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ScienceDirect

Energy Procedia 92 (2016) 82 – 87

Energy Procedia

6th International Conference on Silicon Photovoltaics, SiliconPV 2016

Surface recombination velocity of local Al-contacts of PERC solar cells determined from LBIC measurements and 2D simulation

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Abstract

Industrial production volumes of passivated emitter and rear contact (PERC) solar cells increase due to significantly higher cell efficiencies compared to full area back surface field (BSF) solar cells at similar costs. The main features of PERC cells are dielectric surface passivation of the rear and local contact formation with Al leading to a p^+p junction beneath the Al/eutectic. For non-optimized process conditions, the eutectic in the local Al contact area does not form and so-called voids result. Since it is known that there are voids causing high or low recombination activity, a determination of the surface recombination velocity (SRV) is necessary for identification of the potential for process optimization. The passivation quality of the BSF, locally formed in the rear side contacts, is studied in detail via local internal quantum efficiency (IQE) measured by high resolution light beam induced current (LBIC). The significant spreading of the IQE values is attributed to a variation in local BSF layer thickness at different areas. The SRV of the local contact is determined by fitting the LBIC measurements of voids by 2D simulations. These simulations are based on a detailed modeling of SRV in local contact areas involving a non-uniform SRV in the void's vicinity. The non-uniform SRV in voids is traced back to laser induced damage nearby the local contact opening in the dielectric layer. Additionally the existence of laser damaged areas close to filled contacts is demonstrated in this work.

Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.

Keywords: PERC; voids; surface recombination velocity; simulation; LBIC

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Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.
doi:10.1016/j.egypro.2016.07.033

1. Introduction

Void formation in PERC solar cells was first investigated and discussed in more detail by Urrejola *et al*. [1]. In most studies scanning electron microscopy (SEM) has been used to analyze local contact structures after the co-firing process. However, cross-sectional images obtained by this method give very locally restricted information concerning the contact structure. Dressler *et al*. demonstrated that the application of scanning acoustic microscopy (SAM) is a reliable technique to detect voids in PERC solar cells [2]. Additionally, this non-destructive method allows a spatially resolved detection of voids on large cell areas in a short time. The studies of Dressler *et al*. – combining SAM and electroluminescence measurements - gave a first hint that cell efficiency is not necessarily affected by a high amount of voids [2]. Detailed studies concerning the thickness of the local back surface field (LBSF) in voids and filled contacts revealed in general a thinner LBSF or completely missing LBSF for voids compared to filled contacts by applying identical process parameters [3]. According to Lölgen, a reduction of the surface recombination velocity (SRV) is achieved by the application of a BSF [4]. Hence, one crucial factor of voids concerning their negative impact on the electrical solar cell parameters is a sufficiently low SRV, implying a sufficiently thick LBSF formation [5, 6, 7, 8, 9].

Within this work a combination of high resolution LBIC measurements and SAM measurements allow the comparison of the electrical characteristics of voids and filled contacts. It has already been demonstrated by applying a 2D simulation that voids feature a non-uniform SRV, which is attributed to laser damaged areas nearby the local contact structure [10]. One key aspect of this work is the transfer of these findings to filled contacts.

2. Experimental

2.1. Device configuration

The investigated PERC solar cells are processed from p-type Czochralski (Cz) Si wafers (125 x 125 mm^2, thickness around 170 µm), with resistivity of 2-3 Ωcm. The n^+-type emitter (R_{sheet} = 60 Ω/sq) on the front side is coated with a stack of thermal oxide / SiN_X:H and contacted by screen-printed Ag. The rear side of the solar cell is covered by a stack of an Al_2O_3 layer (10 nm, atomic layer deposition) and a SiN_X:H layer (120 nm, remote PECVD). Local openings in this dielectric stack (geometry: opening width of 40 µm, line shape, constant pitch of 1 mm) are achieved by laser ablation (picosecond pulsed laser, 532 nm wavelength, Gaussian profile). A commercially available Al paste is used to form the local contacts on the rear side.

2.2. Local contact structure

Fig. 1, left and center, shows the cross-sectional views of a “void” and a “filled contact” achieved by SEM imaging. The images reveal a contact width of ~ 70 µm, an increase of about 30 µm compared to the opening width in the dielectric layer directly after laser ablation (40 µm). This widening is attributed to the co-firing process, including the dissolution of silicon [5, 6, 11, 12, 13, 14, 15]. In the void, the eutectic is missing. However, both local contacts are characterized by a uniform LBSF formation.

In order to obtain information about the spatial distribution of voids in the device, SAM measurements were carried out. The method is based on the detection of ultrasonic signals, emitted by a transducer and reflected and scattered by different materials and surfaces within the solar cell. In the end, a grey-scale image of the scanned area is achieved. A more detailed description of the measurement principle is given in [1, 15]. An image of such a SAM measurement (area ~ 50 x 60 mm^2) is shown in Fig. 1, right. For a better separation of the signals, the front side fingers (thin horizontal lines) run perpendicular to the rear side contacts. Voids appear as dark vertical lines. Obviously, this section features a high amount of voids within the local rear contacts.