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Effect of UV filtering on dye-sensitised solar cells

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Abstract:

This work aimed to investigate the effect of commercial UV filter films (PS65, SEC04) on the performance and long-term outdoor stability of dye-sensitised solar cells (DSCs). The application of UV filter films to the DSCs lead to a slight decrease in cell performance. However, the cell performance remained constant after 2,000 h of outdoor exposure. Electrochemical impedance analysis showed a small transfer resistance in the TiO_2 photo-anode, which corresponded to the low recombination process of the electrons in TiO_2. The low electron recombination process supports the stable performance of the DSCs with the SEC04 film under outdoor conditions.

Keywords: **dye-sensitized solar cells performance, electrochemical impedance spectroscopy, outdoor testing, UV filter films.**

Classification number: **2.2**

Introduction

During the past half-century, the excessive consumption of fossil energy, together with the uneven distribution of fossil energy resources in the world, has pushed humanity to face serious environmental problems such as the greenhouse effect and lack of renewable energy resources. To overcome these problems, the development of clean and renewable energy sources must be a mandatory requirement at present and in the future. Among existing renewable energy sources, solar energy is considered to be the cleanest and safest choice. Solar cells are considered to be the most convenient method to turn solar energy into electricity and may even be an alternative to other energy sources since the invention of single-crystal solar cells in 1954. However, the issue of high cost is the biggest obstacle to be overcome in order for Si crystalline solar cells to be used by the masses [1, 2].

Dye-sensitized solar cells are progressively more developed to meet today's needs. The combination of photosensitizers with broad spectroscopic absorption and nanocrystalline oxide membranes allows for improved photo-multiplier tube (PMT) transformation efficiency, which has resulted in a significant transformation of light into electrical energy under a broad spectrum from UV to near-IR. Efficient solar energy-to-electricity conversion of 7.1% (AM 1.5, 750 W/m^2) was reached by Grätzel and O'Regan of the Swiss Federal Institute of Technology Lausanne, Switzerland (EPFL) in 1991 as an effective and eco-friendly replacement for crystal solar cells [1, 3]. EPFL recently achieved a record photovoltaic conversion efficiency of 15% [4]. DSCs has garnered full attention over the past decade due to low production costs and the ability to convert sunlight into electricity in an environmentally friendly manner. Hence, DSCs open up excellent prospects for the production of solar cells at a lower price than traditional technologies.

UV filters are flexible films that are applied to a glass surface to block UV and visible light at different levels. Over the past decade, there has been an increase in the number of manufacturers producing these filters. Most current filters can eliminate 95-99% UV radiation from in the wavelength range of 200 to 380 nm. UV filters are usually made of tightly pressed polyester layers that have many effects such as absorbing, scattering, or reflecting UV and visible light. Most of these membranes are soaked in dye or carbon particles or coated with a metal layer by a sputter. The metal coating is usually aluminium, which reflects the incident light, thus reducing UV transmission and visible light. Non-metallic layers contain organic compounds that absorb UV

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rays, preventing the UV rays from penetrating through the membrane. The four most prestigious compounds used for UV absorption include benzotriazoles hydroxyphenyl, hydroxyphenyl-triazines-s, oxalanilides, and 2-hydroxy benzophenones. Because the specific compounds used are often considered proprietary information, it is difficult to determine which compounds are present in current products.

DSCs utilize a TiO_2 photoanode, which is a semi-conductor that is photo-active in the UV range. Under UV lights, TiO_2 is activated and produces electrons and holes that bombard the dye in the electrolyte. As a result, UV filters are required to restrict the photo-catalytic properties of TiO_2 when the DSCs undergo outdoor exposure tests.

In this study, two types of UV filters were collected from several commercial products. Those with UV transmittance below 1% were used to protect the DSCs from the effects of UV radiation under outdoor conditions.

Experimental

Material

Ruthenium dye (N719), high stability electrolyte (HSE), thermal plastic sealant (surlyn), platinum paste (PT1), reflector titania paste (WER2-O), transparent titania paste (18NR-T), and FTO conducting glass (TEC15) were purchased from Dyesol (Australia). HCl, Ethanol, $TiCl_4$, DMF, and acetonitrile were purchased from Sigma-Aldrich (Germany). The commercial UV filters were supplied by an automobile shop.

