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# Instability phenomena in μc-Si:H solar cells prepared by hot-wire CVD

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## Abstract

We have investigated the various types of instability phenomena in μc-Si:H solar cells prepared by HWCVD 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.

It was found that light-induced degradation is most pronounced for material with some amorphous volume fraction while highly crystalline material is stable under illumination. On the other hand, we have observed a strong degradation of the current–voltage ($J$–$V$) parameters after treatment in de-ionized water of the cells with highly crystalline i-layers, while cells with compact i-layer material show very little changes.

*Keywords:* Solar cells; Hot-wire deposition; Light soaking; Instability phenomena

## 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]. The use of μc-Si:H in combination with amorphous silicon (a-Si:H) as absorber layers in tandem cells promises a considerable increase of the conversion efficiency of thin film silicon solar cells. Besides the enhanced absorption in the long wavelength region, the presumed stability against degradation under light soaking is one of the main advantages of μc-Si:H solar cells compared to amorphous silicon solar cells. However, it has been shown that the best μc-Si:H material for solar cells with exceptionally high open circuit voltages of up to 600 mV is grown near the transition to amorphous growth [1–3]. μc-Si:H solar cells show a typical behavior when varying the structure from highly crystalline to amorphous by variation of the silane concentration (SC), independent from the deposition technique. Starting at low SC values, $\eta$, FF and $j_{SC}$ increase with SC, reach a maximum and decrease at the highest SC while the $V_{OC}$ increases over the entire SC range. This behavior indicates a structure change from highly crystalline to amorphous in the absorber material. Raman measurements disclose some amorphous volume fraction in optimized solar cells with the highest efficiencies. In particular, solar cells prepared by HWCVD, which show high open circuit voltages up to 600 mV at high fill factors and efficiencies [2], contain amorphous volume fractions of more than 50% and thus might be subject to light induced degradation caused by the Staebler–Wronski effect.

On the other hand, it has been known for some time that μc-Si:H prepared by PECVD and HWCVD, in particular for the case of high crystalline volume fractions, shows instabilities connected with in-diffusion and adsorption of chemical species which affect the electronic conductivity and the charge state of defects [4–6]. Some of these reactions have been found to be reversible upon annealing, others not. Up to now these instability problems have been addressed in detail mainly at the material level [4–6] and an initial study on solar cells has been made [7].

In this paper, we compare the different kinds of degradation and instability phenomena for solar cells with i-layers deposited by HWCVD.

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## 2. Experimental details

Solar cells with different structural properties of the i-layer were used for the light-soaking and water-treatment experiments of this study. There were cells prepared under conditions close to the transition to amorphous growth, resulting in compact material, and cells containing high crystalline volume fraction material with pronounced porosity. The i-layers of the solar cells were prepared by HWCVD. As deposition feed gas, a mixture of silane ($SiH_4$) and hydrogen ($H_2$) at different silane concentrations SC ($[SiH_4]/[SiH_4+H_2]$) was used. The cells were deposited in a p–i–n deposition sequence onto a textured ZnO substrate, using a μc-Si:H p-layer, an a-Si:H n-layer, both prepared by PECVD and a sputtered ZnO/Ag back contact, defining the area (1 $cm^2$) of the individual cells. For structural analysis, Raman spectroscopy was carried out on the solar cells after removing the n-doped layer. The Raman intensity ratio $I_C^{RS}=(I_{520}+I_{500})/(I_{520}+I_{500}+I_{480})$ of the crystalline peaks (520 $cm^{-1}$ and 500 $cm^{-1}$) and the amorphous peak (480 $cm^{-1}$) was used as a semi-quantitative measure for the crystallinity [8].

The light-soaking experiments were carried out at open circuit at a temperature of 50 °C using an AM1.5-like spectrum with an intensity of 100 mW/$cm^2$.

For the water treatments, the cells were first annealed in vacuum or in dry air 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.

The solar cells were characterized by $J$–$V$ measurements in the dark and under AM1.5 illumination (100 mW/$cm^2$, class A simulator).

