

Suppression of Thermal Degradation in Perovskite Solar Cells by Robust Encapsulation

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Abstract

We investigated thermal stability in perovskite solar cells under the temperature of 85 °C with two types of encapsulations. The degradation in the device with robust encapsulation was found to be suppressed, when the power conversion efficiencies (PCEs) of the device were remained 88% of its initial value during 750 h storage at 85 °C, because of the suppression of the degradation in perovskite photoactive layer and the hole transporting layer.

1. Introduction

Perovskite solar cells have received considerable attention because of the remarkable progress in their PCEs [1-3]. The high PCE was achieved by long diffusion length in perovskites of more than 1 μm , leading to an open-circuit voltage (V_{oc}) of upper 1 V [4]. A perovskite solar cell with interfacial engineering for carrier injection showed the best PCE of 19.3% [5]. (Reported PCEs for perovskite solar cells could be obtained to access the National Renewable Energy Laboratory web site [6].

Furthermore, perovskite solar cells can be easily fabricated by solution processing, leading to low-cost and high-efficiency solar cells.

However, perovskite solar cells have a challenge in terms of durability, which should be resolved for outdoor applications [7-10].

Here, we focus on the thermal degradation in perovskite solar cells and propose the device structure for suppression of the degradation.

2. Experiment

Fabrications of Perovskite Solar Cells

Perovskite solar cells were fabricated with the two-step spin-coating method [9]. The scheme of this method is described in Figure 1. A mesoporous TiO_2 (mp- TiO_2) / compact TiO_2 (c- TiO_2) / fluorine-doped SnO_2 (FTO) substrate was prepared by spin-coating a TiO_2 nano-dispersion (~ 10 nm in diameter) on a commercial c- TiO_2 / FTO substrate. This mp- TiO_2 layer was sintered at 500 °C for 45 min. A lead iodide (PbI_2) layer was deposited on the mp- TiO_2 layer by spin-coating of solution of PbI_2 in N,N -dimethylformamide at 6500 r.p.m. for 5 s. The PbI_2 film was annealed at 130 °C for 30 min. A solution of $\text{CH}_3\text{NH}_3\text{I}$ in 2-propanol was drop-cast onto the PbI_2 film and followed by spin-coating at 2000 r.p.m. for 30 s to remove the excess of $\text{CH}_3\text{NH}_3\text{I}$. The perovskite layer ($\text{CH}_3\text{NH}_3\text{PbI}_3$)

was formed as a black film by annealing the $\text{PbI}_2/\text{CH}_3\text{NH}_3\text{I}$ at 130 °C for 30 min. The hole-transporting material was deposited by spin-coating on $\text{CH}_3\text{NH}_3\text{PbI}_3/\text{mp-TiO}_2/\text{c-TiO}_2/\text{FTO}$ substrate at 4000 r.p.m. for 30 s. The spin-coating solution was prepared by dissolving spiro-OMeTAD, lithium bis(trifluoromethanesulfonyl)imide and 4-*tert*-butylpyridine in chlorobenzene. A vapor-deposited gold film was formed as cathode with the thickness of 100 nm.

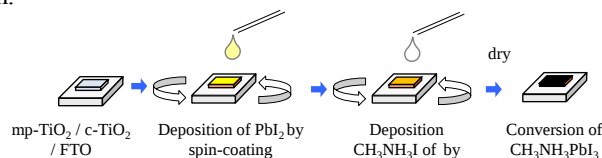


Fig. 1 Schematic images of the two-step spin-coating method.

The devices were encapsulated with two different ways. One device was encapsulated robustly with ultraviolet cured resin (device A). The other device was simply sealed with thermoplastic resin (device B).

Photovoltaic Properties

Figure 2 shows the J - V curve for a perovskite solar cells encapsulated with two different ways, measured in reverse (from V_{oc} to the short-circuit current density (J_{sc})) at a simulated AM 1.5 G solar irradiation of 100 mW cm^{-2} . The device A exhibited $J_{\text{sc}} = 18.4 \text{ mA cm}^{-2}$, $V_{\text{oc}} = 0.974 \text{ V}$, Fill Factor (FF) = 0.572, corresponding to PCE = 10.2%, whereas the device B showed $J_{\text{sc}} = 17.6 \text{ mA cm}^{-2}$, $V_{\text{oc}} = 0.962 \text{ V}$, FF = 0.580, yielding PCE = 9.8%. It is suspected that the initial PCEs were not influenced by types of encapsulation.

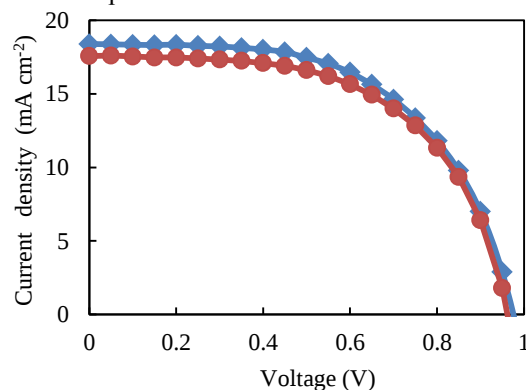


Fig. 2 J - V characteristics of photovoltaic devices with different encapsulation (blue diamond: device A, red circle: device B).

