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Selective deposition contact patterning using atomic layer deposition for the fabrication of crystalline silicon solar cells

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ABSTRACT

Selective deposition contact (SDC) patterning was applied to fabricate the rear side passivation of crystalline silicon (Si) solar cells. By this method, using screen printing for contact patterning and atomic layer deposition for the passivation of Si solar cells with Al_2O_3, we produced local contacts without photolithography or any laser-based processes. Passivated emitter and rear-contact solar cells passivated with ozone-based Al_2O_3 showed, for the SDC process, an up-to-0.7% absolute conversion-efficiency improvement. The results of this experiment indicate that the proposed method is feasible for conversion-efficiency improvement of industrial crystalline Si solar cells.

1. Introduction

Screen-printed crystalline silicon (Si) solar cells are widely utilized in the photovoltaic industry. Si solar cells with full-area screen-printed Al-back surface field (Al-BSF), due to a high surface recombination velocity ranging from 200 to 1250 cm/s, offer only a limited efficiency [1,2]. With improved screen-printed Al-BSF, the efficiency of commercial p-type Si solar cells is approaching nearly 20%. After production application of the two-step emitter process, the passivated emitter and rear contact (PERC) structure with local Al rear contacts offers the potential for use in high-efficiency screen-printing Si-solar-cell application processes within the photovoltaic industry [3]. A recently introduced dielectric for outstanding rear-surface passivation of p-type Si PERC-type solar cells is Al_2O_3 [4]. It is well known that dielectric thin films of negative-fixed charged Al_2O_3 grown by atomic layer deposition (ALD) exhibit excellent surface passivation on crystalline Si wafers [5–7]. Indeed, with the p-type Si solar cell, no parasitic shunting occurs when fixed charged Al_2O_3 is applied to its rear side [8].

Point contact patterning by laser-fired contact, laser contact opening, and photolithography processes has already been demonstrated [9–11]. Unfortunately, PERC-type solar cells require expensive processing equipment for the formation of local point contacts by such means. A common alternative technique is the screen printing method, a simple print-and-bake approach to pattern the opening that uses an etch paste for low-cost patterning of dielectric films [12,13].

Herein we demonstrate the utility of a method of screen-print-based selective deposition contact (SDC) patterning utilizing ALD-deposited Al_2O_3 film to obtain excellent passivation properties.

2. Experimental details

In this study, we used p-type crystalline Czochralski (Cz) Si wafers with a resistivity of between 1 and 2 Ω-cm, a thickness of 180 ± 20 μm, and an area of 156 × 156 mm^2. The Cz Si wafers were anisotropically etched in an alkaline solution containing deionized water, sodium hydroxide (NaOH) and isopropyl alcohol. After texturing, the crystalline Si wafers were immersed in a standard cleaning solution and, finally, dipped into 5% HF to remove the native oxide layer. Subsequent to these texturing and cleaning steps, we made a p–n junction by $PoCl_3$ diffusion in a batch-type furnace, which afforded phosphorous of 75 Ω/sq sheet resistivity. After the removal of the residual phosphorous glass by 5% HF at room temperature, a SiNx:H antireflection coating approximately 80 nm thick was deposited by plasma-enhanced chemical vapor deposition on top of the emitters.

An industrial PERC process flow typically involves wet chemical polishing of the textured rear surface [14]. In the present case, preparatory to Al_2O_3 deposition for rear-surface passivation, all of the Si wafers were exposed to a single-sided wet chemical polishing process to reduce the rear-surface roughness. After this planarization of the rear

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side, the wafers were cleaned with a standard cleaning solution and rinsed. We then developed the selective deposition contact (SDC) patterning process illustrated in Fig. 1. The screen mask was designed to exhibit a basic dotted pattern consisting of dots of 100 μm average diameter and 900 μm contact pitch. The distance between the individual rows was maintained at a consistent 1 mm. A resin-type polymer pattern for the opening of local point contacts was formed using a dotted screen mask and resin-type polymer paste. The composition of the polymer paste is comparable to that of Al paste, but not, significantly, to those of Al metal powders and glass frits. The viscosity of the polymer paste was controlled within 20–50 cps by means of organic additives. After printing, the polymer paste, as typically, was dried at temperatures between 70 and 120 °C. Next, thermal Al_2O_3 thin films, grown at 125 °C in an industrial solar ALD reactor (Lucida GS1200, NCD, Korea) using trimethylaluminum (TMA) and ozone as precursors, were selectively deposited onto the polymer-patterned Si by ALD. After the Al_2O_3 deposition, the wafers were dipped into acetone to remove the polymer paste. Finally, the Al layers were deposited by physical vapor deposition, and the front and back contacts were applied by screen-printing of commercially available thick film pastes, dried to remove solvents, and fired in an industrial infrared-heated belt furnace. According to this process sequence, summarized in Table 1, screen-printed large-area p-type Si PERC-type solar cells were fabricated.

