

A-SiO:H THIN FILMS WITH INCREASED LIGHT INDUCED DEGRADATION STABILITY FOR THIN FILM SILICON SOLAR CELLS

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ABSTRACT: Silicon based multi-junction thin film solar cells suffer from light-induced degradation (LID) due to the Staebler-Wronski effect. The top-absorber in such a cell is usually made out of intrinsic amorphous silicon (i)a-Si:H which suffers most from LID. Intrinsic amorphous silicon oxide (i)a-SiO:H promises an increased LID stability. We deposited (i)a-SiO:H absorber layers with different ratios of CO₂/SiH₄ by radio frequency plasma enhanced chemical vapour deposition (RF-PECVD). The (i)a-SiO:H absorber layers were characterized regarding to their electrical and optical properties. The defect density N_d has been determined by the constant photocurrent method (CPM). It was found that (i)a-SiO:H has an increased LID stability compared to a-Si:H. The measurement results were then transferred into the simulation software Advanced Semiconductor Analysis (ASA). We carried out simulations for the initial and light soaked state of solar cells with a reference (i)a-Si:H absorber layer and the new (i)a-SiO:H absorber layer. The cells showed after light soaking nearly equal efficiency.

Keywords: a-SiO:H, Amorphous Silicon, Multijunction Solar Cell, Thin Film Solar Cell

1 INTRODUCTION

To increase the efficiency of stacked silicon thin film solar cells it is necessary to overcome the problem of LID [1]. One approach is to develop new absorber materials with better LID stability. A promising absorber material is a-SiO:H, because it shows less LID due to the Staebler-Wronski effect [2], while having a higher bandgap than a-Si:H [3].

For further increase in the efficiency of stacked silicon thin film solar cells one needs to use a wide bandgap absorber material in the top cell of the layer stack. A wider bandgap of the absorber increases the open-circuit voltage V_{oc} of the cell [4]. Simulations done by Yunaz et al. [5] showed that only a top-cell with at least a bandgap of 2.0 eV would provide high enough V_{oc} values for efficiencies of over 20% in a triple-junction silicon thin film solar cell.

These triple-junction cells including an a-SiO:H top cell reach stabilized efficiencies close to 12% on laboratory scale [6].

2 EXPERIMENTAL DETAILS

We deposited (i)a-SiO:H films on Schott AF32 eco glass substrate (100x100x1.1 mm) by RF-PECVD at 13.56 MHz. We used SiH₄, H₂ and CO₂ as process gases. We evacuated the process chamber to a base pressure of ~ 5 x 10⁻⁸ mbar before starting the deposition processes. The deposition conditions are listed in table 1.

Table I: Deposition conditions of (i)a-SiO:H films

Paramter	Value	Unit
Substrate temperature T	195	°C
Deposition pressure p	0.5	mbar
Power density P	15	mW/cm ²
SiH ₄ flow r _x	210	sccm
H ₂ flow r _y	1050	sccm
CO ₂ flow r _z	21-252	sccm

The film thickness was kept constant at 300 nm and was measured by reflectometry and spectroscopic ellipsometry. The spectroscopic ellipsometry data (J.A. Woollam, M2000) were fitted with a Tauc-Lorentz model [7] using the WVASE software. The Tauc bandgap E_{g,Tauc} [8] was determined from Varian Carry 500 spectrophotometer data for transmission and reflectance in the UV-VIS range.

The defect density N_d and Urbach energy E_u [9] were determined by constant photocurrent method (CPM) [10]. The defect density N_d was calculated from CPM measurements using the “absorption coefficient at a single energy” method [11].

The thin films were light soaked for totally 100 hours with 100 mW/cm² by a SOL2 solar simulator from Dr. Hönle AG to investigate the metastable changes related to the Staebler-Wronski effect. During the degradation the temperature was kept constant at 25 °C.

The defect density was recorded by CPM at different stages of degradation. Before the degradation experiment the samples were annealed in air at 160 °C for 30 minutes to set up an initial state.

