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Enhanced recovery of light-induced degradation on the micromorph solar cells by reverse bias

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Abstract. The recovery of light-induced degradation of the tandem micromorph solar cells by applying reverse bias is compared with the single junction a-Si solar cells for the first time. The illuminated current density-voltage characteristics and external quantum efficiency show that the degraded efficiency of both the micromorph and a-Si solar cells can be recovered by applying sufficient reverse bias. The micromorph solar cells can be recovered with smaller reverse bias as compared with a-Si solar cells. The simulation and experimental results show that higher hydrogen concentration in the bottom cell of the micromorph solar cells can help accelerate the recovery process.

Key words

micromorph solar cell, light-induced degradation, reverse bias, recovery

1. Introduction

The micromorph solar cells consisting of microcrystalline silicon (μc-Si) bottom cell and amorphous silicon (a-Si) top cell are considered to be one of the most promising thin film solar cells[1]. Their tandem structure has contributed to the high cell efficiency. Also, the μc-Si cell shows high stability against light-induced degradation[2-4]. However, the a-Si top cell of the micromorph solar cell is influenced by the Staebler-Wronski Effect (SWE) [5] where the photoconductivity of hydrogenated amorphous silicon (a-Si:H) degrades after light illumination [5]. This degradation is due to the generation of extra silicon dangling bonds in a-Si:H after prolonged illumination. The dangling bonds act as recombination centers and thus reducing the photo current [6]. Previous studies had reported that the light-induced degradation of a-Si:H solar cells can be recovered by applying strong reverse bias [7-8]. In this paper, the degradation caused by light soaking and the recovery by applying reverse bias of both tandem micromorph and single junction a-Si solar cells are investigated.

2. Experiment

The device structure of the micromorph and the a-Si solar cells were glass/SnO_2/a-Si/SiOx/μc-Si/TCO/Ag and glass/SnO_2/a-Si/TCO/Ag, respectively. The micromorph solar cell which is a combination of a μc-Si bottom cell with the thickness of ~1.8 μm and an a-Si top cell with the thickness of ~320 nm, and the thickness of the single junction a-Si solar cell is ~320 nm. Front transparent conducting oxide (TCO) layer is engineered to improve light transmittance and light scattering. SnO_2 is used as the front TCO layer. The insertion of SiO_x as an intermediate reflector between the a-Si:H cell and the μc-Si cell will increase the J_{sc} of the top cell and in the meanwhile reduces SWE. The function of the back TCO layer is to improve adhesion and to enhance the reflectivity of the back reflector. The initial efficiency of the micromorph solar cells used in this work was around 10.1~10.5 % with an open circuit voltage (V_{oc}) of 1.15~1.31 V, a short circuit current density (J_{sc}) of 11.6~12.1 mA/cm^2, and a fill factor (F.F.) of 68~73 %. The initial efficiency of the single junction a-Si solar cells used in this work was around 9.8 % with an V_{oc} of 0.91 V, a J_{sc} of 14.7 mA/cm^2, and a F.F. of 74 %. For all experiments in this work, the light-induced degradation was stabilized after at least 5 days at AM1.5 exposure under the open-circuit condition. In order to prevent the temperature recovery effect, the cell temperature was controlled at not higher than 40 ^oC.

Stabilized degraded efficiency is reached after at least 5 days of light soaking, which then different reverse bias was applied to the cells at 1 sun illumination for 30 minutes for the recovery process.

3. Results and Discussion

Fig. 1 shows the illuminated J-V characteristics of the micromorph and single junction a-Si solar cells after light soaking and recovery by applying reverse bias. After light soaking, the efficiency of the micromorph solar cell degrades 9.9 % and the one of the a-Si solar cell degrades 17.4 %. The degradation is due to more Si dangling bonds generated after light soaking. Previous literature reports that the light-induced degradation of a-Si:H solar cells can be recovered by applying strong reverse bias [7-8]. By applying the reverse bias, the protons move toward the p-layer of the top cell and then reacts with a Si dangling bond and a photo-generated electron to form a Si-H bond. The light illumination is to provide the electron for the formation of Si-H bond and the hole for dissociation of hydrogen. The efficiency is recovered when the density of Si dangling bonds decreases. After applying -1 V for 30 minutes with 1 sun illumination, the efficiency recovery of the micromorph solar cell is 64 %, and the one of the a-Si solar cell is 13.9 % after applying -2V for 30 minutes. Efficiency recovery is as defined by the following equation:

$$\text{Efficiency recovery} = \frac{\eta_r - \eta_d}{\eta_i - \eta_d} \qquad (1)$$

Where η_r, η_d and η_i are the efficiency after recovery, the degraded efficiency, and the original efficiency.