Fabrication of DSCs

Anode preparation: the TEC15s glass substrates (as current collectors) were sonicated in a detergent solution for 15 min, then in 0.1 M HCl/ethanol for 30 min, and finally washed with distilled water. The substrate was soaked in a 40 mM $TiCl_4$ solution at 70°C for 30 min and then washed with distilled water and ethanol. The TiO_2 paste with a thickness of 12-14 µm was coated onto the conductive side of the substrate using the screen-printing method. Then, the TiO_2 coated electrodes were heated to 500°C under airflow for 30 min to obtain the TiO_2 photoanode.

Cathode preparation: the cathodes of the DSCs were fabricated via the screen-printing method using a PT1 platinum paste. The prepared cathodes were annealed at 450°C for 30 min.

DSCs assembly: the DSCs were assembled by placing a 25 µm Surlyn gasket between the photoanode and counter electrode and pressed with heat press at 170°C for 15 s. The N719 dye solution (10 mM in DMF) was injected into the space cells through a hole in the back of the cathode and remained for 4 min to ensure the dye was fully adsorbed in the TiO_2 film. Excess dye and DMF solvent were removed from the cell. Then, the space was cleaned with acetonitrile three times. HSE as the electrolyte solution was successively injected into the cells through a hole in the back of cathode. The dye soaking and electrolyte filling were carried out in a nitrogen-filled glove box to avoid oxygen and water. The cells were capped with a thin glass cover with a thermal sealant by heat press at 170°C for 15 s.

Characterization of DSCs performance: the photovoltaic performance was measured using a Keithley model 2400 multisource meter and an Oriel Sol1A (94061A, Newport, USA) solar simulator. A monocrystalline silicon reference solar cell (91150V - Oriel-Newport-USA) verified at NREL (USA) was used to adjust the solar simulator to the standard light intensity of one sun (100 mW/cm^2). Electrochemical impedance spectroscopy (EIS) on the fabricated DSCs was collected using an Autolab 302N (Ecochimie, Netherlands). The EIS measurement was carried out at open-circuit voltage under illumination. The frequency range is 0.01-100 kHz, and the alternating voltage amplitude was set at 10 mV.

Outdoor testing: the UV filter was applied on the photoanode side of the DSCs before aging testing. The outdoor test was carried out on the roof of a building at the University of Science, VNU-HCM. The tilt angle of the DSCs was 45° and faced due south [5]. The I-V curve and EIS were measured offline every seven days for two months.

Results and discussion

Filters

The filters from four commercial UV filter films were used to protect the DSCs. The optical properties of the four types of UV filters were assessed through optical transmission in the UV-Vis region. The UV-Vis spectra of the UV filters (Fig. 1) were measured between wavelengths of 200-900 nm, and the optical parameters of these UV filters are summarized in Table 1.

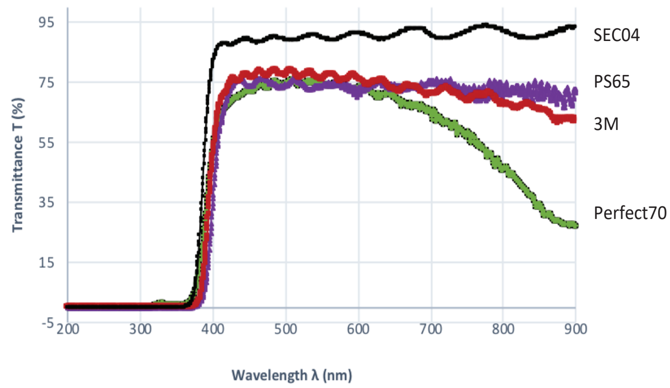

Fig. 1. The UV-Vis transmittance spectra of UV filters.

Table 1. Optical properties of UV filters.

UV filters name	Mean %T (500-800 nm)	λ at 50% T (nm)	λ at T<1% (nm)
SEC04	92	387	368
PS65	74	401	379
3M	74	397	379
Perfect70	67	392	357

In comparison with other commercial UV filters, the SEC04 filter has the highest mean percent transmittance (T%), and the PS65 filters have a better UV cut-off wavelength. Therefore, the SEC04 and PS65 filters were selected to protect for DSCs for the outdoor testing.