At last we transferred the recorded measurement values before and after degradation of the (i)a-SiO:H absorber layer with the highest bandgap (r_c = 1.2) and the reference (i)a-Si:H absorber layer into the simulation software “Advanced Semiconductor Analysis” (ASA) [12] and simulated a single junction solar cell with the layer stack shown in fig. 1.

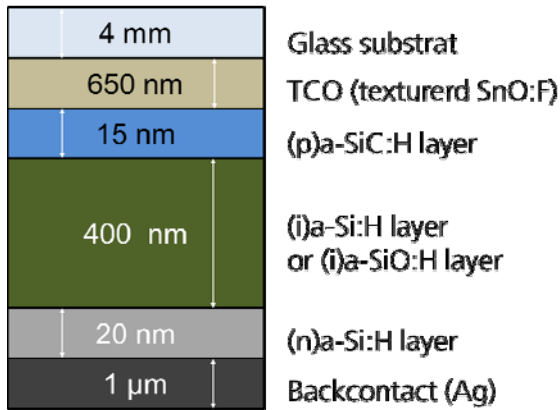


Figure 1: Layer stack for the ASA simulations

3 MEASUREMENT RESULTS

3.1 Optical properties of (i)a-SiO:H absorber layers

Fig. 2 shows the dependency on the bandgap $E_{g,Tauc}$ of the ratio r_c . It was observed that the bandgap increases linearly with the CO_2/SiH_4 ratio r_c . The bandgap increased from $E_{g,Tauc} = 1.78$ eV for the reference (i)a-Si:H layer to $E_{g,Tauc} = 1.91$ eV for the (i)a-SiO:H layer with $r_c = 1.2$.

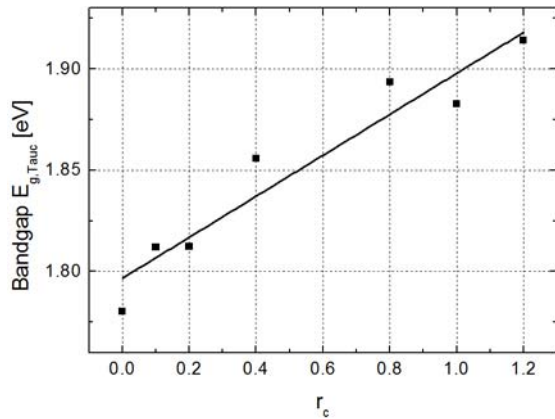


Figure 2: Variation of bandgap $E_{g,Tauc}$ with r_c

The optical constants (n, k) were derived from the spectroscopic ellipsometry measurement data. Fig. 3 shows exemplary the measurement data of the optical constants for the (i)a-Si:H reference layer and two (i)a-SiO:H layers with $r_c = 0.4$ and $r_c = 1.2$. The reference layer showed the highest refraction index n and also the highest extinction coefficient k . By increasing the CO_2/SiH_4 ratio the optical constants of the (i)a-SiO:H layer were lowered.

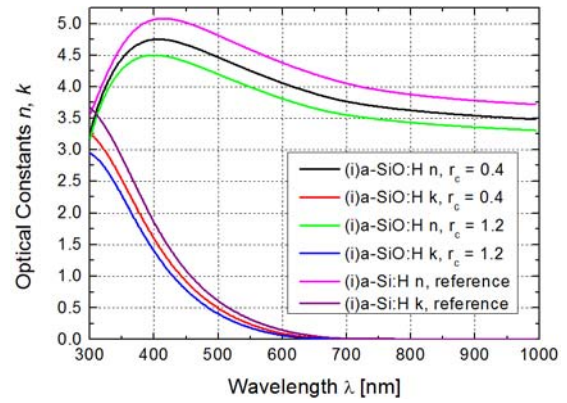


Figure 3: Optical constants for different r_c values

3.2 Defect characterization of (i)a-SiO:H thin films

The obtained CPM spectra for various (i)a-SiO:H films with increasing r_c are plotted in Fig. 4. Because of the increasing bandgap the CPM spectra are shifted to lower energies for the layers with higher bandgaps. We also observe a decrease of steepness of the linear part of the curves with higher ratios of r_c . This means that the Urbach energy increases and the density of states (DOS) for the extended tail states also increases. One can see that the values for the absorption coefficient α at the characteristic energy of 1.2 eV, where one can read the defect density N_d , increase. This means that the defect density N_d for the layers with higher ratios of r_c increases.