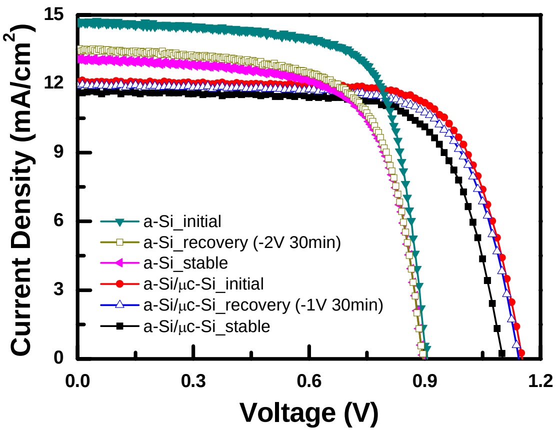


Fig. 1. The illuminated J-V characteristics of the micromorph and a-Si solar cells after light soaking and the recovery by applying reverse bias.

The EQE after light soaking and the recovery by applying reverse bias of the micromorph and a-Si solar cells are shown in Fig. 2. For the micromorph solar cell, the degradation only occurs in the a-Si top cell and the EQE of μc-Si bottom cells show very minimal light-induced degradation because it only perceive red light. Red light with photon energy smaller than the band gap of the amorphous phase in μc-Si material is only absorbed in the crystalline phase, where light-induced degradation will not happen. The inset is the EQE of the a-Si solar cell after light soaking and recovery by applying -2 V reverse bias with 1 sun illumination. The EQE degrades from 0.82 to 0.75 at the wavelength of 525 nm after light soaking and recovered back to 0.77 after applying reverse bias of -2 V for 30 minutes. Fig. 3 shows efficiency recovery vs. reverse bias voltage of micromorph and a-Si solar cells. For the higher reverse bias, protons can move faster to react with Si dangling bonds at larger electric field. Hence, efficiency recovery increases with field strength. It should be noticed that the required reverse bias to recover for both of the micromorph and a-Si solar cells are different. For the thicker thickness (~2120 nm) of the micromorph solar cell, larger reverse should be applied to activate the protons drift to the Si dangling bonds. The micromorph solar cell can be recovered after -0.6 V application. However, the a-Si solar cell needs higher reverse bias (> -2 V) than the micromorph solar cell. It indicates that it might have other factors to influence recovery mechanism.

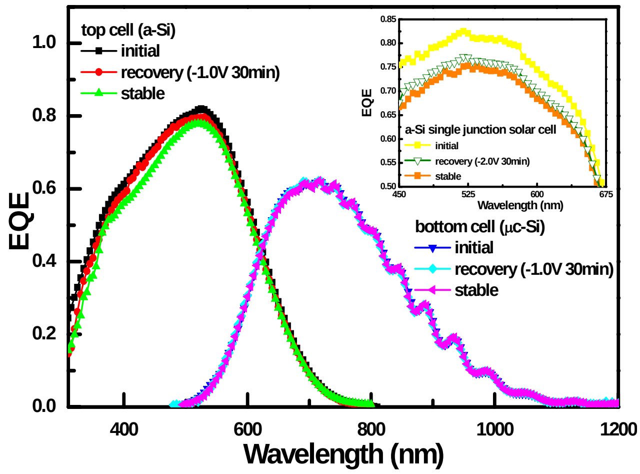


Fig. 2. The EQE of the micromorph solar cell after light soaking and the recovery by applying reverse bias. Only the a-Si top cell of the micromorph solar cell is degraded after light soaking. The inset is the EQE of single junction a-Si cell at wavelength from 450 to 675 nm, and the EQE is recovered after bias application.

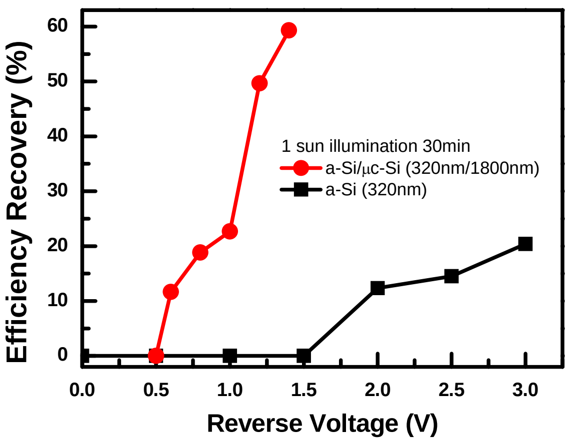


Fig. 3. The efficiency recovery vs. reverse bias voltage. The efficiency recovery increases with the increasing field strength. The micromorph can be recovered with smaller

reverse bias (-0.6 ~ -1.5 V) as compared with the a-Si solar cells (-2 ~ -3 V).

Fig. 4 (a) shows the simulated electric field profile of single junction a-Si solar cell with reverse bias of -2 to -3 V. The electric field increases with the reverse bias. Protons can move faster to passivate with the Si dangling bond under larger electric field. For the micromorph solar cell, the electric field is nearly the same on the top cell (a-Si) under different reverse bias, and the electric field most drops on the bottom cell (μc-Si) (shown in Fig. 4 (b)). It means the velocity of the protons in the a-Si cell of the micromorph solar cell does not increased under larger electric field. The electric field increases with the reverse bias on the bottom cell, the protons in the bottom cell can drift easier to the top cell, and the dangling bonds can be passivated. Note that the electric field varies with the reverse bias only in the μc-Si bottom cell because the current is bottom-limited.

