IMPACT OF INSTABILITY IN µc-Si:H i-LAYERS ON THE PERFORMANCE OF SOLAR CELLS

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We investigate the instability phenomena in pin solar cells with a µc-Si:H i-layer deposited under conditions close to the transition to amorphous growth, resulting in compact material, and other cells containing a high crystalline volume fraction of material with a pronounced porosity. The cells were first annealed in vacuum at 160 °C and then treated in de-ionized water at 80 °C for different lengths of time, stored under ambient conditions and annealed again. We observed a strong degradation of the current-voltage (*J-V*) parameters after treatment in de-ionized water, for the cells with highly crystalline and porous i-layers, while cells with compact i-layer material show very little changes in their *J-V* parameters.

1. Introduction

Microcrystalline silicon (µc-Si:H) solar cells have recently undergone a rapid development, and great success has been achieved in improving their efficiency [1,2]. Their main advantage over amorphous silicon solar cells is their presumed stability against degradation under light soaking. However, it has been shown that the best material for solar cells is grown near the transition to amorphous growth, and contains some amorphous volume fraction. Recently, it has been demonstrated that highly efficient µc-Si:H solar cells grown by hot wire chemical vapour deposition (HWCVD) exhibit some degradation upon light soaking [2]. On the other hand, it has been known for some time that µc-Si:H, in particular for the case of high crystalline volume fractions, shows instabilities connected with in-diffusion and adsorption of chemical species.

The influence of atmospheric gas adsorption and/or oxidation on surface states, electronic transport and the density and charge state of defects in µc-Si:H was investigated in great detail in the early days of µc-Si:H research, by Vepřek *et al.* [3]. These phenomena are easily observed with infrared spectroscopy, conductivity measurements and electron spin resonance. Recent studies of adsorption or oxidation in µc-Si:H prepared by HWCVD or plasma-enhanced chemical vapour deposition (PECVD) revealed similar instability effects in the state-of-the-art material which is presently used in high efficiency solar cells [4,5]. Some of these reactions have been found to be reversible upon annealing, others not.

It is proposed that these instability phenomena are closely related to the porosity of the material, which is considerably more pronounced in highly crystalline µc-Si:H. Up to now, these problems have been addressed in detail mostly at the material level. An initial study of how these phenomena affect solar cells is presented in [6]. Such investigations are of great significance in connection with the application of thin film µc-Si:H solar cells. In this paper, we present some

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additional results concerning the comparative behaviour of cells deposited by HWCVD and PECVD, grown using different silane concentrations but treated under identical conditions.

2. Experimental details

Two types of μc-Si:H pin solar cells were used, in which the intrinsic absorber layer was prepared by either HWCVD or PECVD. The PECVD cells were deposited at 95 MHz. For the HWCVD system, we use a tantalum wire arrangement. The doped p- and n-layers were prepared with PECVD for both types of cell. In each group, there were cells prepared under conditions close to the transition to amorphous growth, resulting in compact material, and cells containing a high crystalline volume fraction material, with pronounced porosity. The variation of the absorber layer structure was obtained by variation of the silane concentration $SC=[SiH_4]/([SiH_4]+[H_2])$, defined as the ratio of the silane to hydrogen flow during the process. The structural composition of the intrinsic absorber layers was determined in terms of the Raman intensity ratio I_C^{RS} as a semi-quantitative measure of the crystalline volume fraction [6]. See Table 1 for details. The pin solar cells were deposited on 10×10 cm Corning 1737 glass substrates covered with ZnO TCO, and the individual cells were defined by 1 cm² back silver contacts.

Table 1. *J-V* parameters (efficiency *Eta*, open circuit voltage V_{OC}, fill factor *FF*, and short circuit current density J_{SC}) of μc-Si:H solar cells measured under AM 1.5 illumination before treatment in water. Also given are the silane concentration *SC* and the Raman intensity ratio I_c^{RS} for the i-layer. The solar cells with the HWCVD i-layer were deposited on textured ZnO, the solar cells with PECVD i-layers were deposited on smooth ZnO. This explains the difference in the J_{SC} values.

deposition	SC (%)	I_c^{RS} (%)	Eta (%)	V_{OC} (mV)	FF (%)	J_{SC} (mA/cm^2)
HWCVD	3	64	5.0	445	55	20.6
	6	37	6.7	540	63	19.8
PECVD	1	> 70	1.3	365	54	6.8
	2	≅ 70	3.9	462	66	12.7
	5	60	5.3	520	71	14.5

The cells were first annealed in vacuum at 160 °C, and then treated in de-ionized (DI) water at 80 °C for different lengths of time, stored under ambient conditions and annealed again. After each treatment, the current-voltage (*J-V*) characteristics of the cells were measured under illumination and in the dark. The presented results are the mean values for 5 equivalent cells with area 1 cm^2, deposited on the same substrate. The error bars in the figures correspond to the standard error of the measurement.