This behavior is confirmed by dark con

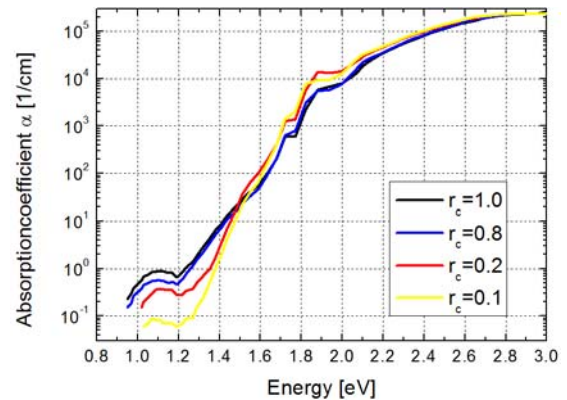


Figure 4: CPM spectra for various (i)a-SiO:H films with increasing r_c

Fig. 5 displays the effect of the increasing ratio r_c on the Urbach energy E_u . The Urbach energy E_u shows a linear dependency on the CO_2/SiH_4 ratio r_c . A higher Urbach energy indicates less sharp band edges which results in a poorer material quality.

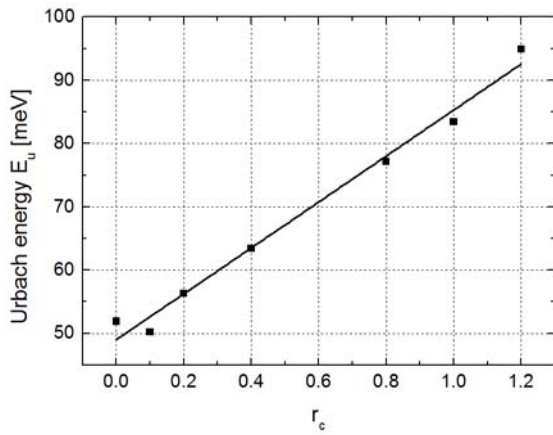


Figure 5: Urbach energy as a function of r_c

As can be seen from Fig. 6 the defect density N_d increases with higher r_c ratios. The defect density for the reference (i)a-Si:H sample was $N_d = 1.04 \times 10^{15} \text{ cm}^{-3}$. For the (i)a-SiO:H film with $r_c = 1.2$ the defect density reached $N_d = 2.65 \times 10^{16} \text{ cm}^{-3}$.

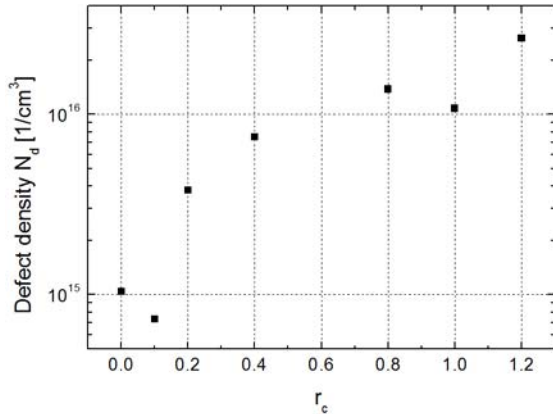


Figure 6: Variation of defect density N_d with r_c

3.3 Light induced degradation in (i)a-SiO:H thin films

The changes of the defect density N_d for different values of light soaking time in dependency of r_c were investigated and are shown in Fig. 7.