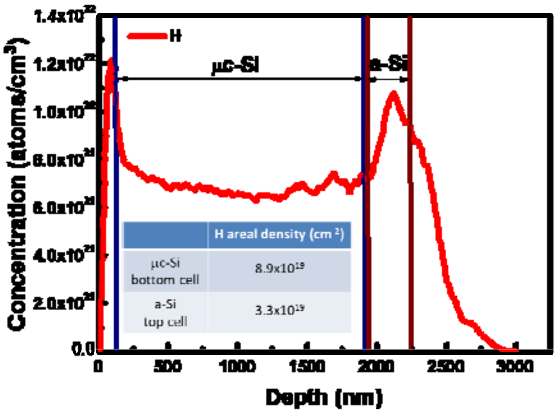
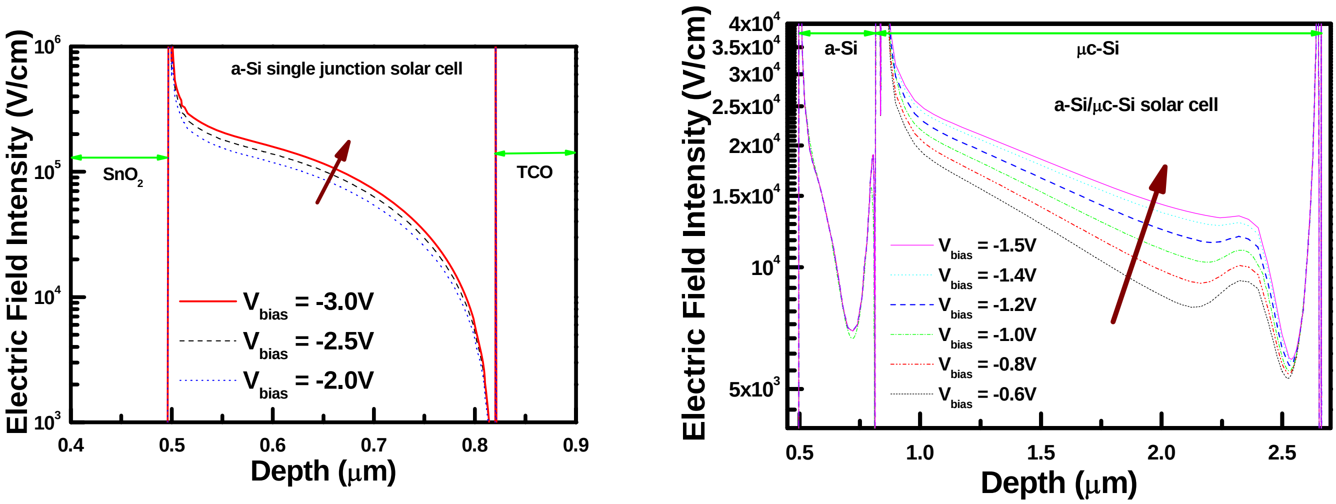


Fig. 5. The SIMS profile of the micromorph solar cell. The hydrogen concentration in the bottom cell (~8.9x10^{19} /cm^2) is higher than the top cell (~3.3x10^{19}/cm^2). It provides the evidence that the proton might drift to the top cell due to the higher hydrogen concentration with larger electric field.



(a) (b)

Fig. 4. The simulation of the electric field distribution of the (a) single junction and (b) the micromorph solar cells. (a) The electric field on the a-Si solar cell increases with the reverse bias. The defects can be passivated easily by the protons with higher reverse bias. (b) The electric field on the top cell of the micromorph solar cell almost not varied. The electric field most drops on the bottom cell of the micromorph solar cell. And the protons in the bottom cell might drift to the top cell due to higher electric field.

Fig. 5 shows the secondary ion mass spectrometry (SIMS) profile of the micromorph solar cell. The hydrogen atoms in the bottom cell of the micromorph solar cell are 8.9x10^{19} /cm^2, which is higher than the one of the top cell (3.3x10^{19}/cm^2). It proves that the protons in the bottom cell might drift to the top cell and then passivate with the Si dangling bonds under higher electric field.

4. Conclusion

Micromorph solar cells' recovery behavior after light-induced degradation was studied under various electrical bias and also compared with the single junction a-Si solar cells. The experimental results show that efficiency recovery increases with the field strength. The required reverse bias for the micromorph solar cell is less than the a-Si solar cell. The SIMS profile shows the hydrogen concentration in the bottom cell of the micromorph solar cell is higher than the top cell. The protons in the bottom cell of the micromorph solar cell might drift to the top cell under higher electric field.

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