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Role of i layer deposition parameters on the V_{oc} and FF of an a-Si:H solar cell deposited by PECVD at 27.13 MHz

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Abstract

A study of the i-layer porosity as a function of the deposition parameters by PECVD technique, is presented here. It is demonstrated in particular, that for a fixed deposition rate of 2 Å/s, increasing the plasma power tends to increase the layer density, while increasing the pressure tends to increase the layer porosity. Regarding the cells, no correlation between the layer density and the initial cell performances is observed. On the contrary, the i-layer porosity seems to influence the cell degradation: High porosity of the i-layer leads to high degradation, which gives an easy tool to investigate the layer quality.

Keywords: PECVD; Porosity; FTIR; Ellipsometry; Degradation

1. Introduction

The i layer plays a key role in the p-i-n a-Si:H solar cell, not only because it is the active part of the cell where the carriers are generated, but also for economical reasons: With a typical thickness of 3000 Å, its deposition rate has a large impact on the manufacturing costs. High i-layer deposition rates are thus highly desirable, but increasing the deposition rate often leads to powder formation [1] and strong degradation of the cell by light soaking.

In a production environment, a typical deposition rate for amorphous solar cell by PECVD technique is 1–2 Å/s, and raising the deposition rate to 3 Å/s in a large-area reactor whilst at the same time keeping a good uniformity, a low powder formation, and a low SiH_4 consumption, is already a challenging objective. In addition to this, the cell degradation must be kept as low as possible. The process development becomes a really difficult task, because of two main reasons:

- First, the physical mechanisms by which the cell's performances and in particular its fill factor, drop during light soaking, are not fully understood.
- Second, experiments based on light-induced degradation are always time-consuming and must be based on statistics.

In the present study, we have tried to answer the following two specific questions in the context of increasing the deposition rate for the i layer of amorphous silicon solar cells from 2 to 3 Å/s:

- What is the effect of the different deposition parameters (pressure, power and SiH_4 concentration) on the intrinsic layer quality and on the cell's degradation?
- Can we find any link between i-layer properties and subsequent cell degradation, so as to be able to predict future cell degradation directly after i-layer deposition?

For our work, we have used a commercial KAI S plasma box, 35×45 cm, which was developed for the production of the TFT (thin-film transistor) active matrix as used in LCD flat panel displays. We have furthermore studied the effect of plasma power, process pressure, and SiH_4 concentration, at a constant deposition rate of 2 Å/s, on the i layer porosity, as well as on the values of V_{oc} and FF for corresponding complete pin-type solar cells, before and after light soaking.

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Table 1
Parameters levels for the DOE

	Low level	High level
Power (W)	30	100
Pressure (mbar)	0.2	0.6
SiH_4/H_2 (%)	20	60

2. Experimental

2.1. Deposition recipes

The first step of the experiment consisted in finding three deposition recipes, resulting in a constant deposition rate of 2 Å/s, but with different values of deposition parameters, plasma power, process pressure and silane concentration. A design of experiment (DOE) was used in order to determine the effect of plasma power, process pressure and silane concentration (silane to hydrogen dilution ratio), as well as their ‘interactions’ on the deposition rate, at a temperature of 200 °C. The process window was chosen as indicated in Table 1.

The process window was not chosen to be too wide, so as to prevent any risk of transition between the α regime and the γ' regime, and not chosen to be too narrow, so as to be able to see clearly the effect of the different parameters. Although the deposition rate was a non-linear function [2] of the parameters varied, inside this process window, it was possible to use the calculated effects to predict the values of power, pressure and silane dilution and thus obtain three parameters settings for a unique deposition rate of 2 Å/s. The three recipes found are summarised in Table 2.

It can be observed that in each recipe, one of the parameters is set at a high level, and the two other parameters are set at a low level, for a corresponding deposition rate close to 2 Å/s.

2.2. Layer characterisation

Using the three deposition recipes, three layers of thickness 2 μm were deposited on glass substrates and Si wafers, on top of a 350 Å thick sticking layer (SiC) to avoid peeling off of the layer. The thickness was measured with a profilometer alpha step 200.

The layer porosity was measured by two means:

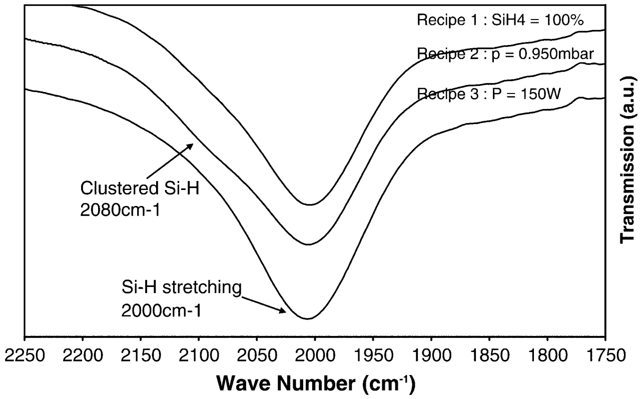

Fig. 1. FTIR spectra of the 2-μm thick i layers deposited on silicon wafers, using the three different recipes at 2.3 Å/s deposition rate.