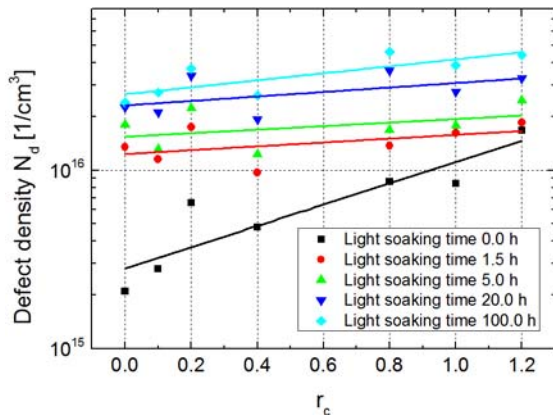


Figure 7: Variation of defect density N_d for different light soaking times with increasing r_c

The (i)a-SiO:H layers show a smaller increase in the defect density N_d with the time than the reference (i)a-Si:H layer. The reference (i)a-Si:H absorber layer showed an

increase in the defect density of a factor of 11.4 after 100 h of light soaking, while the (i)a-SiO:H layer with the highest r_c showed an increase of defect density N_d of a factor of 2.6. This means that the (i)a-SiO:H layers are less sensitive to light induced degradation related to their higher initial defect density N_d . The results are summarized in table 2.

Table II: Defect density N_d quotients after degradation for different CO_2/SiH_4 ratios r_c

CO_2/SiH_4 (r_c)	N_d 100 h light soaked / N_d initial
0.0	11.4
0.1	9.7
0.2	5.7
0.4	5.5
0.8	5.4
1.0	4.6
1.2	2.6

4 SIMULATION RESULTS

Fig. 8 shows the IV-curves for a single junction solar cell with an (i)a-SiO:H absorber layer ($r_c = 1.2$) and for a cell with the reference (i)a-Si:H absorber for the initial state and after 100 h of light soaking

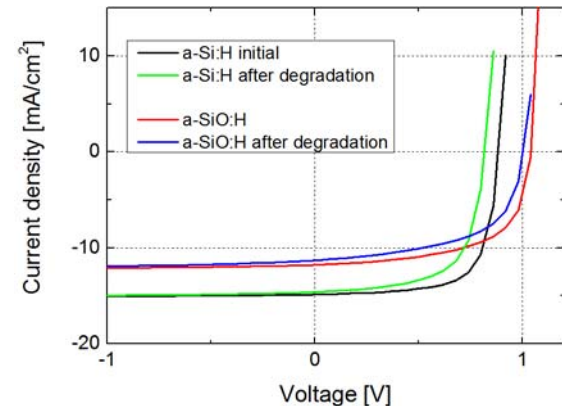


Figure 8: IV-curves for (i)a-SiO:H absorber layer and reference (i)a-Si:H absorber for the initial and degraded state

Both cell types show a loss of V_{oc} and fill factor after degradation, whereas the current density remains unchanged. The loss in fill factor for the cell with the reference (i)a-Si:H absorber layer is higher. The reference cell shows a LID of 20.7%, while the (i)a-SiO:H cells has 15% of LID. The simulated cell results are summarized in table 3.

Table III: Cell results for cells with (i)a-SiO:H and (i)a-Si:H absorber layers

	a-SiO:H initial / degraded	a-Si:H initial / degraded
V_{oc} (V)	1.041 / 1.000	0.882 / 0.816
J_{sc} (mA/cm^2)	11.77 / 11.31	14.86 / 14.61
Fill factor (%)	62.1 / 58.45	71.3 / 64.87
Efficiency (%)	7.6 / 6.61	9.34 / 7.74
LID loss (%)	14.98	20.67

5 SUMMARY

We deposited (i)a-SiO:H absorber layers with different ratios of $r_c = \text{CO}_2/\text{SiH}_4$. We observed a linear increase of the bandgap for higher r_c ratios, but also an increase of the Urbach energy E_u and the defect density N_d in comparison to the reference (i)a-Si:H absorber layer. After 100 h of light soaking the (i)-SiO:H layer showed less LID in comparison to the reference (i)a-Si:H layer. Simulations of a standard a-Si:H PIN solar cell and a a-SiO:H PIN cell using the ASA software reveal a difference in the LID of 5.7 %.

6 ACKNOWLEDGEMENT

This work was supported by the European Union – European Fond for regional development “Investments for the Future” and the government of Northrhine-Westphalia under contract number 64.65.69-EN-2001A (ALPS).

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