POLYCRYSTALLINE SILICON THIN-FILM SOLAR CELLS ON GLASS

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ABSTRACT

In this paper we report on the current status of our development of polycrystalline silicon (poly-Si) thin-film solar cells on glass. Poly-Si films have been prepared by either the 'seed layer concept' or solid phase crystallization (SPC). Post-deposition treatments (defect annealing and defect passivation) have been used to improve the quality of the poly-Si films. In the paper the most important features of the different process steps are discussed.

1. INTRODUCTION

So far the existing amorphous Si (a-Si:H) or micro-crystalline Si (μc-Si:H) thin-film solar cells on glass are limited to single junction efficiencies of about 10%. To overcome the current limits new approaches are necessary. This paper deals with such new approaches using polycrystalline Si (poly-Si). The poly-Si films have been prepared by either the 'seed layer concept' or by solid phase crystallization (SPC).

2. SEED LAYER CONCEPT

The 'seed layer concept' is used to form large-grained poly-Si films on glass: In a first step a very thin large-grained poly-Si film (seed layer) is formed on glass and in a second step this seed layer is epitaxially thickened to form the absorber layer (base) of the solar cell. The corresponding poly-Si thin-film solar cells feature the following structure: glass, p^+-type poly-Si seed layer, p-type poly-Si absorber, n^+-type a-Si:H emitter, transparent conductive oxide (TCO), and metal contacts to both TCO and absorber. The solar cells have been prepared using the following sequence of process steps: seed layer formation, absorber deposition, defect annealing, defect passivation, emitter deposition, and contact formation (including TCO deposition). The post-deposition treatments (defect annealing and passivation) have been applied to improve the quality of the poly-Si films. In the following subsections the different process steps are described in more detail.

2.1 Seed layer formation

Large-grained poly-Si seed layers were formed directly on glass using the aluminum-induced layer exchange (ALILE) process [1]. Starting point for the ALILE process is the following stack: glass/Al/a-Si. Annealing of the initial glass/Al/a-Si stack leads to a layer exchange and a concurrent crystallization of Si. At the end a glass/poly-Si/Al(+Si) stack is formed. Finally the Al(+Si) layer is removed by chemical mechanical polishing (CMP). The resulting thickness of the poly-Si seed layer is about 200nm. The seed layer is heavily doped with Al (p^+-type). Therefore the seed layer act as a Back Surface Field (BSF). Characteristic features of the seed layer are a large grain size and a preferential (100) orientation of the grain surface. The preferential (100) orientation is favorable for the subsequent epitaxial growth of the absorber. For example, a seed layer prepared at 425°C showed an average grain size of 7μm, a maximum grain size of 18μm, and a preferential (100) orientation $R_{(100)}$ of about 60% [2]. Preferential (100) orientations $R_{(100)}$ of up to 75% were obtained [1].

Although the poly-Si seed layer is highly doped the sheet resistance is too high. An appealing option to reduce the sheet resistance is the application of TCO-coated glass as substrate for the ALILE process. In our experiments we used smooth ZnO:Al films which were deposited at the 'Forschungszentrum Jülich' (Germany). After the CMP process the structural properties of the seed layer were investigated at IMEC (Belgium) by Electron Back Scatter Diffraction (EBSD) [2]: A seed layer prepared at 425°C showed an average grain size of 5μm and a maximum grain size of 16μm. This means that the grain size on ZnO:Al-coated glass is slightly smaller than on bare glass. The preferential (100) orientation $R_{(100)}$ of the seed layer formed at 425°C was about 60% which means that $R_{(100)}$ is not affected by the ZnO:Al layer underneath. So far the results on ZnO:Al-coated glass are quite encouraging.