–Spectroscopic ellipsometry on a UVISEL SPM ellipsometer from Jobin–Yvon
–FTIR spectroscopy on a Perkin Elmer 1720X system.

2.3. Cell deposition and characterisation

Three p-i-n diodes were deposited on commercial AFG SnO_2 substrates, in the KAI S single chamber system, the contamination from p to i layer being avoided by a patented process developed at the IMT and described elsewhere [3]. The same p and n amorphous layers were deposited for the three diodes (both layers deposited at 200 °C and 27 MHz). Only the i layer recipe was modified, one of the three recipes defined in the first section being used for each diode. The back contact consisted in a 1600-Å thick ITO layer underneath a 1000-Å thick aluminium layer. Both contact layers were sputtered in an MRC 603 SCHAETZ system through a shadowing mask consisting of a sheet-metal with 48 holes of 0.2 cm^2. The $I–V$ measurements have been performed on a Wacom WXS-140S-10 simulator.

3. Results

3.1. Layers

The FTIR spectra of the three layers are given in Fig. 1. The infrared absorption band located at 2000 cm^{-1}

Table 2
Deposition recipes found with their corresponding deposition rate

	SiH_4/H_2 (%)	Pressure (mbar)	Power (W)	Measured deposition rate (Å/s)
Recipe 1	100	0.3	65	2.3
Recipe 2	40	0.95	65	2.3
Recipe 3	40	0.3	150	2.2

Table 3
Microstructure parameter of the three i layers as measured by IR spectroscopy and deconvolution of peaks 2000 and 2080 cm^{-1}.

	Recipe 1	Recipe 2	Recipe 3
$R = I_{2080}/(I_{2080}+I_{2000})$	0.29	0.32	0.22

Table 4
Porosity of the three i layers as measured by ellipsometry (EMA technique)

	Recipe 1	Recipe 2	Recipe 3
Density (%)	90.4	89.3	91.4

corresponds to the stretching mode of the Si–H species [4]. A shoulder at 2080 cm^{-1} is generally attributed to SiH_2 stretching or SiH in internal surfaces [5]. The microstructure parameter R, reported in Table 3, is defined as the ratio of the peak areas, i.e. as $R = I_{2080}/(I_{2080}+I_{2000})$. R characterises the porosity of the layer and is obtained by deconvolution of the two peaks. The values obtained in Table 3 show that R is significantly lower for the layer deposited at a high plasma power (150 W, recipe 3), and that the layer deposited at the highest process pressure (0.95 mbar, recipe 2) has the highest R.

The porosity measured by ellipsometry using the EMA (effective medium approximation) technique gives the result as a volume percentage of dense amorphous silicon with respect to the total volume (volume of dense silicon + volume of voids). The measurements obtained by this technique and given in Table 4 are consistent with the FTIR measurements, and confirm that for a constant deposition rate of approximately 2 Å/s, the plasma power tends to increase the density and the process pressure tends to increase the porosity.

3.2. *Cell: initial performance*

For each i layer, eight cells of 0.2 cm^2 have been measured by I–V. The V_{oc} and FF are reported in Fig. 2 (the I_{sc}-value is not reported since it is strongly dependent on the back reflector which is not the object of this study).

For the three different recipes of i layer, the value of V_{oc} is between 850 and 870 mV. Thus, no significant effect of i layer deposition condition is observed on the value of V_{oc}.

The values for the FF are slightly different for three different recipes. A maximum value of 74% (median value for eight cells) was obtained for the recipe using pure SiH_4 and moderate pressure and power. A minimum value of 71% (median value for eight cells) has been obtained for the recipe using high power and moderate pressure and dilution. This recipe is also the only one having resulted in the peeling off of the i layer on glass, which is a indication of a high stress in the layer. This high stress and corresponding higher bombardment at the p/i interface might be the cause for the lower value of FF.

In general, neither initial V_{oc} nor initial FF appear to be correlated with the i layer. The different layers have no impact on the V_{oc}, and the layer having the highest density gives the cell with the lowest fill factor! In our series, porosity does not appear to be a relevant parameter for initial cell performance. This result is in contradiction with a previous result obtained by Guha et al. [6] which correlates the porosity of the i layer with the cell's initial efficiency.