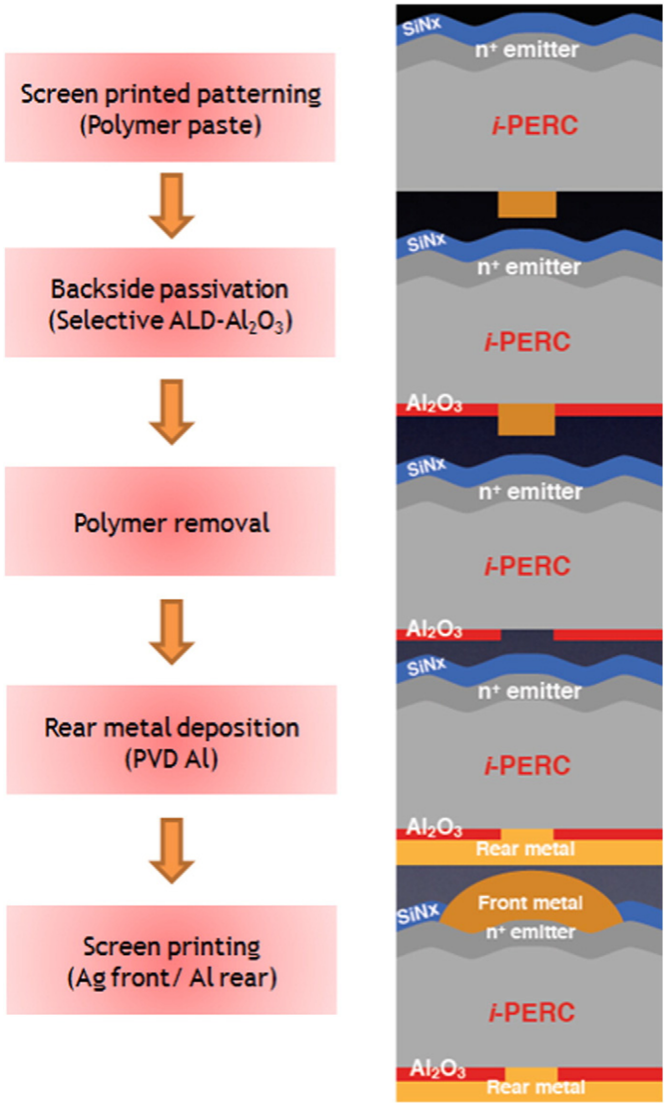

Fig. 1. SDC process sequence.

Table 1
Baseline p-type Cz Si PERC-type solar cells, from SDC with ALD Al_2O_3 films.

Texturing
$PoCl_3$ diffusion (75 Ω/sq)
PECVD SiNx ARC front
Rear side emitter removal & planarization
Selective deposition patterning contact & ALD Al_2O_3 passivation
Physical vapor deposition Al (evaporation)
Screen-printing Ag front/Al rear
Co-firing

A specimen's pattern size was measured by scanning electron microscopy (SEM; 15 kV accelerating voltage, 14 nA probe current; JSM-7000F, JEOL Japan). The selective deposition and etching process was analyzed according to energy-dispersive X-ray spectroscopy (EDX) data that was also acquired at 5 kV and 14 nA. All of the samples were additionally characterized, over a cell area of 156 × 156 mm^2, by current–voltage (I–V) measurements in a solar simulator under AM 1.5G at 25 °C. The cell-conversion efficiency was then measured five times, and the results were averaged.

3. Results and discussion

3.1. SDC process

We tested the SDC process on a chemical-mechanically polished Si wafer. The optical microscopic (OM) images shown in Fig. 2 indicated that a distinct polymer pattern had been formed by screen printing and that Al_2O_3 film grown by ALD on the polymer pattern had been completely removed. The OM images also showed that the average dot diameter in the printed pattern was 90 ± 9 μm (dot diameter of designed screen mask: 100 μm) and that the size of the via-hole etched into the Al_2O_3 was close to 100 μm.

According to the patterning procedure outlined in Fig. 1, we examined the rear side of the p-type Si wafer to investigate the SDC process for PERC solar cells. The SEM images in Fig. 3 show that, due to surface roughness, the printed patterns had deviated slightly from the circular shape. Nonetheless, Fig. 3(a) confirms that the Al_2O_3 thin film deposition onto the polymer-patterned Si by ALD-based screen printing was successful. Fig. 3(c) shows post-Al_2O_3-deposition EDX results. This Al EDX signal was only rarely observed in the polymer pattern. The arrows of Fig. 3(b) indicates the contact opening by removing the polymer pattern. The dot size of the printed pattern was close to 100 μm, while the via-hole size was close to 120 μm. The contact broadening of the PERC solar cells is attributable mostly to surface roughness.

To confirm the cleanliness of the etched process, EDX was performed on the wafers in the etched region to identify any carbon residue or residual Al_2O_3 film. Fig. 3(d) shows the results of EDX performed after etching in acetone. The via-hole was etched clean, no residue having been left behind, as shown in Fig. 3(d).

3.2. ALD Al_2O_3 passivation

Al_2O_3 as deposited by ALD typically uses TMA as the aluminum source, ozone-replacing water serving as the oxidant. Al_2O_3 layers grown at over 200 °C by ALD provide an excellent level of surface passivation. However, the effective lifetime of ALD Al_2O_3 films deposited below 200 °C using TMA and water sources begins to deteriorate quickly [15]. In order to avoid burn-out of the polymer pattern, low-temperature (below 150 °C) ALD deposition is required. Low-temperature ALD Al_2O_3 film deposition using ozone as the oxidant yields a reasonable level of surface passivation. Moreover, replacing water with ozone has advantages. The ALD passivation properties of Al_2O_3 films grown below 200 °C using ozone are equivalent to those of Al_2O_3 films grown at 200–300 °C using water as the oxidant. Water