Heating Test

The devices were applied to heating test under the temperature of 85 °C. Figure 3 shows the PCEs of two kinds of devices as a function of storage time. We found the different behaviors on the degradation curves of two devices. The PCE of the device A remained high, resulting in only 12% reduction of its initial value during 750 h storage. On the other hands, the device B was gradually degraded, which retained only 30% of its initial value.

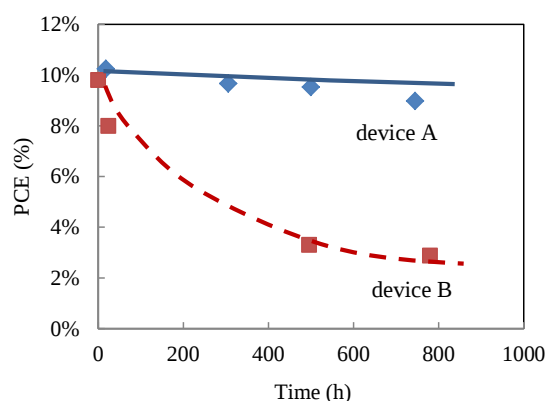


Fig. 3 Characteristics of perovskite solar cells as a function of storage time at 85 °C.

In order to clarify the cause of degradation, we analyzed the change of crystal structure by X-ray diffraction (XRD) and measured the conductivities of a spiro-OMeTAD layer by four-terminal sensing technique.

The XRD peaks of perovskite ($\text{CH}_3\text{NH}_3\text{PbI}_3$) with device A were remained after heating for 500 h at 85 °C as shown in Figure 4. However, the XRD peaks of perovskite with device B were disappeared under the same condition.

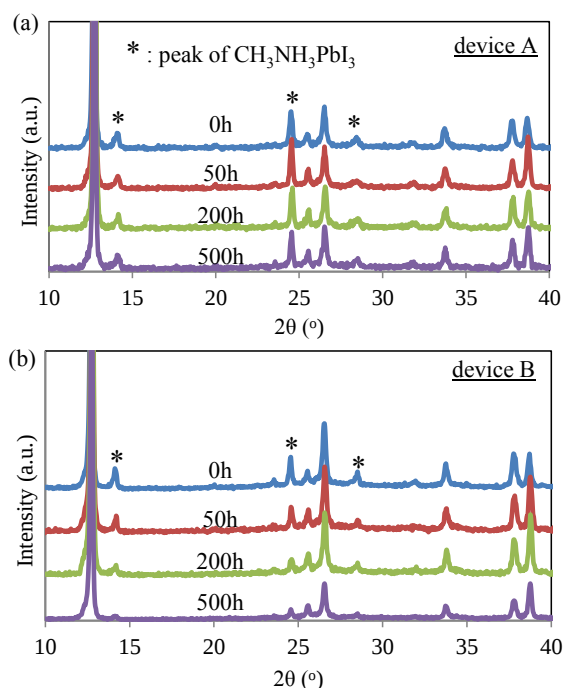


Fig. 4 XRD spectra of perovskite films as a function of storage time at 85 °C.

The conductivities of a spiro-OMeTAD layer in device A still maintained even after the storage time of 500 h, while those in device B were gradually decreased under the same condition, as shown in Figure 5, probably due to the decrease of doping amount in a spiro-OMeTAD layer. By using robust encapsulation, the degradation of crystal construction of perovskite and the doping amount of spiro-OMeTAD can be suppressed.

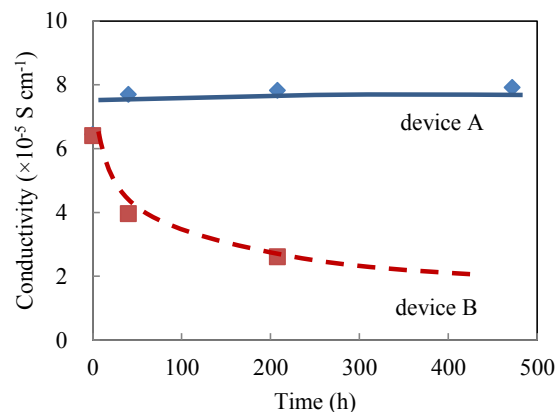


Fig. 5 Conductivities of a spiro-OMeTAD layer as a function of storage time at 85 °C.

3. Conclusions

We investigated the thermal degradation of perovskite solar cells. The thermal degradation in the perovskite solar cells with robust encapsulation can be suppressed, resulting that the PCEs of the devices were remained 88% of its initial value after 750 h storage at 85 °C. Even though the instability of perovskite solar cells against thermal stress is controversial, the robust encapsulation makes it possible to provide the thermal stability.

Acknowledgements

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