3.3. *Cell: performance after degradation*

The cells have been degraded under the following conditions: AM1.5, 50 °C. The V_{oc} and fill factor have been measured after 304 h, 539 h, 754 h and 968 h,

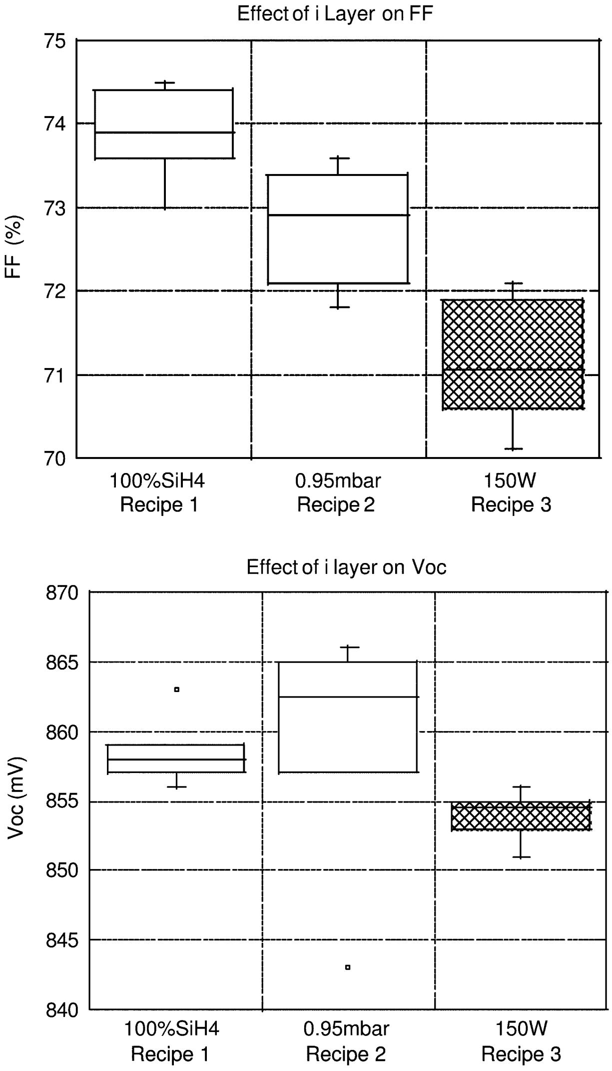

Fig. 2. Initial FF and V_{oc} for the different i layers deposition recipes.

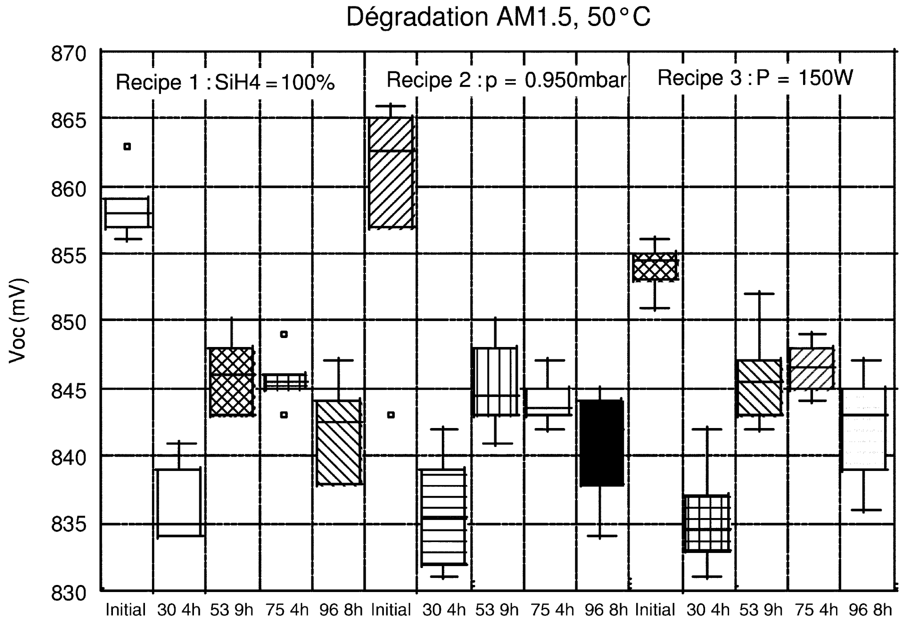

Fig. 3. Light soaking duration effect on V_{oc} for the different i layers.

and are reported, respectively, in Figs. 3 and 4. As expected, the cells degrade mainly during the first 300 h.

V_{oc} shows an unexpected behaviour since it decreases dramatically after 300 h, but increases again after 539 h and finally, decreases slowly until 968 h. This effect is an artefact, due to temperature variations in the measurement room, the value V_{oc} being highly sensitive to the measurement temperature.

Final degradation of V_{oc} is the lowest (1.42% relative) for the layer deposited at 150 W (recipe 3) and it is the highest (2.22% relative) for the layer deposited at 0.950 mbar (recipe 2).

