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Improvement of a-Si:H solar cell performance by SiH_4 purging treatment

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ABSTRACT

Amorphous silicon (a-Si:H) thin film solar cells were prepared in a single chamber large area plasma enhanced chemical vapor deposition (PECVD) system. A purging process using silane (SiH_4) gas was developed to remove the residual contaminations in the reactor after a nitrogen trifluoride (NF_3) plasma dry cleaning process. Such a purging treatment leads to a clear improvement in initial fill factor (FF) and in efficiency of as-prepared a-Si:H solar cells. Secondary ion mass spectroscopy (SIMS) results demonstrate that fluorine impurity concentration [F] at the p-layer as well as p/i interface of solar cells reduces by more than one order of magnitude after this purging process. Additionally, high [F] is accompanied with high oxygen impurity concentration [O] which plays a great role in the solar cell performance. Low degradation rate of open circuit voltage (V_{oc}) and fill factor (FF) of solar cells after a purging process after a 1000 h light soaking further illustrates an improvement in the material properties. Implanting such a purging process in the practical production line, about 2 W in power for a-Si:H solar modules (1.1 m × 1.3 m) are gained and meanwhile the champion solar module (1.1 m × 1.3 m) of stabilized power of 113 W with 160 nm thick intrinsic layer has been achieved.

1. Introduction

Silicon thin film solar cells e.g. hydrogenated amorphous silicon (a-Si:H) and amorphous/microcrystalline silicon (a-Si:H/μc-Si:H) solar cells have been employed in industrial mass production [1–5]. A record stabilized efficiency of 10.8% for a large area micromorph tandem solar module (1.4 m^2) was reported [1]. For such kinds of silicon thin film solar cells, the silicon layers are prepared usually with multi-chamber [6] or single-chamber [7] systems by plasma enhanced chemical vapor deposition (PECVD) technology. In a multi-chamber deposition system, the p-, i-, n-type silicon layers are grown in individual chambers with the specific dopant gases. In a single-chamber deposition system, the frequent using of plasma cleaning process is required to avoid the cross contamination [8]. The sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) gases are used for cleaning reactor by plasma etching [5,9–12]. A small amount of etching gases might reside in the reactor after such a cleaning process. As a result, a parasitical contamination in the later preparation of solar modules could take place and leads to a drop in power of solar modules. Thus the optimization of cleaning process would be of significance for a stable mass production.

In this study, hydrogenated amorphous silicon (a-Si:H) thin film solar cells were prepared in single-chamber PECVD system and the NF_3 gas was used to clean the reactor by plasma etching. An additional purging process with SiH_4 after plasma etching was developed to reduce the contamination. The solar cell performances as well as material properties are studied by current–voltage (I–V) test, external quantum efficiency (EQE) and secondary ion mass spectroscopy (SIMS) measurements.

2. Experimental details

All a-Si:H solar cells with a p-i-n configuration were deposited on 3.2 mm thick float glass in single-chamber PECVD system (KAI 1200) at 40.68 MHz. The chamber cleaning process was employed after each deposition of sequent p-i-n silicon solar cells. An additional purging process using SiH_4 gas after plasma etching was carried out at 2.5 mbar for 100 s. For comparison, the a-Si:H solar cells without this purging process i.e. type A solar cells that differ from type B solar cells with purging, were prepared. The preparation procedure chart of a-Si:H solar cells in PECVD system is shown in Fig. 1. Note that there is a process named situ water flush applied between the p-layer and i-layer depositions so as to decrease the boron related cross contamination [13,14]. The samples prepared with p-layers are not removed out of reactors and no power is imposed during the flushing with water vapor. The thickness of

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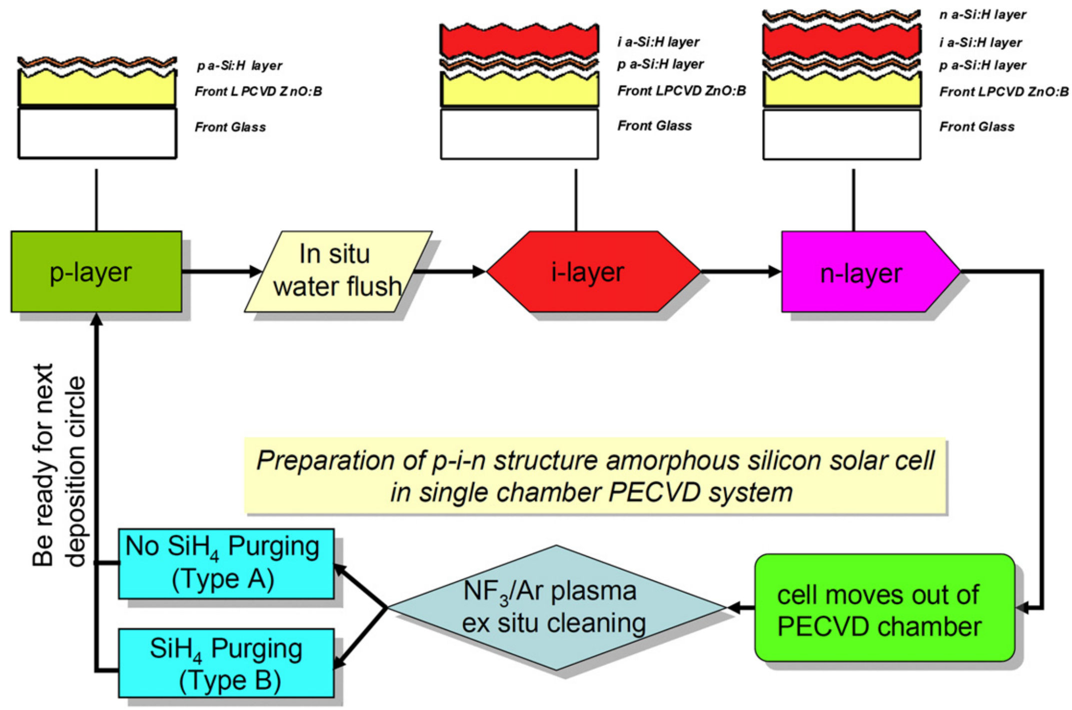

