

## Outdoor testing and ageing of dye-sensitized solar cells for building integrated photovoltaics



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### ABSTRACT

To elucidate the possibility of practical use of dye-sensitized solar cells (DSSCs) in Building Integrated Photovoltaics (BIPV) application, outdoor test has been carried out for over four years. This is almost the longest outdoor test of DSSCs. Performances of DSSCs prepared with two different kinds of dyes are tested. DSSCs with dye Z991 generate about 15% more electricity yearly than those with dye Z907 in the first two years and then the gap is widening because of the better stability of dye Z991. Efficiency of DSSCs with dye Z991 decreases 17% at the first two years and then becomes stable, while DSSCs with dye Z907 are out of use after 4-year outdoor testing. For BIPV use,  $P_{max}$  increases with the solar irradiance  $P_i$  and gets the highest value around 12:00, while the efficiency is almost unchanged from 8:00 to 16:00 as the sun moves. The output of DSSCs increases not linearly with the irradiance, especially under irradiance lower than 20 Wh, implying that efficiency measured under AM1.5G conditions is not a crucial indicator to evaluate the performance of DSSCs. The total energy yields of DSSCs throughout the years are slightly higher than that of pc-Si cell with the same installed capacity, and DSSCs generate 15–20% more electricity from May to August when temperature is higher and irradiance is lower. The results show potential application in outdoor BIPV, especially in hot and humid climate, although larger exposed area is still required to attain the same installed capacity with pc-Si cell.

### 1. Introduction

With the increasingly serious environmental pollution and emerging energy crisis, seeking renewable and clean energy sources has become an urgent demand for the sustainable development of human society (Grätzel, 2005). Solar cell, which converts abundant solar energy into electricity, serves as an alternative renewable and clean energy resource. Solar cells can be utilized in various ways including mobile charging devices (Garcia-Valverde et al., 2016), solar lamps (Hyun et al., 2015) and building integrated photovoltaics (BIPV) (Hinsch et al., 2009). Among them, BIPV is an effective way to harness the abundant solar energy, as solar cells are installed together with the buildings, and directly provide power for the electricity-consuming equipment in the buildings.

As the third generation solar cells, DSSCs have attracted many researchers' attention, not only because of their environmental friendly and low-cost fabrication process, colorful appearances, but also due to their lower dependence on the angle of incident light and higher efficiency under low irradiance comparing with traditional Si-based solar cells (O'Regan and Grätzel, 1991). The latter two advantages are especially favorable for BIPV applications, where large amount of solar cells are usually installed on the facades of the buildings and can hardly receive high intensity irradiation. Therefore, DSSCs seem to be an attractive option as the photovoltaic device for BIPV application (Asghar et al., 2014; Zhang et al., 2016).

The power output and efficiency of DSSCs have been extensively studied indoor under standard conditions (1000 W/m<sup>2</sup>, 25 °C), and the long-term stability has also been widely investigated (Bari et al., 2011;

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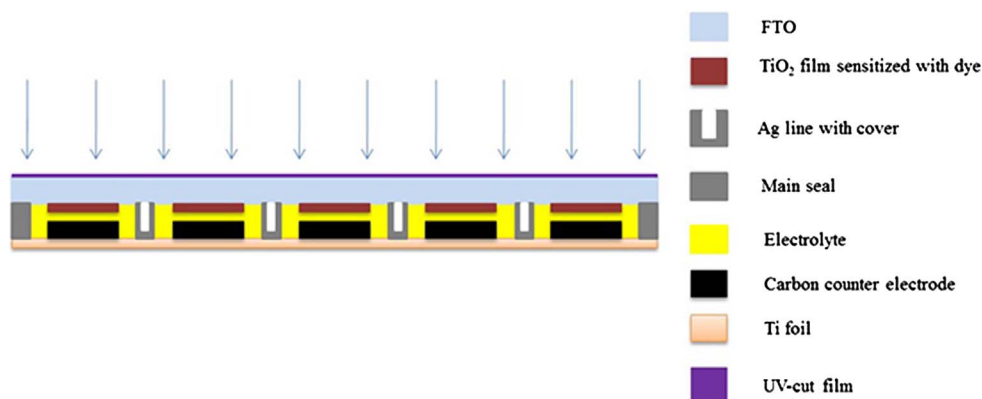


Fig. 1. Schematic of the DSSC.

