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Short-term light soaking effect on dye-sensitized solar cells

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Abstract. Dye-sensitized solar cells (DSSCs) are one of the most promising third generation solar cells and have been regarded as a competitive alternative to the conventional silicon-based photovoltaic devices due to their relatively low production cost. Light soaking effect is an intriguing phenomenon that exists in DSSCs, which refers to the enhancement of the electrical parameters in the cells after being exposed to light soaking. In this paper, we report on the variation in the electrical parameters of DSSCs under continuous exposure to a simulated solar irradiation for a period up to 6h. Increments of J_{sc} and V_{oc} in DSSC were observed after 6h of light soaking, which led to improved efficiency from 3.87% to 4.50%. The improvements may be ascribed to the formation of electron trapping states below the TiO_2 conduction band edge, which facilitated the charge carrier transport.

1. Introduction

Since its inception in 1991 [1], dye-sensitized solar cell (DSSC) has garnered immense interest of the scientific communities owing to its several attractive features including ease of fabrication, low production cost and high conversion efficiency [2]. Generally, a DSSC comprises of three main components: dye-sensitized mesoporous titanium dioxide (TiO_2) film deposited on transparent conductive oxide (TCO) substrate as working electrode or photo-anode, redox couple (typically iodine/triiodide) in organic solvent as electrolyte, and lastly, FTO glass coated with catalyst material such as platinum or carbon as counter-electrode.

As reported in literature, the photocurrent of DSSC will show an increasing trend under exposure to continuous illumination, and this intriguing phenomena has been observed in both small cells and large modulus [3–5]. This increase in photocurrent with prolonged illumination can sustain for few hour or even days [6]. This phenomena is usually termed as “light soaking effect”. The study of this effect has impact to the stability test of DSSCs and also optimization of cell manufacturing process [7].

In this work, the light soaking effect on sealed DSSC was investigated and current-voltage characterization was performed to measure the photovoltaic performance of DSSCs with increasing light soaking duration.

2. Experimental works

The photo-anode of DSSC was prepared by casting a layer of TiO_2 paste (Ti-Nanoxide D, Solaronix) on the fluorine doped tin oxide (FTO) substrates using the doctor blade technique [8] and the coated



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substrate was subjected to elevated temperature. Subsequently, the substrate was immersed in N719 dye (Ruhenizer 535-bisTBA, Solaronix) with chenodeoxycholic acid as co-adsorbent for dye loading. For the preparation of counter electrode, the platinum (Pt) paste (Platisol T/SP, Solaronix) was applied on another bare FTO substrate, followed by sintering at elevated temperature. The photo-anode and counter electrode were assembled and sealed with a thermoplastic film (Meltonix 1170-25, Solaronix). The electrolyte (Iodolyte AN-50, Solaronix) was injected into DSSC, followed by sealing of the holes.

The surface morphologies of the FTO substrate and TiO_2 -coated FTO substrate were characterized by using field emission scanning electron microscopy (FESEM, FEI Nova NanoSEM 450). The current-voltage measurements and light soaking test were performed using Oriel Sol2A solar simulator which was calibrated to 100 mWcm^{-2} that corresponded to standard AM 1.5 solar condition. The current-voltage characteristics of DSSCs were measured and controlled by using Keithley Series 2400 Source Meter. For the light soaking process, the shutter of the solar simulator was opened to unblock the light source and allow the simulated light to be shined on the DSSC.

3. Results and discussion

The FESEM images of the bare FTO substrate and TiO_2 -coated FTO substrate are depicted in figure 1. The distinctive morphology of tin oxide crystals can be observed from figure 1(a). In figure 1(b), it can be seen that the TiO_2 nanoparticles are uniformly distributed on the surface of FTO substrate. Besides a tiny amount of aggregated TiO_2 nanoparticles, there is no visible gap or crack on TiO_2 film. The uniformity of TiO_2 film is essential to allow electrical contiguity among TiO_2 nanoparticles [9], which is important to achieve low charge recombination and increase the light harvesting efficiency [10].

