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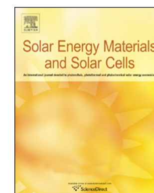

Laser contact openings for local poly-Si-metal contacts enabling 26.1%-efficient POLO-IBC solar cells

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ABSTRACT

We demonstrate damage-free laser contact openings in silicon oxide layers on polycrystalline silicon on oxide (POLO) passivating contacts. A pulsed UV-laser evaporates the upper part of the polycrystalline silicon layer, lifting off the silicon oxide layer on top. On *n*-type POLO (and *p*-type POLO, respectively) samples a saturation current density of 2 fA cm^{-2} (6 fA cm^{-2}) and an implied open-circuit voltage of 733 mV (727 mV) are achieved with a laser contact opening area fraction of 12.3% (8.7%). The application of this ablation process in an interdigitated back contact solar cell leads to an independently confirmed power conversion efficiency of 26.1%. The excellent contact quality of the laser contact openings is proven by the low series resistance of 0.1 Ω cm^2 on the solar cell with a contact area of only 3%.

1. Introduction

Passivating contacts enable the highest power conversion efficiencies of up to 26.7% [1] for single junction silicon solar cells. The two approaches with the highest demonstrated cell efficiencies use amorphous silicon heterojunctions [1–3] or polycrystalline silicon on oxide (POLO) junctions and related schemes, e.g. TOPCon [4,5]. In contrast to amorphous silicon, polycrystalline silicon (poly-Si) is processed in the same temperature range as standard screen-printing pastes and thus might be more compatible with this process. Using fire-through screen-printing pastes, contact resistances at the poly-Si-metal interface of 2 mΩ cm^2 were measured [6], which are comparable to conventional c-Si-metal contacts. However, first results with fire-through pastes showed an increase in the recombination in the metallized regions [6]. Larionova et al. reported contact resistances of 5 mΩ cm^2 and a preservation of the passivation quality using a non-fire-through paste on bare poly-Si [7]. To increase the rear reflection of the cell, a dielectric layer can be deposited on the poly-Si layer, which, in the case of a non-fire-through paste has to be removed locally for contact formation.

We apply the POLO junctions to POLO interdigitated back contact (IBC) cells, where both *n*-type POLO (*n*POLO) and *p*-type POLO (*p*POLO) contact fingers are on the rear side. As a result, the POLO contact fingers can have direct contact to each other. Alternatively, they can be separated e.g. by a trench or an intrinsic poly-Si in the lateral direction. If the fingers are in direct contact, the recombination current at the interface of the lateral *pn* polycrystalline Si junction is a significant part of the global recombination current in the cell causing low fill factors and open-circuit voltages [5,8–10]. Thus, such a configuration should be avoided. We have already demonstrated cells where we removed the *pn* poly-Si interface by KOH etching, achieving an independently confirmed power conversion efficiency of 25.0% [5]. In that case, the resulting trench was passivated by AlO_x and the contact openings were etched wet chemically using a photoresist mask. This process degraded the passivation layers and decreased the implied efficiency by 0.2%$_{abs}$ [11]. Even if the photolithographic process could be substituted by a screen-printing mask, it remains an expensive multi-step process.

The aim of this work is to remove the dielectric layer with our layer-selective laser ablation process (LASA) [12] without compromising the passivation quality of the POLO-junction underneath. This is not trivial due to the small poly-Si thickness of only 40–150 nm. We characterize the saturation current densities before and after laser ablation for different laser wavelengths (355 nm and 532 nm) and different laser fluences. We apply this process to POLO-IBC cells. In this work, we avoid a lateral *pn* poly-Si interface and a passivated trench by patterning the

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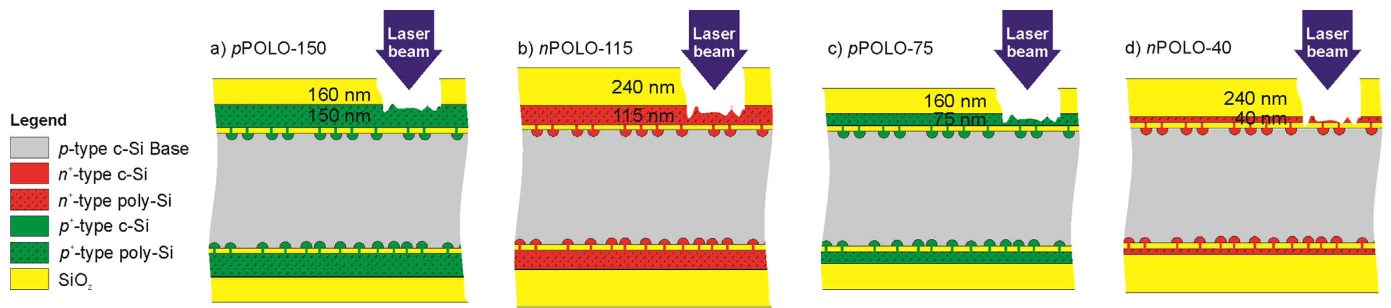

Fig. 1. Schematic cross sections of the four laser-treated test samples passivated with *p*-type poly-Si (a and c) and *n*-type poly-Si (b and d). The poly-Si thickness decreases from a) 150 nm to b) 115 nm to c) 75 nm to d) 40 nm. The thicknesses of the poly-Si and SiO_2 capping layers are shown proportional to each other. We name the samples according to the doping and thickness of the poly-Si.

