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## Influence of laser damage on the performance of selective emitter solar cell fabricated using laser doping process

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### ABSTRACT

This article investigates the impact of laser damage on the performance of a selective emitter solar cell fabricated using a laser doping process (LD). After the optimization of the laser doping process, an amorphous silicon layer with a thickness of approximately 100 Å was observed on the laser-doped emitter. The amorphous laser damage decreased the power conversion efficiency due to poor contact between the Ag front electrode and the selective emitter. To effectively improve the quality of the front contacts, a solution etch-back process was applied after the laser doping step (LEB), and the series resistance of the selective emitter solar cell was restored to 0.55 Ω cm<sup>2</sup> from around 1.0 Ω cm<sup>2</sup>. The contact formation during the LEB process clearly improved, and it was verified by comparing the densities of the Ag crystallites after Ag electrode removal from the LEB cell and the LD cell. The improvement in the formation of the front contact resulted in the LEB selective emitter solar cell recording a maximum 19.16% of power conversion efficiency, with a standard deviation of 0.055.

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## 1. Introduction

The cost per watt-peak is an important measure for c-Si solar cells, and there are many efforts underway to improve such measure. Advanced photovoltaic technologies, such as a rear local contact cell, heterojunction solar cell, and back contact cell, are currently being developed in order to fabricate high performance c-Si solar cells [1–4]. Those technologies have been able to provide excellent efficiency gains in terms of energy conversion, but significant breakthroughs are still needed to reduce their production costs [5,6].

Selective emitter solar cells have the potential to simultaneously improve energy conversion efficiency and to reduce production costs, which can be achieved by designing an efficient process scheme. In that sense, the laser doping method can be a reasonable choice in the fabrication of selective emitter solar cells. Various approaches can produce selective emitters, and some researchers have focused on developing the laser doping processes that uses a solid dopant film, such as a spin-on-glass dopant or phosphorous silicate glass (PSG), due to their excellent stability

during the doping process [7–16]. However, the spin-on-glass method has a disadvantage in that it requires multiple process steps, which includes a dopant spin casting process prior to the laser doping process [13]. The other disadvantage is that the casting dopant solution is an expensive material. On the other hand, direct laser doping on a PSG layer only requires one additional laser doping step since the dopant source is coated during POCl<sub>3</sub> diffusion [14]. An additional advantage of using direct laser doping is that the laser systems of 100–200 ns pulse width and a 532 nm wave length are relatively cost effective. However, the disadvantage of this approach is that poor contacts are formed due to damage in the a-Si layer during the laser doping process, which degrades the performance of the device due to an incomplete contact formation between the Ag electrodes and the selective emitters [15,16]. In this study, we focus on analyzing the influence of laser induced damage on the cell performance and suggest an effective solution using a solution etch back process.

## 2. Experimental details

Laser-doped selective emitter solar cells were prepared using 6 in. boron doped p-type Czochralski (CZ) wafers. The wafers were textured using an alkaline solution to form random pyramids. To

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form a p–n junction, a  $\text{POCl}_3$  precursor was diffused onto the wafer in a tube thermal furnace, and the resulting sheet resistance was  $40 \pm 2 \Omega/\text{sq}$ . The laser doping was performed using a 532 nm laser with a 150 ns pulse width. The laser used an Nd:Yag laser source, and it irradiated a TEM00 beam profile with a flat-top square shape from a scanner with a  $\pm 3\%$  beam uniformity. The density of the laser energy was adjusted from  $2.8 \text{ J}/\text{cm}^2$  to  $13 \text{ J}/\text{cm}^2$  and was found to be optimum at  $5.6 \text{ J}/\text{cm}^2$  with a 25 kHz repetition rate. After laser doping, the sheet resistance of the selective emitter was measured at  $32 \Omega/\text{sq}$ . In the subsequent etch back process, the laser-doped wafers were dipped in an acid solution to remove the laser damage. The acid solution etches the laser-doped emitter, removing the a-Si laser damage from the surface. The sheet resistances (Rsh) then increased to  $40\text{--}60 \Omega/\text{sq}$  on the selective emitter and to  $120 \Omega/\text{sq}$  on the window area where the laser doping had not been performed. The detailed Rsh information is listed in Table 1. Then, a  $\text{SiN}_x$  anti-reflection layer was