Fig. 1. The schematic of preparation procedure of p-, i- and n-type silicon layers in single chamber PECVD system with and without SiH_4 purging treatments. The structures of corresponding devices with p-layer, i-layer and n-layer are also added.

intrinsic layers for both types of solar cells is about 250 nm. Boron doped zinc oxide (ZnO:B) films, acting as front and back contact electrodes, were deposited in low pressure chemical vapor deposition (LPCVD) systems (TCO 1200) [15,16]. The screen-printed white paint was pasted onto the ZnO:B back electrode serving as back reflector [17].

For SIMS measurement, a special sample with two p-type a-Si:H layers and an intrinsic layer was prepared as follows. Before the preparation of the SIMS sample, the plasma etching with NF_3 gas for reactor was carried out. The first p-type a-Si:H layer i.e. p-a-Si:H layer 1 grew on the glass substrate directly after the NF_3 plasma cleaning process. Then the same NF_3 cleaning treatment was carried out again and was followed by an additional purging process with SiH_4 gas for 100 s. Before NF_3 cleaning treatment, the sample prepared with p-a-Si:H layer 1 was removed to the transfer chamber from the reactor chamber. After that, the second p-type a-Si:H layer (p-a-Si:H layer 2) as well as an intrinsic layer was deposited on the p-a-Si:H layer 1. Moreover, similar to the practical preparation of solar cells mentioned above, an in situ water flush process was applied after the deposition of p-a-Si:H layer 2. The preparation procedure chart and corresponding sample structure are shown in Fig. 2.

The a-Si:H solar cells are tested for current–voltage (I–V) curves under standard test conditions (25 °C, 1000 W/m^2, AM1.5). The short circuit currents are determined by the external quantum efficiency (EQE) measurement. The light induced degradation of solar cells is carried out under the standard light soaking conditions (1000 W/m^2, AM1.5, 50 °C). The chemical composition analysis is carried out with the secondary ion mass spectroscopy (SIMS) measurement.

3. Results and discussions

3.1. Results

Table 1 lists the I–V parameters of the as-prepared and degraded a-Si:H solar cells without and with purging by SiH_4 gas i.e. type A and type B solar cells, respectively. Note that the cells A1, A2 and A3 as well as cells B1, B2 and B3 listed in Table 1 were prepared with the same deposition conditions in terms of the same cell type. The efficiencies of as-prepared type B a-Si:H solar cells (cells B1, B2 and B3) are slightly higher than those of the as-prepared type A a-Si:H solar cells (cells A1, A2 and A3), which are attributed to the improvement of fill factor (FF). The FF in average for type A solar cells without purging process is 66.2% while it is 69.1% for type B solar cells with purging process. In addition, the as-prepared type A a-Si:H solar cells show slightly higher open circuit voltages (V_{oc}) 889.5 mV in average compared to that of the type B a-

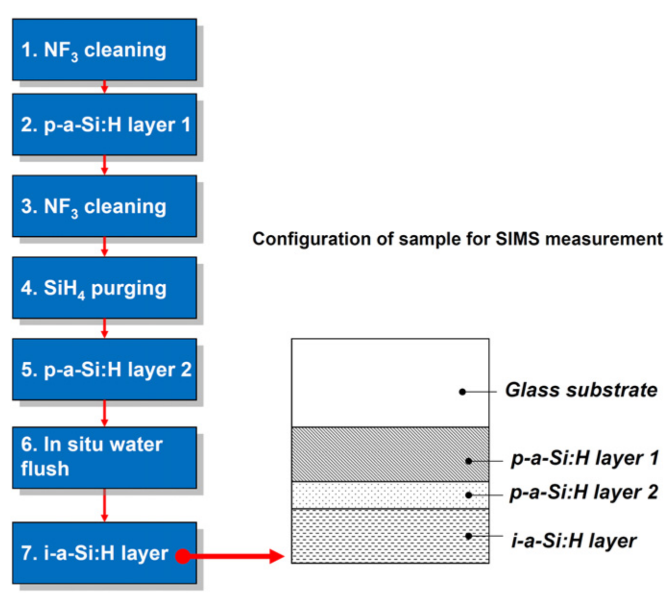

Fig. 2. The schematics of preparation procedure of a special sample for SIMS measurement as well as corresponding configuration of the special sample.