramids by utilizing differences in etching rates for the planes in the (1 0 0) and (1 1 1) direction [7]. The saw-damage etching process carries out isotropic wet-chemical etching to eliminate micro-cracks caused by the use of a strong alkaline solution (e.g., KOH) for wire sawing. However, this process creates squares and inclined planes due to incomplete isotropic etching, as illustrated in Fig. 4, where the inclined plane is rough with no flat character. For the SDE sample, Fig. 3(b) (2, 5, and 10 min) shows that pyramids are preferentially created in an inclined plane of squares that