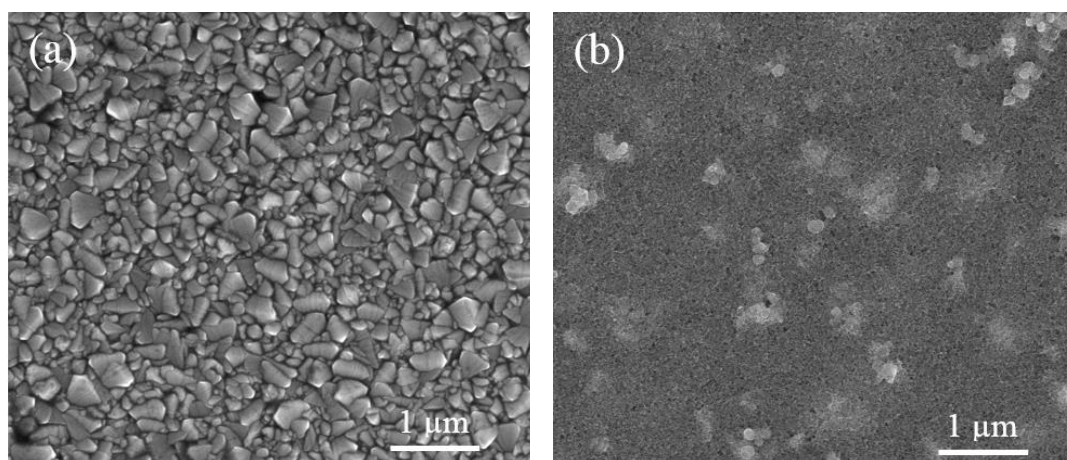


Figure 1. FESEM images of (a) bare FTO substrate and (b) TiO_2 film coated on FTO substrate

The photocurrent density-voltage curves of DSSC at increasing hours of light soaking are illustrated in figure 2, while the corresponding photovoltaic parameters are summarized in table 1. Improvements in short circuit current density (J_{sc}) and open circuit voltage (V_{oc}) of DSSC can be observed clearly from figure 2, with the enhancement became less pronounced at longer light soaking duration as it slowly reached a steady condition.

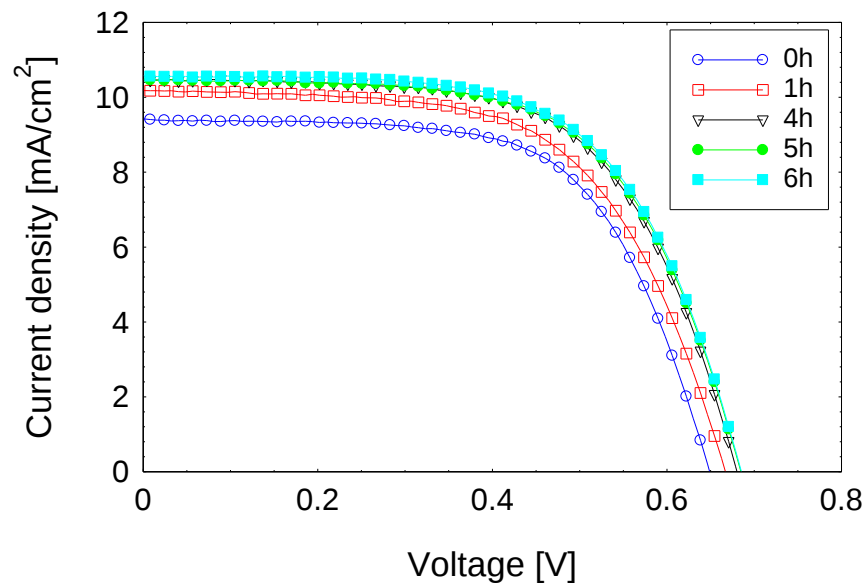
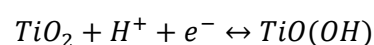


Figure 2. Photocurrent density-voltage curves of DSSC at increasing hours of light soaking

Table 1. Summary of the DSSC photovoltaic performance under light soaking test

Duration of light soaking (h)	V_{oc} (mV)	J_{sc} (mAcm^{-2})	Efficiency, η (%)	Fill factor, FF (%)
0	649	9.39	3.87	63.51
1	667	10.19	4.10	60.37
4	680	10.47	4.42	62.14
5	684	10.47	4.47	62.33
6	685	10.56	4.50	62.27

The evolution of the photovoltaic parameters (V_{oc} , J_{sc} , fill factor and efficiency) at increasing hours of light soaking was depicted in figure 3 to figure 6. From figure 3, it can be observed that V_{oc} of DSSC increased steadily from 649 mV to 685 mV after 6 h of light soaking. Improvement of J_{sc} from 9.39 mAcm^{-2} to 10.56 mAcm^{-2} after the same duration of light soaking was depicted in figure 4. The increment of J_{sc} and V_{oc} led to improved efficiency from 3.87% to 4.50% as shown in figure 5. The enhancements may be attributed to the formation of electron trapping states below the TiO_2 conduction band edge of due to the intercalation of the light-induced proton into TiO_2 lattice [11]. It was suggested that the protons were originated from the dye or water traces within the electrolyte [7]. In the study carried out by Betz et al [12], it was found that photo-induced proton interaction will lead to the generation of new electronic states or trapping states in the forbidden energy band gap of $\text{TiO}_2(\text{B})$. During this process, Ti^{IV} is reduced to Ti^{III} due to charge neutralization, and this phenomenon can be described by the equation below [11]:



These trapping states facilitate the transport of photo-generated electrons within the TiO_2 film by forming new pathways for electron transport [13]. In addition, these additional energy levels allow the electrons to move away faster from dye molecules after the photo-excitation process, and thus

enhancing the electron injection from photo-excited dye into TiO_2 conduction band [13]. Improved electron injection after the light soaking process was reported by Cabau et al. [14] as well, which was ascribed to the improved TiO_2 /dye interaction. From the increased J_{sc} after the light soaking process, it can be concluded that the formation of electron trapping states facilitates the charge transport without promoting recombination between the electrons and triiodide ions in the electrolyte [7]. This is because of the longer distance between the trapping states and the electrolyte compared to the surface states, and hence the recombination is likely to occur via the surface states rather than the trapping states [11]. Despite the increase of V_{oc} and J_{sc} , the fill factor of DSSC exhibited a slight decrease from 63.51 % to 62.27 % after 6 h of light soaking as shown in figure 6.

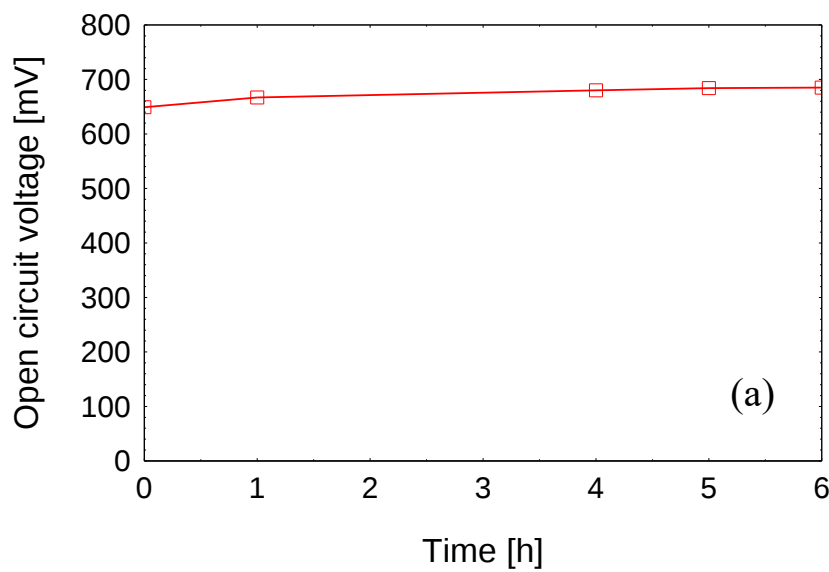


Figure 3. Variations of open circuit voltage (V_{oc}) at increasing duration of light soaking

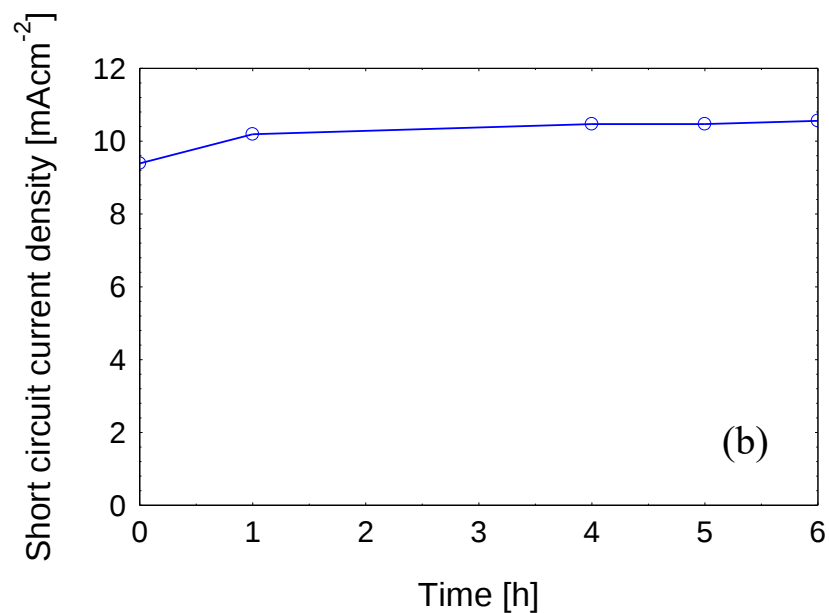


Figure 4. Variations of short-circuit current density (J_{sc}) at increasing duration of light soaking

