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Blistering in ALD Al_2O_3 passivation layers as rear contacting for local Al BSF Si solar cells

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ABSTRACT

Random Al back surface field (BSF) p-type Si solar cells are presented, where a stack of Al_2O_3 and SiN_x is used as rear surface passivation layer containing blisters. It is shown that no additional contact opening step is needed, since during co-firing local Al BSFs are induced at the location of these blisters. The best fill factors and short circuit currents are obtained in the case of (i) a hydrophobic pre-passivation cleaning, since it leads to a small density of larger blisters, and (ii) 10 nm of Al_2O_3, where the blistering size still increases during firing thanks to additional out-gassing. There is an apparent gain in *Jsc* and *Voc* of, respectively, 1.3 mA/cm^2 and 5 mV for the best random Al BSF cells compared to full Al BSF reference cells, because of better rear internal reflection and rear surface passivation.

1. Introduction

In Si solar cell technology, given that ever thinner wafers imply an increased surface-to-volume ratio, sufficient surface passivation gains importance. The cost of Si constitutes about 50% of the module cost [1]. Therefore, in order to be less dependent on price fluctuations of poly-silicon feedstock and wafers, and to eventually realize cost targets significantly below € 1.00/Wp for c-Si modules, an evolution towards a reduction of “grams of pure Si/Wp” is taking place.

An appealing candidate for outstanding Si surface passivation is aluminum oxide (Al_2O_3), deposited by thermal atomic layer deposition (ALD), plasma-enhanced (PE-) ALD or plasma-enhanced chemical vapor deposition (PECVD). The underlying mechanism is based on chemical passivation—a low density of interface defects D_{it}—and field-effect passivation with a high density of fixed negative charges [2–9].

Annealing a thick enough Al_2O_3 layer, capping it with PECVD silicon oxide (SiO_x) or silicon nitride (SiN_x) or annealing a stack of Al_2O_3 and SiO_x or SiN_x can lead to blister formation. Blistering is the partial de-lamination of a thick enough Al_2O_3 layer caused by gaseous desorption in the Al_2O_3 layer upon thermal treatments above a critical temperature: the Al_2O_3 layer acts as a gas barrier and bubble formation occurs [10]. Blistering of Al_2O_3 and capped Al_2O_3 layers has been observed for various deposition techniques: thermal ALD [10], PE-ALD [11] and PECVD [12,13].

At present, passivated emitter and rear cell (PERC) point contact formation is industrially viable in two ways [14]: (a) the i-PERC process, where the dielectric is opened via laser ablation of the passivating dielectric before the rear-side metallization [15], and (b) laser-fired contacts (LFC), where the contacts are laser-fused after metallization [16].

In this work, blistering is proposed as an approach to create semiconductor–metal contacts. Random local Al back surface field (BSF) solar cells with a blistered layer as rear surface passivation have been prepared. It is shown that blistered passivation layers covered by Al induce semiconductor–metal contacts upon high temperature treatments; hence no additional contact opening step is needed. As evidence, various proof-of-concept cells are presented, and their issues and full potential are discussed.

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Table 1
Baseline random Al BSF (left), full Al BSF reference (middle) and local Al BSF (right) p-type Si solar cell process sequences. The 148.25 cm^2 cells are 150 μm thick, have a base resistivity of 2 Ω cm and an emitter of 60 Ω/sq.

Random Al BSF p-type Si solar cells	**Full Al BSF p-type Si solar cells**	**Local Al BSF p-type Si solar cells**
Texturing front and polishing rear	Texturing front and polishing rear	Texturing front and polishing rear
Diffusion (POCl$_3$) front	Diffusion (POCl$_3$) front	Diffusion (POCl$_3$) front
Blistered passivation rear		*Blister-free passivation rear*
Anti reflection coating (SiN$_x$) front	Anti reflection coating (SiN$_x$) front	Anti reflection coating (SiN$_x$) front
		Laser ablation rear
Al sputtering rear	Al screen-printing rear	Al sputtering rear
Ag screen-printing front	Ag screen-printing front	Ag screen-printing front
Co-firing	Co-firing	Co-firing

