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Layer selective laser ablation for local contacts to thin emitters

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Abstract

High efficiency solar cells require high generation and low recombination rates. High bulk lifetime, well passivated surfaces, and lowly doped thin emitters allow for low recombination rates. Thin passivated emitters should be contacted locally in order to avoid excessive contact recombination. This is common practice for front junction solar cells but is also advantageous for back junction cells. We analyze a novel layer selective laser ablation process. From a passivating stack composed of 70 nm silicon nitride that we deposit on top of 35 nm of amorphous silicon we selectively ablate the silicon nitride layer. Transmission electron microscopy investigations confirm the full ablation of the silicon nitride layer. After the ablation process, a 17 nm-thick amorphous silicon layer remains on the substrate. The crystalline silicon substrate shows no dislocations after the process. Evaporating aluminum on top of the locally ablated nitride layers forms local contacts of the aluminum to the silicon.

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Keywords: Local contact openings; selective laser ablation; amorphous silicon passivation; thin back junction emitter

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1. Introduction

Commonly, industry solar cells have screen printed contacts [1]. Another approach for contacting thin emitters is to remove the dielectric layer from the emitter and to form the contact by electroplating, metal evaporation, or screen printing followed by low temperature annealing. Masking by ink-jet printing [2] or direct laser ablation [3] can also be used for local removing the dielectric. While ink-jet printing consists of at least three process steps (printing a mask, wet chemical etching of the dielectric and removing the

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mask), laser ablation consists of only one. Defects in the underlying substrate have been reported after single dielectric layer ablation [4], hence potentially causing high saturation current densities in the emitter and enhancing the risk of shunt formation.

We recently introduced a novel concept that uses a layer stack of an amorphous silicon (a-Si) passivation layer capped with an amorphous silicon nitride (a-SiN) layer [5]. A picosecond laser ($\lambda = 355$ nm) selectively ablates the a-SiN layer, hence avoiding any damage of the Si wafer. We reported on the high electronic quality of the samples after the layer selective laser ablation (LASA) process by measuring effective carrier lifetimes of 2000 µs on a 100 Ωcm mono-crystalline silicon p-type float zone (FZ) wafer [5]. In this report we focus on the structural analysis of LASA-processed samples via scanning electron and transmission electron analysis.

2. The selective laser ablation process

2.1. Sample preparation

Mono-crystalline silicon (c-Si) p-type FZ wafers with a doping density of 10^{16} cm^{-3} serve as substrate. Figure 1a sketches the sample. The surface of the samples is passivated by a double layer stack. The stack consists of 35 nm plasma enhanced chemical vapour deposited (PECVD) a-Si and a capping 70 nm remote PECVD a-SiN layer. The capping layer has a refractive index of 2.8. We apply a Nd:YVO$_4$ laser with a pulse length of $\tau = 9$ ps (full duration at half maximum) and a wavelength of $\lambda = 355$ nm. The laser beam has a rotationally symmetrical Gaussian profile with a beam radius of $\omega_0 = 32$ µm. The radius is defined by an intensity decline of a factor of e^{-2}. The diameter of the ablated spots is about 20 µm. Our experiments show no ablation for an average laser fluence of $H_{av} < 0.095$ J cm^{-2}. We find damage of the silicon substrate for an average laser fluence of $H_{av} > 0.112$ J cm^{-2}. The sample presented in Figure 1b is processed with an average laser fluence of $H_{av} = 0.096$ J cm^{-2}.

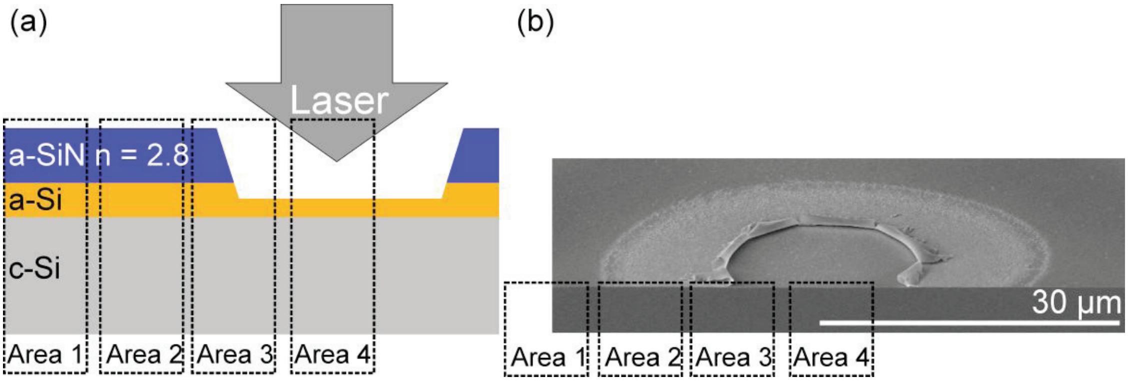

Fig. 1. (a) Schematic and (b) scanning electron microscopy image of the selective laser ablation of a-SiN from a-Si:H. The areas of the transmission electron microscopy investigations are marked with boxes.

2.2. Transmission electron spectroscopy and energy dispersive X-ray analysis

A stabilization layer consisting of a carbon containing glue is deposited for transmission electron microscopy (TEM) investigations. A low voltage focused ion beam sputters a lamella perpendicular to the surface and electron transparence samples are obtained without damaging the samples.