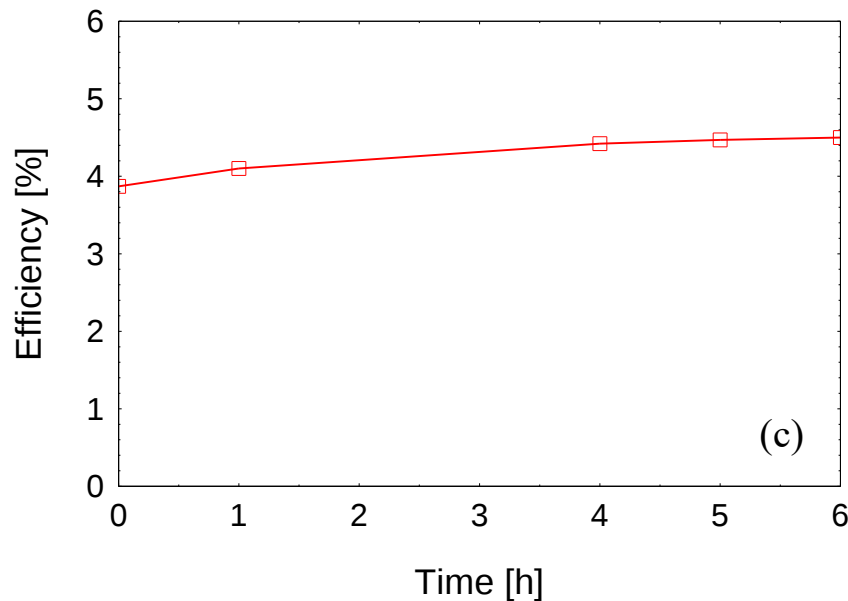


Figure 5. Variations of efficiency (η) at increasing duration of light soaking

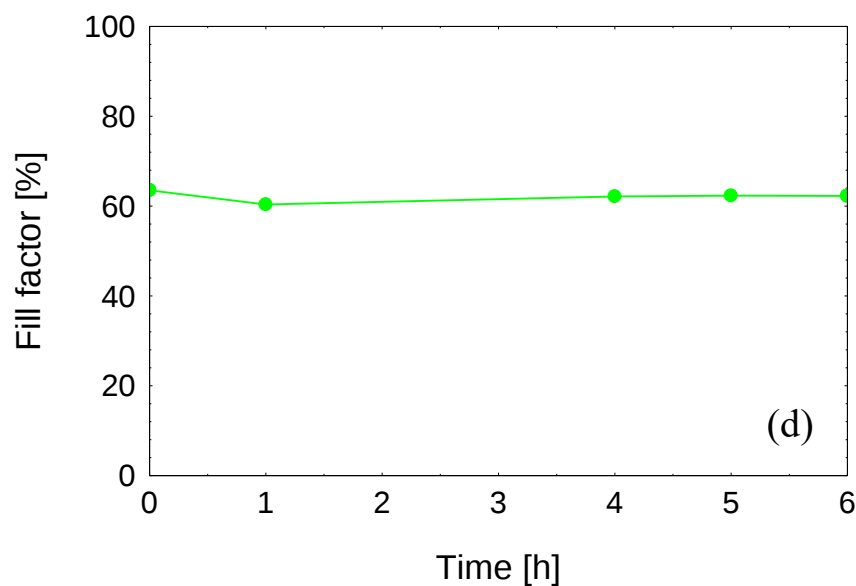


Figure 6. Variations of fill factor (FF) at increasing duration of light soaking

4. Conclusion

In this work, the effect of short-term light soaking on dye-sensitized solar cells was examined by using current-voltage characterization. Enhancement in J_{sc} and V_{oc} was observed after 6 h of light soaking, which can be ascribed the formation of electron trapping states close to the TiO_2 conduction band edge due to the intercalation of the light-induced proton into TiO_2 lattice. These trapping states served as additional pathways for charge carrier transport, and hence facilitating the transport of photo-generated electrons across the TiO_2 matrix to the anode. Besides, the additional transport levels allowed the electrons to move away faster from dye molecules after the photo-excitation process, which improved the electron injection.

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