



Silicon nitride and intrinsic amorphous silicon double antireflection coatings for thin-film solar cells on foreign substrates

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ABSTRACT

Hydrogenated intrinsic amorphous silicon (a-Si:H) was investigated as a surface passivation method for crystalline silicon thin film solar cells on graphite substrates. The results of the experiments, including quantum efficiency and current density–voltage measurements, show improvements in cell performance. This improvement is due to surface passivation by an a-Si:H(i) layer, which increases the open circuit voltage and the fill factor. In comparison with our previous work, we have achieved an increase of 0.6% absolute cell efficiency for a 40 μm thick 4 cm² aperture area on the graphite substrate. The optical properties of the SiN_x/a-Si:H(i) stack were studied using spectroscopic ellipsometer techniques. Scanning transmission electron microscopy inside a scanning electron microscope was applied to characterize the cross section of the SiN_x/a-Si:H(i) stack using focus ion beam preparation.

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1. Introduction

Graphite is a high thermal stability material and available at high purity. Consequently, several cell concepts have been developed for solar cells on graphite substrates, i.e., zone melting recrystallization (ZMR) [1,2], laser edge isolation (LEI) [3], hydrogen passivation [4] and laser single side contact (LSSC) [5]. In our previous work, we reported our 10.2% cell efficiency for a 40 μm thick and 4 cm² aperture area on graphite substrate [5].

In order to improve the thin film cell concept further, the surface recombination must be suppressed using a surface passivation process. Several dielectric materials are widely applied as surface passivation coatings, including aluminum oxide (Al₂O₃) [6,7], hydrogenated amorphous silicon (a-Si:H) [8–11], amorphous silicon carbide (a-SiC_x:H) [12,13], silicon nitride (SiN_x) [14,15] and thermal silicon oxide (SiO₂) [16–18]. When considering passivation of the sunside surface in particular, not only the passivation quality but also optical properties such as antireflection must also be taken into account [19], such as, SiN_x/SiO₂ [20–23], SiN_x/SiN_x [24,25] SiN_x/a-Si:H [26–28] and SiO_x/indium tin oxide [29] stacks. Among these various concepts, the a-Si:H(i)/c-Si(n) hetero-interface has a high passivation quality and can be fabricated

at low temperature (<250 °C). It is used e.g., in heterojunction with intrinsic thin (HIT) layer cell concept [30–32].

In this paper, we combine our cell concept on graphite substrates with surface passivation, using an SiN_x/a-Si:H(i) stack on a phosphor-doped c-Si(n⁺) emitter. The a-Si:H(i) passivation has the advantages of high surface passivation quality and short process times at low temperature. We observed improved cell performance, i.e., an increase in short circuit current (*J*_{sc}), open circuit voltage (*V*_{oc}), fill factor (*FF*) and cell efficiency due to the SiN_x/a-Si:H(i) stack. We report a laboratory cell efficiency of 10.8% on the same aperture area and the graphite substrate.

2. Experimental

2.1. Solar cell design and processing

Our cell concepts are based on high purity graphite substrates (“FP479”, Schunk Kohlenstofftechnik GmbH) with a size of 10 cm × 10 cm × 2 mm. In order to prevent impurity diffusion from the foreign substrate, a SiC layer was deposited as an intermediate layer on both sides of the substrate using a hot wall chemical vapor deposition (HWCVD). Afterwards, a c-Si(p⁺) layer, which served as a seed and back surface field layer (approximately 20 μm thick and with an acceptor concentration of 4 × 10¹⁸ cm⁻³), was deposited on top of the SiC

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layer using convection assisted chemical vapor deposition (CoCVD). The subsequent ZMR process yielded a large size of silicon grain. A 20 μm thick epitaxial $c\text{-Si}(p)$ base layer was applied over the $c\text{-Si}(p^+)$ layer and was grown by CoCVD [33]. This $p\text{-Si}$ layer had a boron doping concentration of about $2 \times 10^{16} \text{ cm}^{-3}$. The $c\text{-Si}(n^+)$ emitter was formed by spin on doping of a phosphorous solution followed by rapid thermal processing in a furnace [34]. It was essential to reduce the bulk recombination using a hydrogen passivation process, which was applied directly after the removal of the phosphorous glass [3]. The hydrogen passivation process was carried out at a low temperature ($< 350 \text{ }^\circ\text{C}$) for 50 min with a plasma enhanced chemical vapor deposition (PECVD) system (Roth & Rau, AK1000). The PECVD system has an $88 \times 96.5 \times 35 \text{ cm}^3$ volume chamber containing a $42 \times 42 \text{ cm}^2$ heating stage.

Due to recent rapid developments in laser technique, LEI process and LSSC formations were applied in our cell concepts. Trenches approximately 30 μm deep (down into the $c\text{-Si}(p^+)$ layer) and 3 mm wide were fabricated for contact stripes around the cells using a Nd:YVO₄ laser (Rofin Power Line LP20, $\lambda_{\text{laser}} = 1064 \text{ nm}$).