The effect of filtering upon the performance of DSCs

Figure 2 shows the I-V curve of an unfiltered and filtered DSC using the SEC04 UV filter. The short circuit current density (J_{sc}) and open-circuit voltage (V_{oc}) of filtered DSC are lower, in comparison with their unfiltered DSC. The effect of filtering upon the performance parameter of the DSCs is presented in Table 2. In both cases where the filter was applied, the efficiency (% η) was reduced due to a loss of light transmission through the UV filter. The reduction in % η is due to the overall transmission losses and increased UV cut-off to device [6]. From the UV-Vis data, the efficiency loss (% Δη) is larger in the DSC filtered with PS65 than it was with the DSC filtered with SEC04. This is an essential factor to consider when using a UV filter because a filter can prevent the effect of UV rays but also significantly reduces the DSCs' performance.

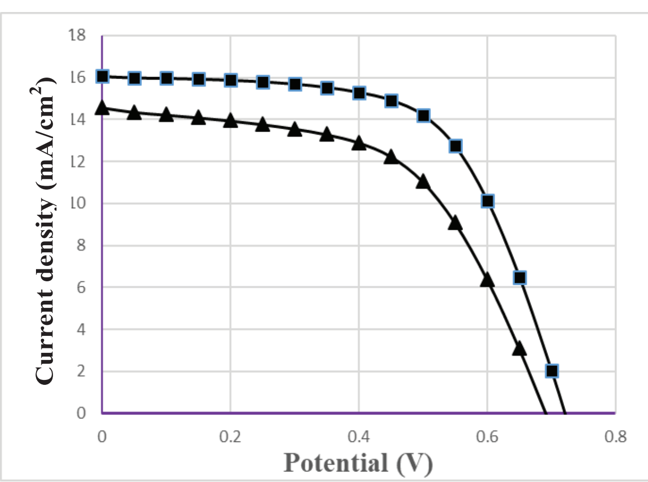

Fig. 2. Comparison of a typical I-V curve of unfiltered and filtered DSCs.

Table 2. The performance parameters of unfiltered and filtered DSCs.

UV filters		J_{sc}(mA/cm^2)	Voc (V)	Fill factor	%η	%Δη
PS65	unfiltered	14.10	0.730	0.63	6.50	20
	filtered	10.80	0.721	0.64	5.00	
SEC04	unfiltered	1620	0.735	0.64	7.60	1.2
	filtered	14.40	0.739	0.65	6.70	

The effects of filtering on long - term stability of DSCs under outdoor testing

Outdoor testing results of DSCs filtered with PS65 and SEC04 are shown in Table 3.

Table 3. The I-V parameter of unfiltered DSC and filtered DSCs.

Type of DSCs	Exposure time (h)	J_{sc} (mA/cm^2)	Voc (V)	Fill factor	η%
unfiltered DSC	0	17.20	0.737	0.641	8.13
	168	19.06	0.737	0.651	9.15
	336	19.46	0.720	0.660	9.17
	504	19.53	0.710	0.650	8.93
	1,152	16.82	0.647	0.649	7.06
	1,248	17.03	0.642	0.615	6.72
	1,992	0.04	0.294	0.086	0.00
DSC-PS65	0	10.86	0.712	0.611	4.73
	168	12.28	0.756	0.615	5.71
	336	13.81	0.758	0.631	6.61
	504	14.41	0.748	0.562	6.06
	1,488	15.35	0.723	0.549	6.09
	2,328	15.51	0.717	0.498	5.54
	3,120	14.45	0.621	0.336	3.02
DSC-SEC04	0	14.39	0.739	0.646	6.86
	168	16.23	0.784	0.678	8.64
	336	17.51	0.781	0.680	9.30
	504	16.93	0.787	0.691	9.20
	1,488	16.85	0.765	0.690	8.90
	2,328	16.30	0.770	0.677	8.50
	3,120	15.44	0.728	0.596	6.70