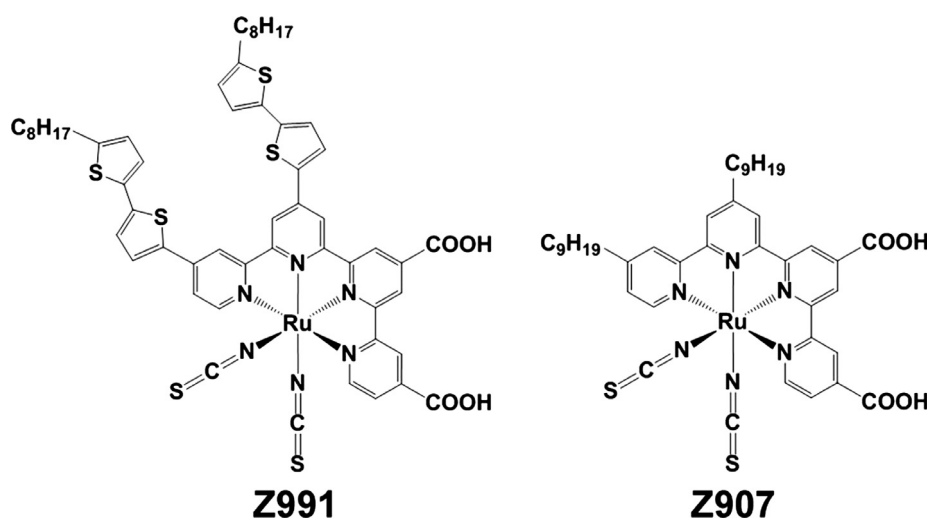


Fig. 2. Molecular structures of Z991 and Z907.

Bella et al., 2015; Lu et al., 2011; Maçaira et al., 2016; Takada et al., 2015). However, it is found that the changes of temperature and irradiance level affect simultaneously and significantly on the energy output of the DSSCs (Haque et al., 2013; Sommeling et al., 2004; Toyoda et al., 2004), making it difficult to precisely predict the complicated effect of environmental factors on the photovoltaic parameters simply by simulation. Therefore, it is highly desired to study the performance of DSSCs under real outdoor operating conditions. A number of literatures focusing on the outdoor performance and ageing of the DSSCs have been published (Asgar et al., 2014; Berginc et al., 2014; Dai et al., 2008; Opara Krašovec et al., 2013; Toyoda et al., 2004). In many studies, the ageing experiment has been carried out for only several months, besides 2.5 years are the longest (Kato et al., 2009). Furthermore, most of the studies are tested offline and the DSSCs are aligned perpendicularly to the sunlight, which rarely match the conditions in BIPV application.

To elucidate the potential and possibility of DSSCs for BIPV application, 18 pieces of DSSCs are installed vertically to assess the performance parameters and stability of DSSCs. The electrical characteristics of DSSCs with two kinds of dyes have been monitored online for over 4 years in Shanghai, China, together with a commercial pc-Si solar cell. Several degradation trends are identified and correlated to the dyes used in the DSSCs.

## 2. Experimental procedure

### 2.1. DSSCs fabrication

The schematic of DSSCs is shown in Fig. 1. The process to fabricate the DSSCs is similar to other literatures (Hwang et al., 2015, 2014). Briefly, TiO<sub>2</sub> film containing three layers was coated on the fluorine-doped tin oxide (FTO) coated glass with screen printer and then

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