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Analysis of contact recombination at rear local back surface field via boron laser doping and screen-printed aluminum metallization on p-type PERC solar cells

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Abstract

The passivated emitter and rear cell (PERC) has entered the solar cell market, and it is expected that the amount of PERC production will increase yearly in the future. Improvements in the cell efficiency have a great influence on reducing the cost of power generation. In this study, we focused on the loss of the back surface field (BSF) at the rear side of a PERC, fabricated PERCs having a local BSF including boron diffused by boron laser doping (B-LD), and evaluated this effect. The results from an analysis using scanning electron microscopy (SEM) indicated that the thickness of the BSF fabricated with B-LD was thicker than that of the BSF fabricated without B-LD. The average value of the saturation current density of the metallized area (including BSF) $J_{0,\,contact}$ was 554 fA/cm^2 in the PERCs fabricated with B-LD and a dedicated Al paste, and the lowest value achieved was approximately 300 fA/cm^2. The number of Kirkendall voids for the PERCs fabricated with B-LD decreased in comparison with the PERCs fabricated without B-LD. The PERCs fabricated with B-LD exhibited reduced rear-side recombination.

Keywords: Si nanoparticle; laser doping; local back surface field

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1. Introduction

Nowadays, the application of a passivated emitter and rear cell (PERC) is attractive for high-efficiency solar cells, and a cell efficiency greater than 22% has been realized at the pilot level [1-4]. The cell properties of a PERC have been improved using various approaches, but characteristic improvements in a PERCs are still demanded. It has been reported by simulation of the loss in the cell properties that the loss in the rear-side local back surface field (BSF) is large [5-8]. For the development of the rear-side local BSF, an Al-alloyed BSF layer is commonly used in a PERC, and there are few examples that have attempted to use this new concept. It has been reported that the saturation current density of the metallized area (including the BSF) $J_{0,\,contact}$ can be reduced by using an Al paste containing a B additive [9, 10] because it improves the BSF effect owing to the high dopant concentration due to the codiffusion of B and Al in the Al–Si liquid phase above the eutectic temperature (577 °C). However, it is well known that a large amount of B additives in the Al paste deteriorate the electrical properties of the Al electrode [10]. Another issue associated with PERCs is Kirkendall voids, and the composition of the Al paste and the firing conditions have been studied to prevent Kirkendall voids in PERCs [11, 12].

We developed a B laser doping (B-LD) technique with B-doped silicon nanoparticles (Si NPs) to achieve an improvement in the efficiency of PERCs by having a local BSF including B [13]. The local BSF with B improved the internal quantum efficiency (IQE) in the long-wavelength region, which means that the back side of the cell increased its efficiency, particularly the open-circuit voltage V_{oc} and fill factor, in comparison with a cell without B-doped Si NPs. We reported that the local BSF layer of a PERC that exhibited a high V_{oc} and high cell efficiency included a B content greater than 0.9 wt%. Moreover, we showed that the B in the local BSF layer influenced the diffusion of Al and enhanced the local BSF effect [14]. It was observed that B-LD combined with screen-printed Al metallization leads to a thicker local BSF and a reduction in the number of voids [15, 16].

In this study, we evaluated PERCs fabricated with and without B-LD to determine $J_{0,\,contact}$ and the number of Kirkendall voids to clarify the effects of B in detail. The local BSF and Kirkendall voids in each cell were observed using scanning electron microscopy (SEM), and $J_{0,\,contact}$ was determined from the changes in the saturation current density J_0 with different electrode contact area ratios.

2. Experiments

A schematic of the B-LD and screen-printed Al metallization procedure is shown in Fig. 1. The local BSF layer of the PERCs using B-LD was fabricated by irradiating a substrate printed with a B-doped Si NP paste with a green laser and subsequent metallization using an Al paste. Figure 2 shows a schematic of the cross section of the PERCs. The B-LD technique with the B-doped Si NP paste was used for the back side of the cells. Figure 3 shows a magnified view of the local BSF of the area enclosed in the yellow square in Fig. 2. Two types of cells with different BSF layers formed by B-LD and only the Al paste were fabricated. The BSF formed by B-LD has a B/Al local BSF layer, and the BSF formed by the Al paste has an Al local BSF layer. Al dissolved as the temperature of the cofiring process increased, and a reaction between Al and Si started. B diffused with Al and Si during the cofiring process, and the B/Al local BSF layer formed as shown in Fig. 4 [14].

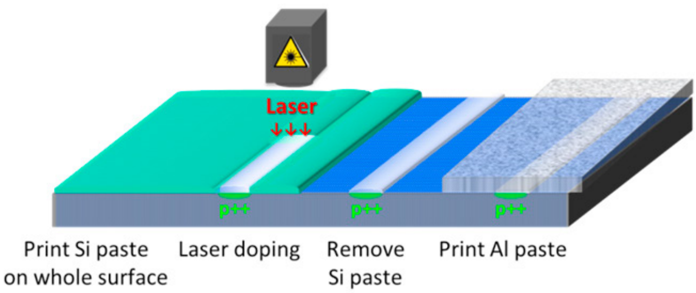

Fig. 1. Schematic of B-LD and screen-printed aluminum metallization.