2.2 Absorber deposition

The p-type absorber layers were grown epitaxially onto the seed layers by electron-beam evaporation of silicon. No additional ionization stage was used. Doping was obtained by co-evaporation of boron. Due to the application of glass the process temperature is limited to about 600°C. The standard thickness of the grown films is about 2μm. We studied the influence of both de-position temperature and deposition rate on the properties of the grown films. In order to analyze the structural quality Secco-etching was applied to films grown on Si(111) wafers. Scanning electron microscopy (SEM) investigations of these films showed that (i) the

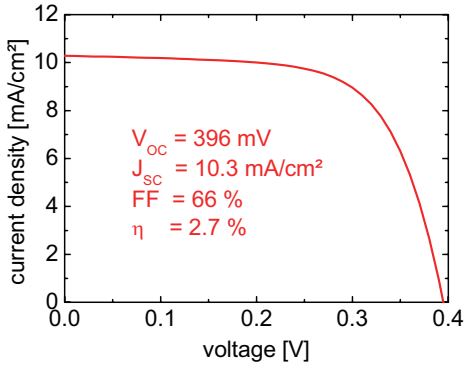

Figure 1: Current-voltage characteristic of the best solar cell so far. The current density and the efficiency were calculated using the active area.

higher the deposition temperature the lower the number of extended defects and (ii) the higher the deposition rate the higher the number of extended defects [3]. The structural quality of the films depends strongly on the crystallographic orientation of the underlying substrate. Films grown on (100) surfaces feature the best structural quality. This confirms the importance of a high preferential (100) orientation of the seed layer grains.

2.3 Post-deposition treatments

The application of post-deposition treatments (defect annealing and defect passivation) is an attractive way to improve the quality of the poly-Si films. Defect annealing (i.e. a short high temperature treatment) has been carried out using a Rapid Thermal Annealing (RTA) system. The temperature region between the strain point and the annealing point was passed with moderate heating and cooling rates. So far, the best results were obtained at an annealing temperature of 950°C and an annealing time of 200s [3]. Defect passivation (i.e. plasma hydrogenation) has been applied in a special tool which allows for substrate temperatures of up to 650°C. A remote lamp heater enables rapid heating and cooling. When the passivation temperature is reached the hydrogen plasma is ignited. After the passivation time the sample is cooled down. During that time the hydrogen plasma remains ignited. This prevents out-diffusion of hydrogen. So far, the best results were obtained at a passivation temperature of 620°C and a passivation time of 10min [3]. It is expected that the optimization of both post-deposition treatments will lead to further improvements.

2.4 Emitter deposition and contact formation

The n^+-type a-Si:H emitter was deposited onto the p-type absorber layer by plasma enhanced chemical vapor deposition (PECVD). On top of the a-Si:H emitter a transparent conductive oxide (ZnO:Al) was deposited by reactive DC magnetron sputtering. The emitter areas were defined by photolithography and subsequent wet-chemical mesa-etching. After mesa-etching metal (Al) contacts were formed on both the TCO and the absorber. The shape of the metal contacts was also defined by photolithography. Solar cells with two different total areas were prepared (1cm x 1cm and 4mm x 4mm).

2.5 Solar cell results

The current-voltage characteristic of the best solar cell is shown in Fig. 1. The current density was calculated using the active area. For the measurement white paper was placed below the glass substrate. This led to an increase of the short circuit current density J_{sc} from 8.1mA/cm^2 (black reflector) to 10.3mA/cm^2 (white reflector). Together with an open circuit voltage V_{oc} of 396mV and a fill factor FF of 66% this has led to an active area efficiency of 2.7% [3].

3. SOLID PHASE CRYSTALLIZATION

In addition to the 'seed layer concept' we have recently started to investigate solid phase crystallization of amorphous silicon on ZnO:Al coated glass. This concept offers a simple contacting scheme and a simple way to implement light trapping. The results obtained so far are quite promising [4].

4. CONCLUSION

Poly-Si thin-film solar cells feature the potential for high efficiencies. But to reach such high efficiencies the material quality of our poly-Si films has to be improved dramatically.

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