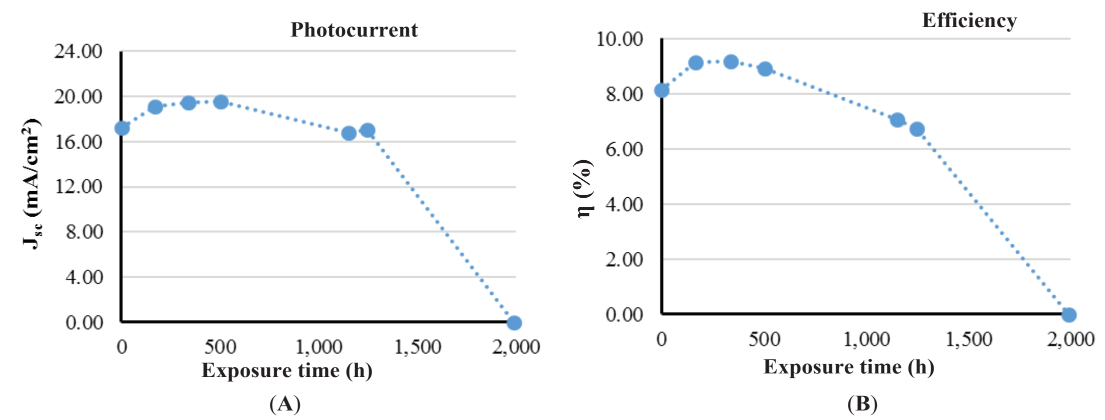

Fig. 3. Stability data of unfiltered DSCs depending on outdoor testing time. (A) Photocurrent, **(B)** Efficiency.

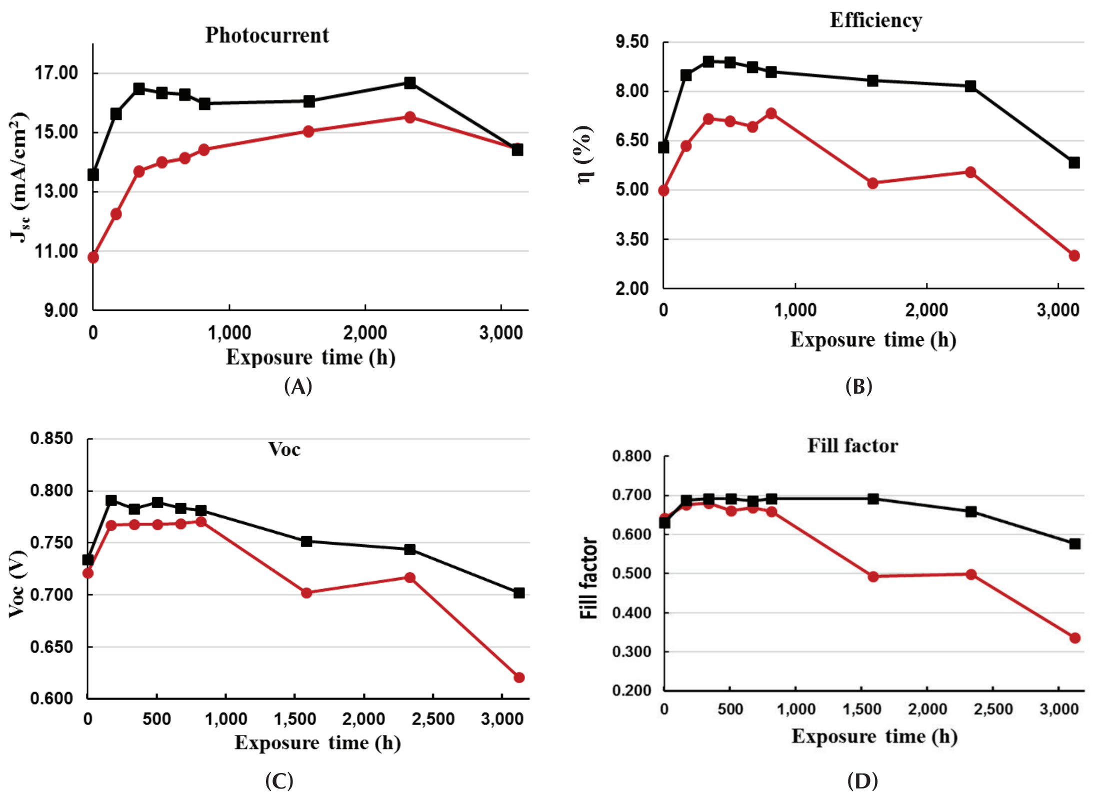

Fig. 4. Stability data of filtered DSCs with SEC04 (-■-), PS65 (-●-) depending on outdoor testing time.