The same tendency is observed for *FF*: The cell deposited with recipe 3 (150 W) shows a mean relative degradation of only 13.6%, and the cell deposited with recipe 2 (0.950 mbar) shows a mean relative degradation of 17.2%.

In Fig. 5 we have plotted the degradation of V_{oc} and *FF* as a function of the i-layer density as measured by ellipsometry. Although the number of points is still a bit low, it clearly transpires that there is a relation between

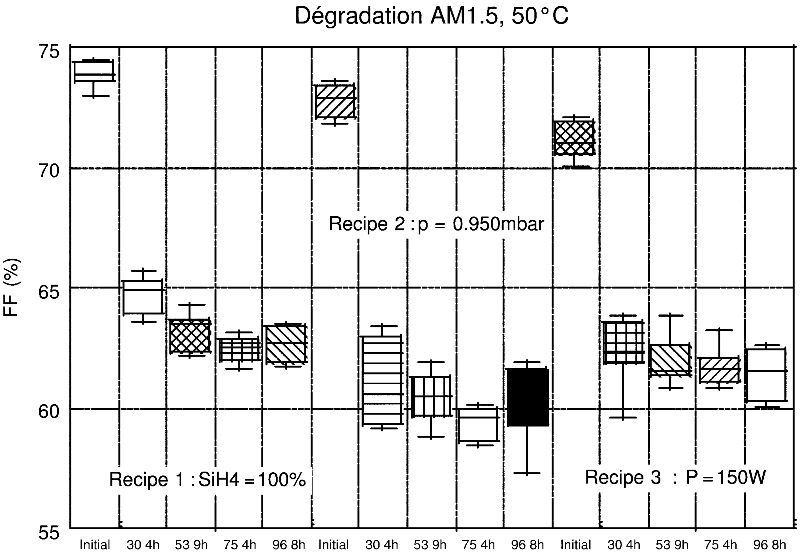

Fig. 4. Light soaking duration effect on *FF* for the different i layers.

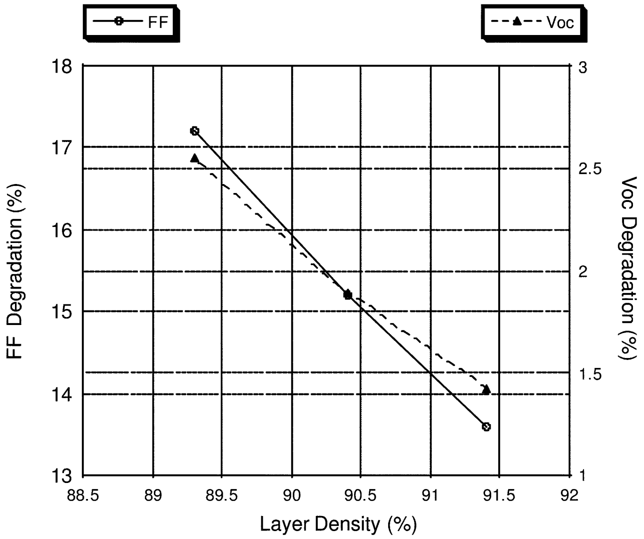

Fig. 5. Effect of i layer density as measured by ellipsometry on relative V_{oc} and *FF* degradation.

the i layer porosity and the cell degradation: Cell degradation is more pronounced if the i-layer porosity is high, and this, for a fixed deposition rate of 2 Å/s.

4. Conclusion

For a fixed deposition rate of 2 Å/s, different i layer recipes have been developed with the help of a DOE. Intrinsic amorphous layers have been deposited and characterised, and from this first part of the experiment, one can draw an important conclusion:

The porosity of the i layer depends on the deposition conditions – At a fixed deposition rate of 2 Å/s, increasing the power tends to increase the density, while increasing the pressure tends to increase the porosity. Moreover, increasing the SiH_4 dilution does not lead to a better density of the layer [7].

Regarding the cells, the characterization before degradation shows that (in our specific case) the cell performances (V_{oc} and *FF*) do not depend on the i layer density.

However, cell degradation can clearly be seen to be linked to the porosity of the i-layer; which gives us a quick and easy tool to predict future cell degradation from i-layer quality. However, before generalizing this criterion a more complete study should be performed in order to widen the range of the layer densities studied.

Regarding our goal of obtaining a higher deposition rate of 3 Å/s, the difficulty is to increase the deposition rate, while keeping a high layer density (more than 90.5% as measured by ellipsometry), so as to ensure that degradation remains within reasonable limits.

According to first conclusions, this can be done by keeping the pressure low and increasing the power. However, increasing the power decreases the initial *FF*, which means that a compromise has to be found in order to optimise the i layer without degrading the initial cell performances.

Acknowledgments

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