3. Results

The results of the measurements of the *J-V* parameters under illumination after various treatments are summarized in Figs. 1 and 2. The data are normalized to the initial values, so that the changes can be seen more clearly.

For the data displayed in Fig. 1, the initial absolute values were measured after annealing for 1h at 160 °C in vacuum. The results are given in Table 1. The samples were then treated in de-ionised water at 80 °C, and their *J-V* parameters measured under halogen lamp illumination after 1 h (DI1 in Fig. 1) and 7 h (DI7) and 11 h (DI11) of such treatment. There is a distinct difference between the behaviour of the samples deposited at higher and lower silane concentrations. The former exhibit only very small changes in the solar cell parameters upon the water treatment and annealing cycles (Fig. 1a). The sample deposited at low silane concentration (Fig. 1b), on the other hand, shows an almost 60% decrease in *Eta*, caused by a 8% decrease in V_{OC} and a 44% decrease in J_{SC}. Note the strong change of the cell performance within the first hour. These values are much

greater than the light induced degradation in µc-Si:H cells with a HWCVD i-layer grown near the transition to amorphous growth [2]. The recovery of the *J-V* parameters after the annealing in vacuum is only partial, but then the second oxidation cycle has a smaller effect than the first one. After the second cycle of water treatment, the samples were not annealed but were kept in ambient
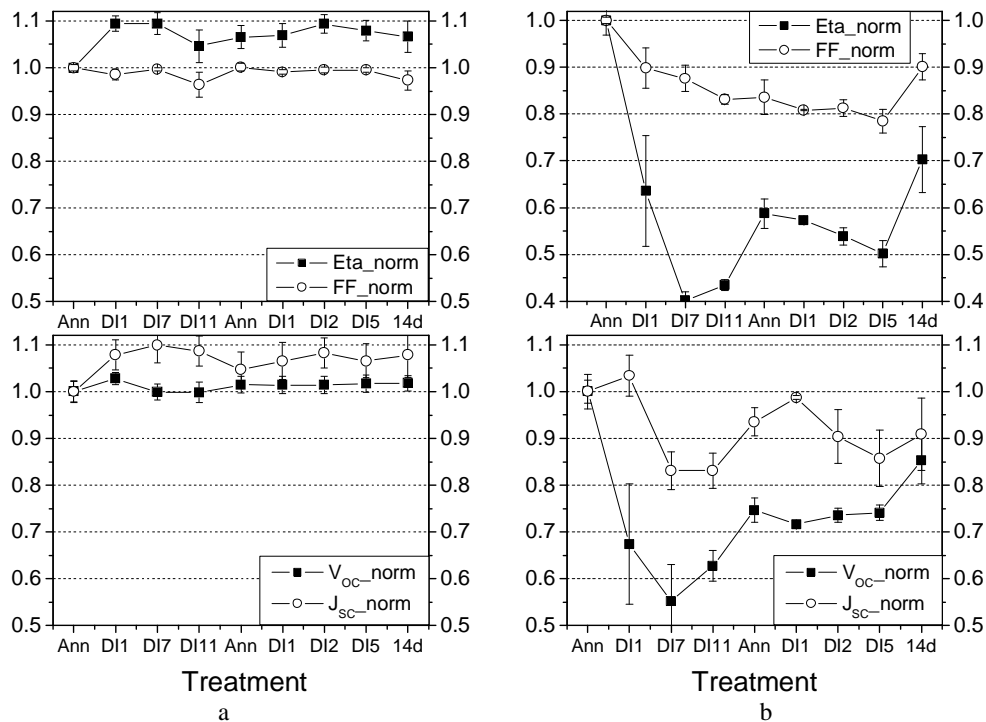

Fig. 1. Normalized *J-V* parameters (efficiency *Eta*, open circuit voltage V_{OC}, fill factor *FF*, and short circuit current density J_{SC}) under halogen lamp illumination of samples deposited by HWCVD with (a) 6% and (b) 3% silane concentration after different treatments: Ann – annealing at 160°C in vacuum, DI*n* – *n* hours in de-ionized water, 14d – 14 days in ambient conditions.

conditions for 14 days. After that, the *J-V* parameters improved similarly to the way they recovered after annealing, and even a little more for *FF*, V_{OC} and *Eta*.