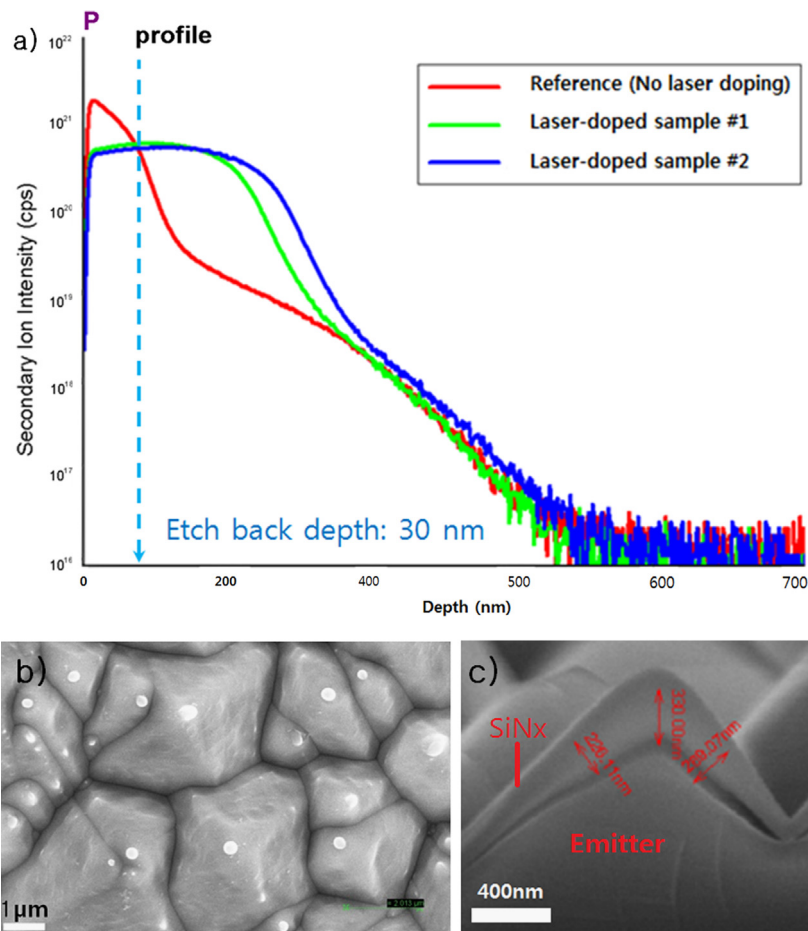
coated on the emitter, and the cell fabrication was completed after completing the printing, firing, and edge isolation processes. The fabricated cells were characterized under an intensity of 1 sun (AM1.5G), and before characterization, a reference cell measured at the Fraunhofer ISE was used for calibration.

### 3. Results and discussion

To understand the real structure of the laser-doped selective emitter, the doping concentration of the emitter was analyzed before and after the laser doping process. The SIMS profile in Fig. 1(a) represents the evolution of the dopant concentration after laser doping. The phosphorous (P) concentration in the region from the surface to a depth of 250 nm shows a plateau shape originating from the liquid phase diffusion of the silicon and the phosphorous silicate glass (PSG) layer [17]. A scanning electron microscopic (SEM) image of the laser-doped sample is shown in Fig. 1(b), where the surface of the pyramids can be seen to have slightly melted. Each pyramid has a small PSG sphere at its peak due to the surface tension during the liquid phase of the PSG. To visualize the depth of the selective emitter, 80 nm of silicon nitride ( $\text{SiN}_x$ ) is deposited on the laser-doped selective emitter and then a cross section of the sample is obtained by cutting the sample. The prepared sample was dipped in an acid mixture of hydrofluoric acid, nitric acid, and distilled water at a ratio of 1:300:100 to selectively etch the doped emitter. The depths of the selective emitter were measured, and these are shown in Fig. 1(c). The emitter depths vary from around 330 nm at the tips to 80 nm in

**Table 1**  
Sheet resistances of LEB and LD cells at selective emitter and window.

	Base doping Rsh ( $\Omega/\text{sq}$ )	Contact Rsh ( $\Omega/\text{sq}$ )		Window Rsh ( $\Omega/\text{sq}$ )	
		After laser doping	After etch-back	After laser doping	After etch-back
LEB	40	32	40–60	n/a	100–120
LD	100–120	50–60	n/a	100–120 (not laser-doped)	n/a



**Fig. 1.** SIMS profile of laser doped emitter (a), SEM images of laser doped wafer surface (b) and cross section of selective emitter solar cell, where the etching of the selective emitter is marked.

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