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Incorporation of deep laser doping to form the rear localized back surface field in high efficiency solar cells

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ABSTRACT

Solar cells with rear localized contacts formed with and without the use of deep boron laser doping are compared as an approach to achieve a more repeatable process for high efficiency solar cells. In particular the paper investigates the impact of the belt firing conditions and screen printable Al paste on the quality of localized contact formation. By adjusting the firing profile, cells incorporating deep boron laser doping on the rear surface are shown to better avoid Kirkendall void formation at contact regions, while the cells without need to balance the percentage of Kirkendall void formation against the localized back surface field (LBSF) thickness. The boron laser doping can be integrated into the laser ablation process used to open the rear dielectric, which minimizes the impact on the process steps. Standard Al paste used for commercial screen printed solar cells is shown to be applicable on the boron laser doped solar cells with a peak firing temperature of 700 °C. On the contrary, a special designed Al paste for LBSF applications has to be used on the cells without boron doping. An average cell efficiency of 19.8% is achieved on boron laser doped solar cells using both types of Al pastes.

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1. Introduction

The full area Al–Si back surface field (BSF) has been widely used in commercial screen printed solar cells for decades due to its simplicity, robustness and ability to reliably provide excellent electrical contact and moderate surface passivation properties. However, with the demand for higher efficiency solar cells, this level of surface passivation becomes a limiting factor in determining device performance. One approach which is currently the subject of much interest in the solar community is to replace the full area rear metal contact with a dielectric passivation layer with locally created contact openings. Metal/Si contacts are made through the openings, and heavily doped regions are created at the interface to reduce recombination. These locally doped regions are referred to as local back surface fields (LBSF). The most popular way to form the LBSFs is through the Al–Si alloying process, which is a similar mechanism to that used in the full area Al contact, but requires specific pastes [1] that may be accompanied with a potential cost increase. Issues such as the formation of Kirkendall void and inadequate LBSF thickness can occur if the process is not finely adjusted and controlled [2,3]. An alternative way of forming LBSFs is to perform laser doping, such as by applying a source of boron dopants on the surface and using the laser illumination to define the local openings through the dielectric layer and simultaneously melt the underlying silicon and form a heavily boron diffused region. In this paper, we investigate the integration of boron laser doping as a technique to form the LBSF regions to relax constraints on the typical firing process and allow the use of conventional Al pastes.

1.1. Industrial LBSF cell processing

There have been numerous solutions proposed to provide a suitable processing sequence to achieve the formation of localized contact regions through rear dielectric passivation [4–8]. One approach which has shown promise as being compatible with large scale manufacturing is a rear dielectric stack of AlO_x/SiN_x, which is then scribed by a laser to realize local openings, screen printed with full area Al on top and then finished with a rapid thermal treatment to temperature above 577 °C to form contacts and LBSFs [9,10]. The resulting effective surface recombination velocity of this type of rear surface tends to be in the range of 50–90 cm/s, instead of 160–600 cm/s which is typically achieved on a full area BSF contact [11–14].

Despite its clear potential to reduce the losses at the rear side of a solar cell, there remain some clear problems with the application

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of this technology. These problems originate from the fact that the Al–Si alloying process at local contact regions is much more complex than that in the full area BSF. During the thermal treatment, Si and Al diffuse into each other at the local contact regions and become molten. Then during the cool down phase, the Si epitaxially grows with Al and B as a dopant, which forms the LBSF. When the temperature drops under the eutectic temperature, all the remaining Al–Si molten region solidifies and forms a eutectic layer. In practice it is difficult to uniformly achieve good quality LBSF regions using this process. The occurrence of Kirkendall voids (regions in which an air gap exists rather than solid Si–Al) has been reported by various authors [1,10,15] as one of the major limiting factors that affects both electrical contact and contact recombination. These voids are believed to form when the Si diffuses too far away into the Al and cannot travel back to the Al–Si interface before the temperature drops below the eutectic temperature [16]. Another potential issue when using screen printed Al to form localized contact regions is inadequate LBSF thickness between the bulk of the Si and Al–Si eutectic [2,3]. Without the protection from an adequate LBSF, the minority carrier recombination velocity at local contact regions is expected to be high.

To try to mitigate the issues discussed above there have been several studies on the impact of processing on the formation of a good quality LBSF. It has been widely accepted that special designed pastes that incorporate some percentage of Si particles must be used to reduce the percentage of Kirkendall voids and increase the thickness of the LBSF [2]. It has also been reported that the rear opening geometry has an impact on the Kirkendall void formation and that line contacts perform better than point contacts [10,17]. In that study, whilst solar cells fabricated using line contacts were reported to have lower champion efficiency than that with point contacts, cells with line contacts showed lower voiding percentages and higher consistency of adequate BSF formation [10]. Narrow line contacts were also found to achieve lower contact resistivity [18]. In addition, very low Kirkendall void percentages have been achieved by adjusting the firing profile with multiple firing steps [15], or by adjusting the screen printed Al thickness, the firing profile and the rear opening geometry, however in this case the LBSF thickness was also reduced [3]. Despite these process variations it remains difficult to uniformly achieve a good quality LBSF using the localized Al alloying technique.