## 3. Results and discussion

### 3.1. Light soaking

Some details of the parameters of the cells subjected to light soaking are given in Table 1. The general trends of the light-soaking degradation of the studied cells are the following [2]. During the first 100 h of light soaking, only small degradation effects are observed and in some cases even a small increase of ç was found. After more than 100 h, all cells show a decrease of the solar cell efficiency $\eta$. The decrease of $\eta$ depends on the crystallinity of the i-layer material, with almost no degradation in the cell with the most crystalline i-layer and lowest $V_{OC}$ and a reduction up to 10% of the initial efficiency in the cells with low Raman intensity ratio $I_C^{RS}$ and high $V_{OC}$. No saturation is observed, even after more than 1000 h of light soaking. After annealing the solar cells at 160 °C for 1 h, they recover and in some cases a small improvement of the efficiencies occurs.

Table 1
Summary of some structural and electrical properties (silane concentration SC, Raman intensity ratio $I_C^{RS}$, thickness of the i-layer $d_{\langle i \rangle}$, open circuit voltage $V_{OC}$, efficiency $\eta$,) of the solar cells subjected to light soaking

| SC (%) | $I_C^{RS}$ | $d_{\langle i \rangle}$ (μm) | $V_{OC}$ (mV) | $\eta$ (%) | $\Delta\eta/\eta$ (%) |
|---|---|---|---|---|---|
| 4 | 0.65 | 1.0 | 518 | 7.6 | 1 |
| 5 | 0.5 | 1.0 | 548 | 8 | 2.6 |
| 5.6 | 0.38 | 1.0 | 562 | 7.4 | 3.3 |
| 5.2 | 0.38 | 1.2 | 571 | 8.1 | 6.6 |
| 5.1 | 0.32 | 1.1 | 568 | 8.4 | 9.9 |
| 5.1 | 0.33 | 1.6 | 559 | 8.7 | 7 |
| 4.9 | 0.38 | 0.8 | 565 | 8 | 7.1 |
| 5.6 | 0.29 | 0.85 | 580 | 8.1 | 5.5 |
| 5.6 | 0.25 | 0.85 | 600 | 8.5 | 7 |
| 5.6 | 0.35 | 1.0 | 585 | 8.9 | 9.2 |
| 5.6 | 0.35 | 1.9 | 568 | 8.7 | 5 |

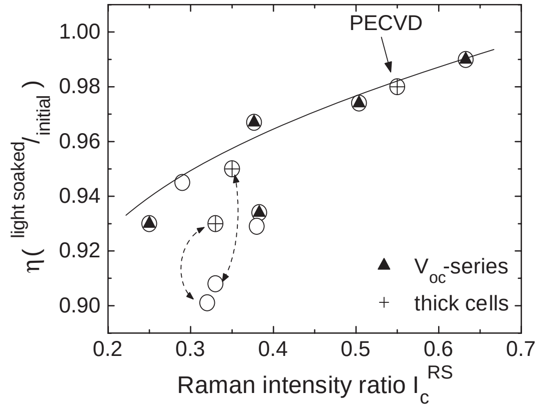

Fig. 1. Ratio of the solar cell efficiency after ≈1000 h of light soaking to the initial efficiency as a function of the Raman intensity ratio $I_C^{RS}$. Arrows indicate solar cells prepared with nominally identical conditions at i-layer deposition (e.g. same SC but different thickness).

Fig. 1 shows the ratio of the efficiency after ≈1000 h of light soaking to the initial efficiency as a function of the Raman intensity ratio $I_C^{RS}$. For the light-soaking experiments, solar cells with different open circuit voltages between 520 mV and 600 mV ($V_{OC}$ series [2]) and different i-layer thickness were chosen [9]. Additionally, a solar cell entirely prepared by PECVD [9] was light soaked. In spite of the large scatter of the individual cells, a clear decrease of the stability with increasing the amorphous fraction can be seen in the figure. This observation and the fact that the $J$–$V$ parameters recover after annealing the cells at 160 °C for 1 h suggests that Staebler–Wronski like defect generation in the amorphous phase is responsible for the light-induced degradation of the solar cells [9].

Table 2
$J$–$V$ 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 AM1.5 illumination before treatment in water

| SC (%) | $I_C^{RS}$ | $\eta$ (%) | $V_{OC}$ (mV) | FF (%) | $j_{SC}$ (mA/$cm^2$) |
|---|---|---|---|---|---|
| 3 | 0.64 | 5.0 | 445 | 55 | 20.6 |
| 6 | 0.37 | 6.7 | 540 | 63 | 19.8 |

Also given are silane concentration SC and the Raman intensity ratio $I_C^{RS}$ for the i-layer.