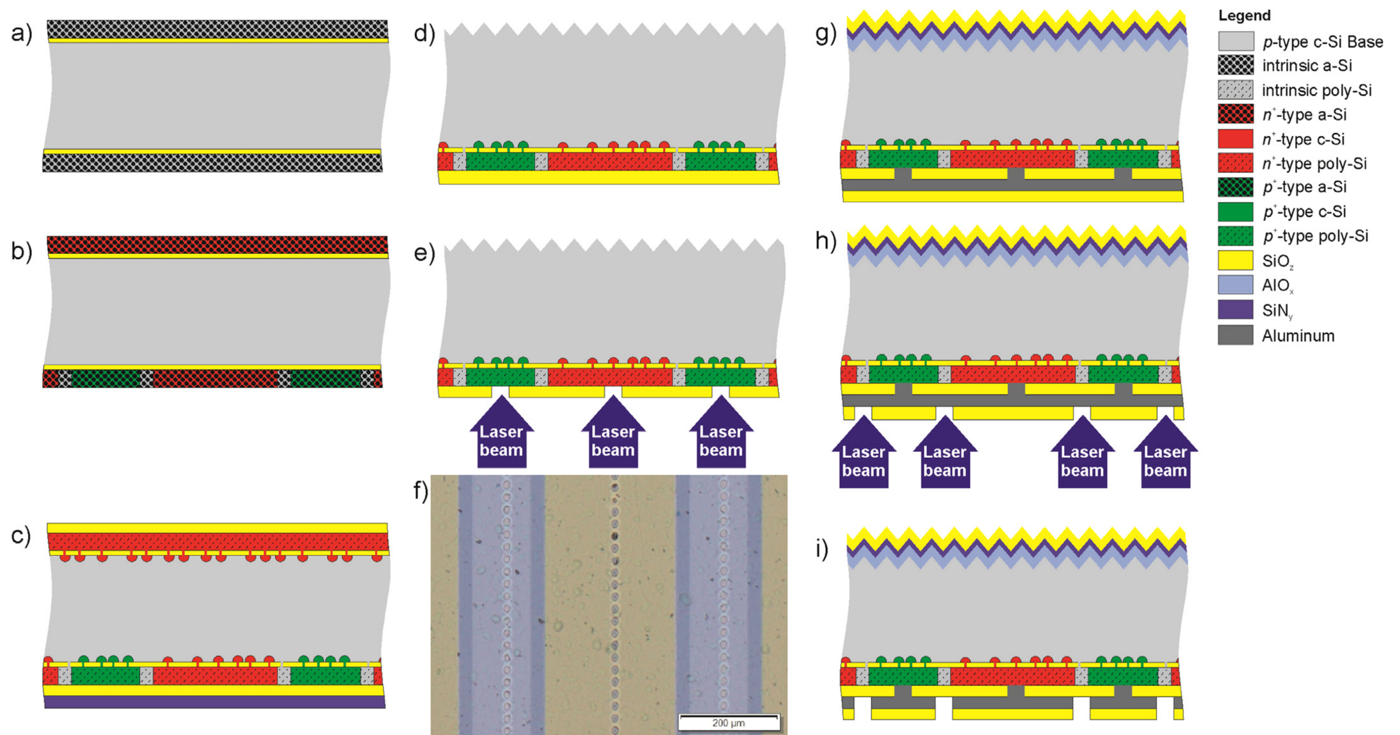

Fig. 2. Schematic cross sections of the process sequence of the IBC solar cell with *n*- and *p*-type poly-Si contact fingers separated by an intrinsic poly-Si gap. f) shows an optical microscope image of the laser contact openings on the *n*- and *p*-type fingers. It is aligned to e).

λ [nm]	355			532		
H [J cm^{-2}]	0.08	0.10	0.13	0.07	0.08	0.10

40 µm

Fig. 3. Optical microscope image of a single laser contact opening (LCO) for both laser wavelengths λ and the different laser fluences H listed above the images of sample *p*POLO-150. The scale for all images is given in the first one.

ion-implantation in such a way, that the *p* and *n* doped poly-Si fingers are separated by an intrinsic, i.e., non-implanted, poly-Si gap region [10,13–18]. This results in a lateral *pin* poly-Si junction at the rear side of the IBC cell, which is in parallel to the *n*POLO/*p*-type c-Si junction.

2. Sample preparation

2.1. Test samples

Fig. 1 shows the schematic cross sections of our four test samples. A 2.2 nm-thick SiO_2 layer grows during a dry oxidation in a tube furnace on a 300 µm-thick FZ *p*-type wafer with a resistivity of 100 Ω cm. A 150 nm- (Fig. 1c and d) or 225 nm-thick (Fig. 1a and b) intrinsic amorphous silicon (a-Si) layer is deposited by low pressure chemical vapor deposition (LPCVD, E2000 from Centrotherm) on top of the SiO_2. A symmetric test sample is obtained by either phosphorus (Fig. 1b and d) or boron (Fig. 1a and c) implantation on both sides. During an annealing step under oxygen atmosphere at 900 °C for 30 min the a-Si transforms to poly-Si and a 240 nm- (on *n*-type poly-Si) and 160 nm-thick (on *p*-type poly-Si) thermal oxide grows on top of the poly-Si layers. In a subsequent high temperature step under nitrogen atmosphere above 1000 °C for 60 min the 2.2 nm-thick SiO_2 layer breaks up

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