Fig. 2 presents similar data for cells with a PECVD i-layer, deposited using different silane concentrations, and HWCVD cells deposited with 3% silane concentration, for comparison. Details of the deposition conditions, the initial *J-V* parameters and the crystalline volume fraction are given in Table 1. In this experiment, the samples were annealed in vacuum at 160 °C (Ann), then treated in DI water at 80 °C for 5 hours (DI5), then kept in air for 46 days (46d) and annealed again. The cycle then started again, but did not include a period of storage in air. The results are similar to those in Fig. 1. The cells with the more compact i-layer, deposited at a higher silane concentration, exhibit very little change in their *J-V* parameters. In contrast, the cells with the highly crystalline and more porous i-layer show a noticeable degradation. The treatment in ambient air produces no significant improvement, and annealing in vacuum is needed to restore the values of the parameters. The second cycle results in a similar drop of the parameters, but a third annealing almost restores them once again.

The data in Fig. 2 permit a comparison between the results of the treatment in DI water on cells deposited by PECVD and HWCVD and between PECVD highly crystalline cells deposited under different conditions. Several initial observations can be made. The overall behaviour of the two kinds of cell (PECVD and HWCVD) is similar – a degradation effect is observable almost exclusively in the highly crystalline cells. The extent of the degradation in efficiency is comparable in the studied highly crystalline cells. When the period of treatment in DI water is shorter (5 hours as compared to 11 hours in Fig. 1, annealing in vacuum recovers the initial parameters of the cell.
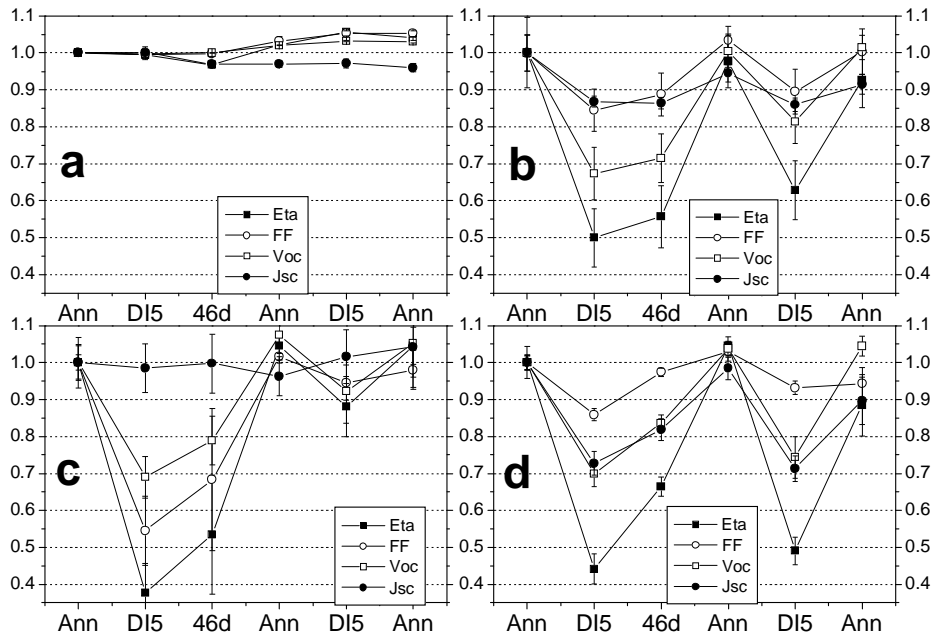
Fig. 2. Normalized *J-V* parameters (efficiency *Eta*, open circuit voltage V_{OC}, fill factor *FF*, and short circuit current density J_{SC}) under halogen lamp illumination of samples deposited by PECVD with (a) 5%, (b) 2%, (c) 1% silane concentration and (d) by HWCVD with 3% silane concentration after different treatments: Ann – annealing at 160 °C in vacuum, DI5 – 5 hours in de-ionized water at 80 °C, 46d – 46 days in ambient conditions.

4. Conclusions

We have studied the influence of metastabilities due to adsorption of atmospheric gases and oxidation on the performance of µc-Si:H solar cells. There is a clear correlation between the observed changes in the *J-V* parameters and the porosity of the i-layer material. This correlation has been observed for both HWCVD and PECVD cells. The changes in the *J-V* parameters show signs of saturation, and are partially or fully reversible. In view of the complexity of the systems, further careful study and correlation between experiments on µc-Si:H single films and corresponding solar cells are necessary, in order to clarify the nature of the processes taking place.

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