Figure 2 shows bright field TEM cross sectional micrographs of Areas 1 and 2 that are indicated in Figure 1. Figure 2a shows the layer stack of 35 nm a-Si and 70 nm a-SiN located in Area 1 with no laser treatment. The layers of Area 2 are only partially ablated due to a low laser fluence in the outer region of the Gaussian profile. Figure 2b still shows the a-Si/a-SiN stack, but the structure of the upper part of each layer is porous. The presence of pores is confirmed by an energy dispersive X-ray analysis (EDX). The ratio of the intensity of the CKα peak over the intensity of the SiKα peak is much higher in the region of a pore. The CKα signal is caused by glue infiltration into the pore during the preparation process.

We interpret the formation of the stack structure composed of a-Si/porous a-Si/a-SiN/porous a-SiN as follows: The laser fluence is partially absorbed in the a-SiN layer forming pores by sublimating the material. But a fraction of the laser passes throughout this layer and is absorbed at the a-Si layer that has a higher absorption coefficient than a-SiN at a wavelength of 355 nm. Hence pores also form in the upper part of the a-Si layer.

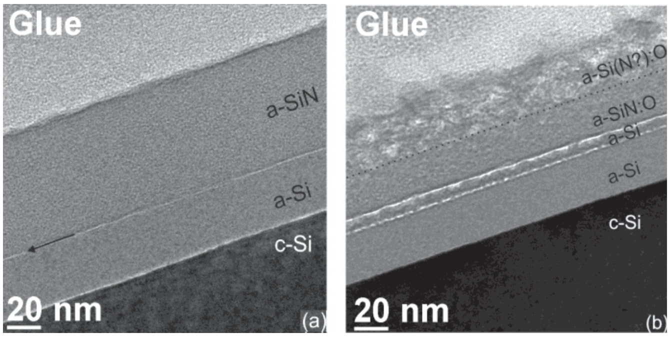

Fig. 2. (a) TEM image of the reference Area 1 without laser treatment. (b) TEM image of Area 2 which is treated with a low fluence of the laser pulse.

Figure 3 shows a 3 μm wide region composed from various bright field TEM images of Area 3. The laser fluence increases with decreasing distance to the centre of the laser spot (Figure 3a through 3g) due to the Gaussian profile. In Area 3 the gas pressure of the sublimated a-Si is high enough to remove the a-SiN top layer. Figure 3d shows the edge of the a-SiN layer. Figures 3e through 3g represent Area 4, where no a-SiN is left. Here the stack is c-Si/a-Si/porous a-Si. High resolution TEM images demonstrate that the a-Si layer is pure amorphous and that the c-Si layer has no dislocations or other crystal defects. These layers are therefore likely not to be electronically degraded by the laser treatment. This is interpretation is in agreement with the lifetime measurements that we reported in Ref. [5]. The LASA process thus removed the a-SiN-layer selectively against the a-Si layer and the wafer surface remains passivated.

3. Conclusion

We demonstrate selective laser ablation of a-SiN from a a-SiN/a-Si layer stack. TEM investigations show the selectivity of the process. A pure amorphous Si layer remains on the surface after ablation. The underlying c-Si does not show crystallographic defects. Subsequent aluminum deposition permits to form local contacts to silicon by means of annealing COSIMA[6]. This is especially interesting for thin emitters of high efficiency solar cells.

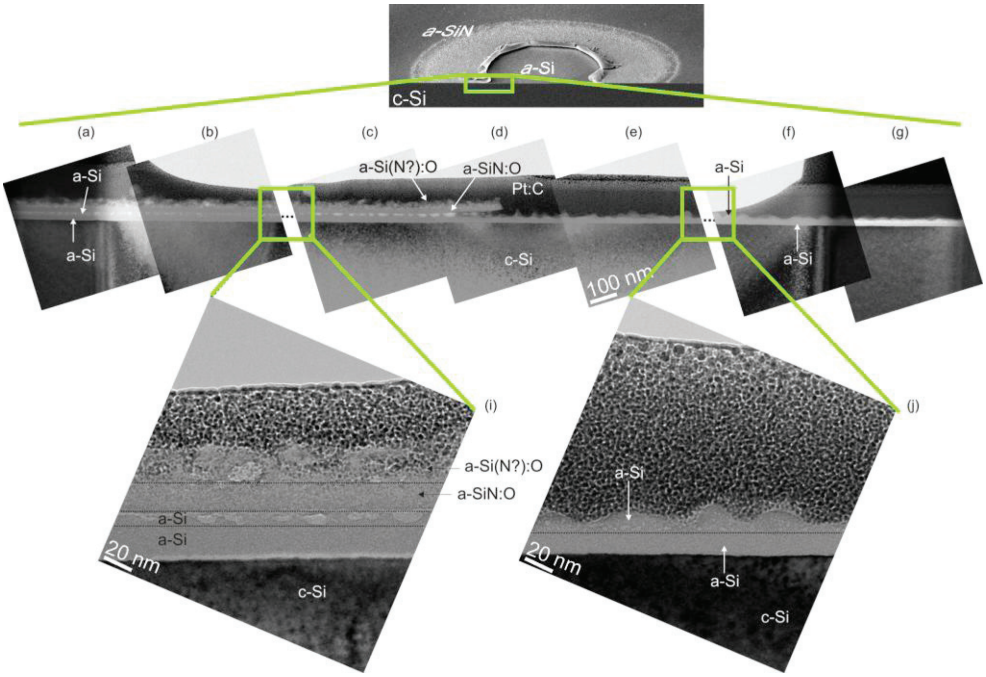

Fig. 3. TEM images of area 3. In images (a) to (c) and (i) a low laser fluence of the laser causes an a-Si/porous a-Si/a-SiN/porous a-SiN layer stack. Image (d) shows the edge of the a-SiN layer. In images (e) to (g) and (j) a higher laser fluence ablates the a-SiN layer completely and a layer stack of a-Si/porous a-Si remains.

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