Afterwards, we simultaneously evaporated emitter contacts and the base contacts on the front. The grid metallization was formed by electron beam evaporation of Ti, Pd and Ag (30 nm, 30 nm and 5 μm thick, respectively). Finally, a silicon nitride layer serving as a single layer antireflection coating (80 nm thick, refractive index from 1.5 to 1.8) was deposited using plasma enhanced chemical vapor deposition (PECVD). The PECVD system was kept at a pressure of 3.5 Pa, a work frequency of 2.45 GHz and microwave power of 1000 W. The total thickness of

the silicon layers was approximately 40 μm . It is important to note that the samples have not been prepared in clean room conditions.

As shown in Figs. 1 and 2, we divided the samples into three batches corresponding to the three different cell concepts. For *Batch C* all steps of the process sequence described above were followed, with the exception of surface passivation, as shown in Fig. 2c.

2.2. Process sequences of $a\text{-Si:H}(i)$ deposition

In crystalline silicon thin film (CSiTF) ($< 40 \mu\text{m}$) solar cells, the electron-hole generation is close to the surface and thus the surface recombination plays an extremely important role in the cell performance. Therefore, in order to improve our cell concepts further, we focused our effort on front surface passivation to reduce the surface recombination using an $a\text{-Si:H}(i)$ layer.

As shown in Fig. 2a and b, two strategies were investigated to find the best surface passivation process sequence using the $a\text{-Si:H}(i)$ layer. As shown in Fig. 1, the samples of one strategy were named as *Batch A*, and in these samples $a\text{-Si:H}(i)$ layers were fabricated before the laser trenching and the LEI process. Moreover, the $a\text{-Si:H}(i)$ layer was deposited directly after the hydrogen passivation in the same PECVD chamber, which may have advantages for the $a\text{-Si:H}(i)/c\text{-Si}(n^+)$ interface characteristics.

The alternative strategy was to fabricate the $a\text{-Si:H}(i)$ layers (applied in *Batch B*) after the laser processing and the grid metallization. The $a\text{-Si:H}(i)$ and SiN_x layers were formed stepwise at the same temperature

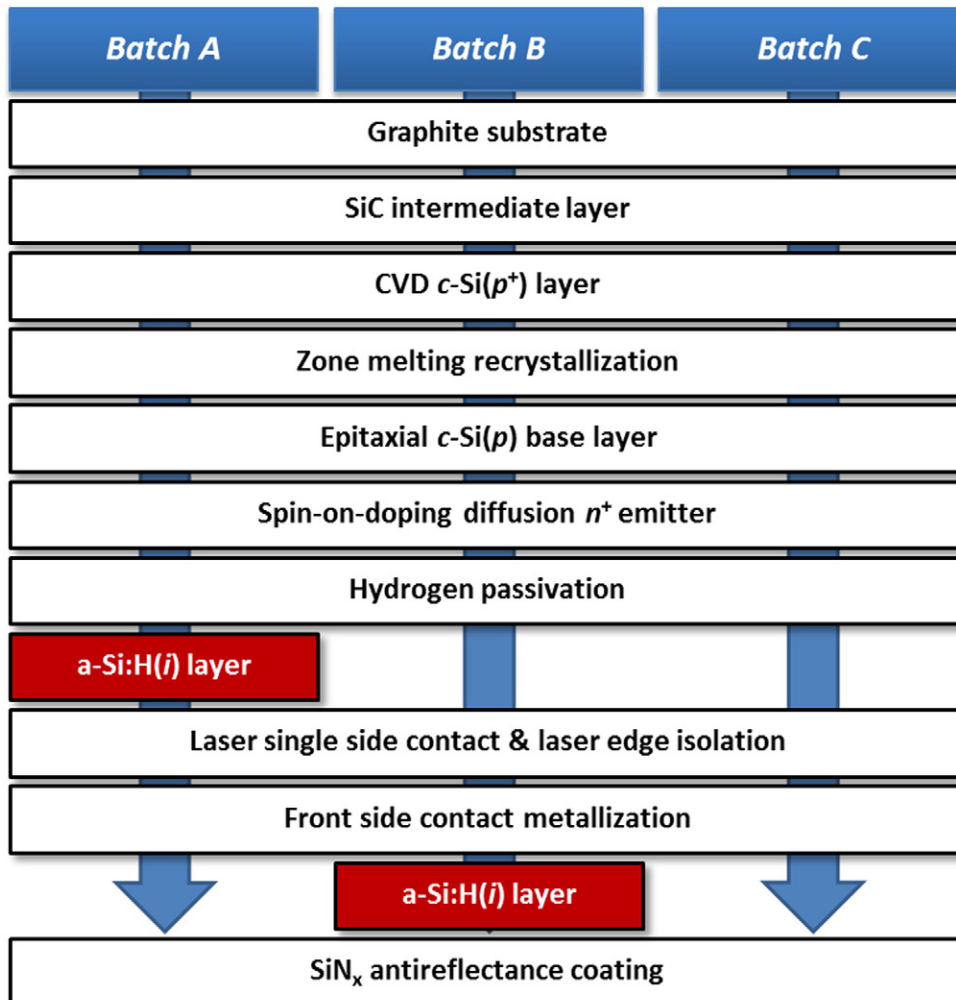


Fig. 1. Processing sequence of the cells. Three solar cell batches were prepared. *Batch A* was passivated by the depositing using the $a\text{-Si:H}(i)$ layer after the hydrogen bulk passivation. The surface passivation layer of *Batch B* was applied before the SiN_x layer. *Batch C* was the reference batch without surface passivation process.

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