Figures 3 and 4 show changes in the performance parameter of the unfiltered DSCs and those filtered with PS65 and SEC04 under outdoor testing conditions. Over the first 336 h, the cells increased in J_{sc}, V_{oc}, fill factor, and efficiency. The efficiencies were increased to 12% and 30% of the initial value for unfiltered cell and filtered cell, respectively. From 500 h to 1,000 h, a reduction of the cell efficiency occurred with unfiltered DSC, while during the same time interval the filtered DSC showed no changes in efficiency. The performance of the unfiltered DSCs suffered a dramatic drop after 1,000 h of testing. Meanwhile, no major changes in cell performance occurred during 2000 h of testing the filtered DSC. Degradation of the filtered DSCs began after 2,500 h of outdoor testing. Less significant degradation of the SEC04 filtered DSCs was found in comparison with the PS65 UV filter.

The electrochemical impedance spectroscopy of the unfiltered DSCs, PS65 filtered DSC, and SEC04 filtered DSC is shown in Fig. 5. The equivalent circuit was fitted as $[R(R_{ce}C_{ce})(R_tC_\mu)(R_dC_d)]$, and the value of these components are detailed in Table 4 [7-9]. A significant decrease in the charge-transfer resistance (R_{ce}) of the counter electrode, as well as electron

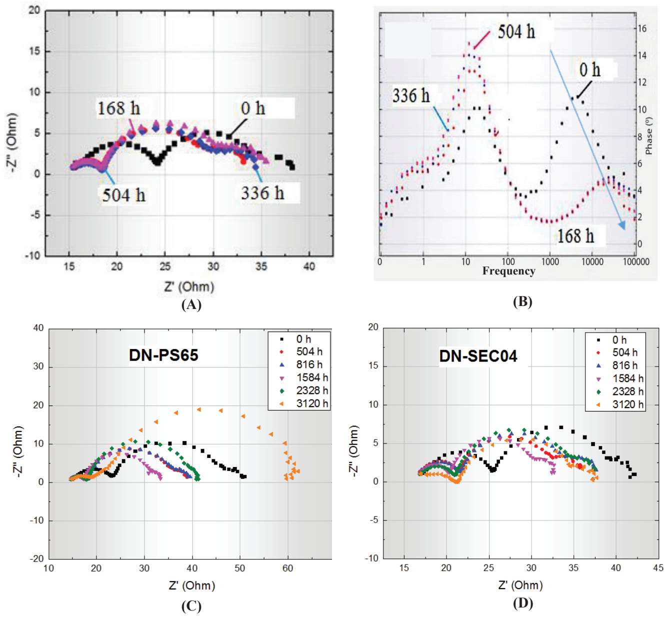

Fig. 5 The impedance spectra of unfiltered DSC (A, B) and filtered DSCs with PS65 (C), SEC04 (D).

transfer resistance (R_t) in the photoanode, after 186 h testing was observed. These phenomena can explain the increase in DSC performance during the first 336 h of testing time. The R_{ce} decreased due to the activation of the Pt cathode under illumination. For the first 186 h, the electron lifetime τ_e of the unfiltered DSC increased, indicating that the recombination rate of the DSCs decreased. Moreover, further decrease of the initial value occurred after an extra 336 h of testing.

The Nyquist plot of the DSC filtered with the SEC04 and PS65 UV filters showed the effect of stabilizing the DSCs over 2,000 h of outdoor testing. This means that the UV filter not only protected the DSC but did not impair the functionality of the DSC.

Table 4. Electrochemical impedance parameter of DSC with and without UV filter.

Type of DSCs	Exposure day	R_{ce} (Ω)	R_t (Ω)	τ_e (ms)
DSC	0	7.42	9.91	9.9
	168	2.86	10.2	13.2
	336	2.70	10.8	13.2
	504	2.91	11.5	13.2
DSC-PS65	0	8.00	21.2	9.9
	168	1.29	21.2	17.5
	336	3.07	14.8	9.9
	504	2.92	16.4	13.2
DSC-SEC04	0	7.52	13.2	9.9
	168	5.77	13.6	13.2
	336	4.12	9.93	9.95
	504	4.42	10.2	9.95

Conclusions

The UV filters SEC04 and PS65 applied to protect the DSC led to a reduction in cell efficiency. However, the stability of the cell was prolonged under extensive outdoor condition testing. The SEC04 filtered-DSC had a lower reduction in efficiency in comparison to the PS65 filtered-DSC because the SEC04 film has a higher average transmission of light than the PS65 filter. Thus, UV filter films are considered an effective, simple, and inexpensive solution to increase the performance of DSCs.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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