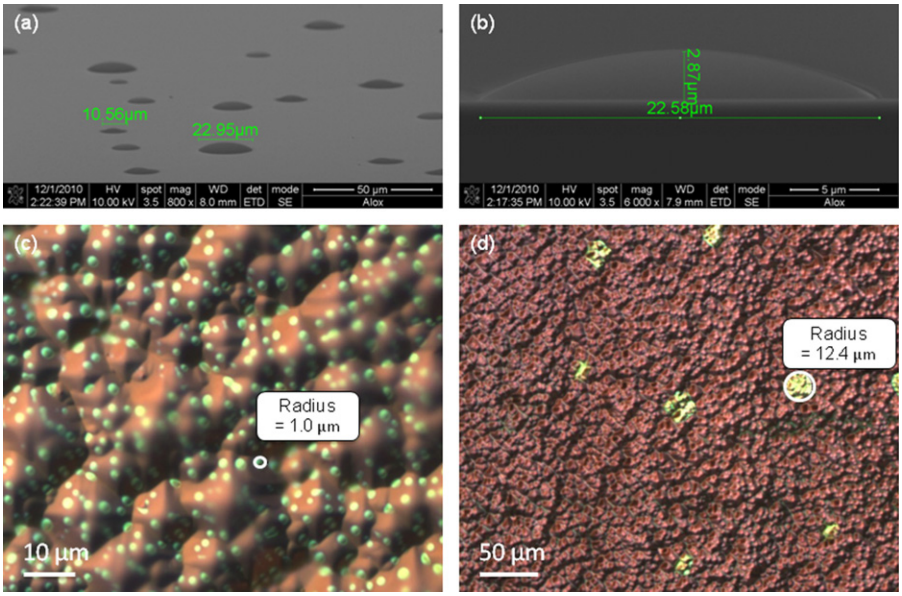

Fig. 1. (a) SEM tilted top-view and (b) cross-section images of a blistered ALD Al$_2$O$_3$/PECVD SiN$_x$ layer on a mirror-polished c-Si substrate. (c) and (d) are optical microscopy top-view pictures of an ALD Al$_2$O$_3$/PECVD SiN$_x$ layer grown on a rough c-Si surface, the pre-ALD deposition clean was hydrophilic or hydrophobic, respectively.

2. Experimental

12.5 × 12.5 cm^2 semi-square random, full and local Al BSF p-type CZ Si solar cells have been made as described in Table 1. In the case of random local Al BSF cells, a blistered layer is used as rear surface passivation without any additional contact opening step. Full and blister-free local Al BSF cells are used as references.

Pre-passivation Si wafer cleanings have an HF-last (Si–H) or oxidizing (Si–OH) last step and finish with Marangoni drying, more details can be found in [17] and are specified in the text if essential.

As rear surface passivation for the random and local Al BSF cells, a stack of ALD Al$_2$O$_3$ and PECVD SiN$_x$ is used. Thermal ALD Al$_2$O$_3$ films of 5, 10 or 30 nm are grown at 200 °C in a commercial (Cambridge Nanotech, Savannah S200) ALD reactor using tri-methylaluminium (TMA) and de-ionized (DI) water as precursors. The SiN$_x$ layer thickness is optimized for the rear internal reflectance in the solar cells by employing the CAMFR framework [18].

The co-firing process step (equals a rapid thermal processor (RTP) with a peak temperature above 835 °C for 1–2 s, see [19]) has been performed at 845, 865 or 885 °C for random and 865 °C for local and full Al BSF cells.

Blistering is visualized and measured with a Nova^{TM} NanoSEM scanning electron microscope (SEM) or an Axio Imager 2 optical microscope (respectively from FEI and Zeiss).

The used current–voltage (*IV*) setup is a steady-state Xe lamp solar simulator (Wacom Electric Co., WXS-200S-20, AM 1.5 G) with an illuminated area of 200 × 200 mm^2, a small bias error and a good stability over time, as shown in [20].

Spatially resolved series resistance of silicon solar cells is measured using a commercial photoluminescence (PL) system of BT imaging (LIS-R1) [21].

An in-house assembled light beam induced current (LBIC) measurement setup is used to map the short circuit current (*J*sc) of solar cells at a wavelength of 1050 nm.

3. Results and discussion

3.1. Blistering in ALD Al$_2$O$_3$/PECVD SiN$_x$ passivation layers

Blistering is the partial de-lamination of a thick enough ($\geq$ 10 nm) Al$_2$O$_3$ layer caused by gaseous desorption in the Al$_2$O$_3$ film upon thermal treatments above a critical temperature (typically 350 °C); the Al$_2$O$_3$ layer acts as a gas barrier and bubble