1.2. Deep laser doping

An alternative technique to the use of screen printable Al paste to form localized BSF regions is to use laser doping. Laser doping has been widely used for semiconductor processing with early demonstrations of laser doping dating back prior to 1970 [19]. In the solar cell application, dopant sources are deposited by various means and then doped into the silicon by different types of lasers for different purpose [20–23]. On the front side, laser doping has been used to realize select emitters [24] or large area laser doped emitters [25,26], and to create buried contacts [27] or aligned metallization [28]. The integration of laser doping into the rear side of solar cells has achieved 20.3% cell efficiency when combined with sputtering Al on the rear surface [29]. Typically laser doping processes result in doped regions with junction depths on the order of 2 μm or less [29–31]. However, when combined with the Al screen print firing process these techniques would not be applicable as during the high temperature firing, the laser doped regions would be completely etched away by Al–Si alloy which tends to be at least 5–10 μm deep. For the laser doped region to be effective there must be adequate depth of LBSF remaining after the Al–Si alloying to provide protection from contact recombination. Recent advances in the development of laser doping have enabled the formation of doped regions with a junction depth of up to 12 μm [27]. It has also been demonstrated in [3] that by adjusting the firing profile, shallow Al–Si alloys (5–7 μm) with no Kirkendall voids can be achieved using screen printing and a modified firing profile. By combining these two techniques, it should be possible to uniformly create LBSF regions across the rear surface of a solar cell.

This paper explores the use of deep laser doping as a possible solution to overcome both the Kirkendall void formation and inadequate LBSF depth at the Al–Si interface. With the LBSF preformed prior to the Al–Si alloying process, cell fabrication with lower firing temperatures is possible. The standard Al paste designed for full area BSF is also applied which can potentially reduce the resistance in the paste.

2. Solar cells with LBSF

The impact of deep boron laser doping on the processing window and electrical performance was investigated by making complete solar cells. The cells, shown schematically in Fig. 1, were fabricated either (a) using laser scribing (LS) to locally remove the rear dielectric or (b) with deep laser doping (LD) through the dielectric layer. In both cases the rear aluminum layer was screen printed followed by various fast firing profiles. To further demonstrate the impact of laser doping on the processing window two different Al pastes were used; the first was a standard Al paste designed for use on full area BSF cells (Monocrystal PASE107) and the other was a paste specially designed for LBSF formation (DuPont 9245). To accentuate the impact of the high efficiency rear side, and to make the front contact formation independent of

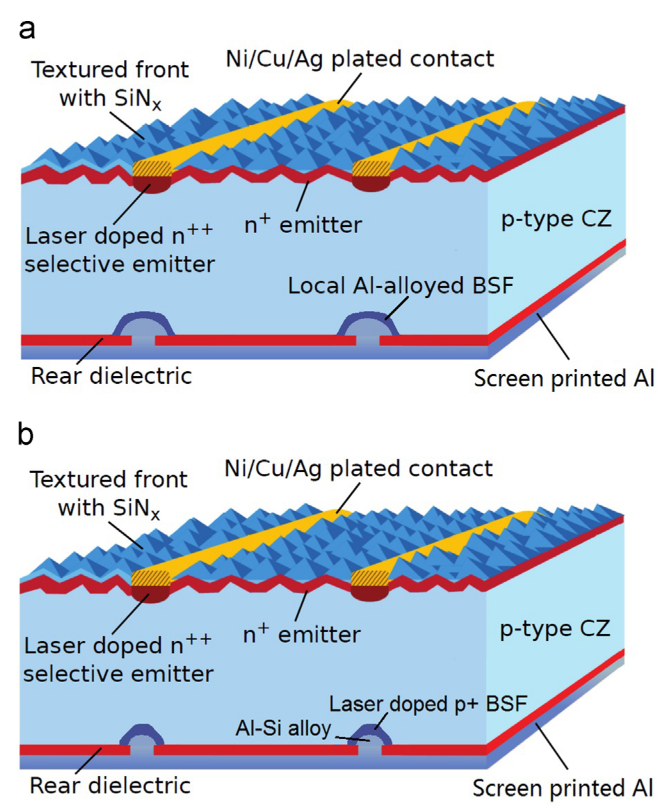

Fig. 1. Schematic cross-section of the cell architectures used in this study, (a) a LS cell with local p+ BSF formed by Al-Si alloy and (b) a LD cell where the LBSF is formed by boron laser doping.

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