

Original research article

Electro-optical characterization of ruthenium-based dye sensitized solar cells: A study of light soaking, ageing and temperature effects



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ABSTRACT

In this work, we report on the electro-optical characterization of Dye Sensitized Solar Cells (DSSCs) which use ruthenium complexes as sensitizers. In particular, several kinds of measurements have been performed to study the electrical performances and the efficiency levels of the cells at different operating conditions. In detail, the measurements have been conducted at varying temperatures and hours of light soaking. Our results show that the short circuit current density J_{SC} , the open circuit voltage V_{OC} and the conversion efficiency η increase with the hours of light soaking, while they decrease with temperature. A thorough investigation on the light soaking process at the device level has been carried out, giving a wealth of experimental data which can be very useful to better single out and quantify the underlying physical phenomena and the effects on the cell parameters, which are still controversial among the scientific community. Finally, the ageing study demonstrates that the cell performance rapidly deteriorates in the first few months of exposure to light. All the obtained results are of great importance for a better understanding of the light soaking phenomenon and for improving the fabrication process of the DSSCs investigated during this study.

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1. Introduction

Starting with a glimpse of basic facts, we are assisting to a continuous and conspicuous increase of the world power consumption. Therefore, it is obvious that fossil fuel – which is nowadays the most commonly employed energy fuel – will soon need to be progressively more and more supported by the use of renewable energy sources (e.g., photovoltaics, wind power). In addition, another noteworthy disadvantage of fossil fuels consists in the fact that they contribute to increment the global warming. For the above-mentioned reasons, one of the most relevant research fields is to investigate on the utilization of sustainable carbon-free sources of energy. Among them, photovoltaics is definitely the most exploited one, since the Sun offers a huge amount of free and clean energy. Solar cells are devices that allow to directly convert the sunlight into electrical power, exploiting the photovoltaic effect discovered by Becquerel in 1839.

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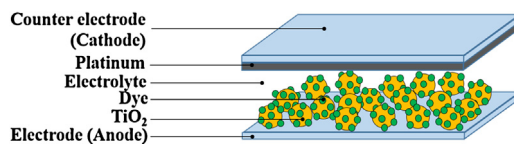


Fig. 1. Typical structure of DSSC cells.

First-generation photovoltaic (PV) cells, composed of crystalline or polycrystalline silicon (i.e., p - n junctions), represent for large scale applications the most-efficient ones. Instead, second-generation solar cells (usually referred to as “thin-film cells” since they are only few-micrometers thick) are made from amorphous silicon or non-silicon materials – such as cadmium telluride (CdTe) or Copper, Indium, Gallium, and Selenium (CIGS). In particular, thanks to the peculiar optical and structural properties, CIGS is considered one of the most suitable materials to produce low-cost and high-efficiency PV modules [1]. In the literature, several research groups have devoted their theoretical and experimental work to make possible CIGS cells with conversion efficiencies of over 20%, quite similar to crystalline silicon cells (around to 25%) [2–8].

Going one step further, a recently-developed type of low-cost PV cells is represented by the Dye Sensitized Solar Cells (DSSCs) that belong to the third generation of photovoltaics [9–11]. This innovative technology was first implemented by Grätzel and O'Regan [12]. DSSCs use a dye molecule to convert the visible light into electrical energy in a manner similar to the photosynthesis process carried out by plants. Both natural or artificial dyes have been proposed in the literature [13–17]. For example, DSSCs with organic metal complexes, such as ruthenium-containing metal organic dyes, and fully natural dyes have been employed as sensitizers: the former present a higher efficiency but are more expensive, since the synthesis of organic dyes is more difficult. The dye can be optimized [18] to make the cells more suitable for a specific application: for example, increasing the absorption in the infrared spectrum allows the fabrication of transparent cells for photovoltaic windows. Instead, the extraction of vegetable dyes from algae, flowers, fruit and leaves is easier and cheaper [19], but the obtained values of efficiency are unfortunately lower than DSSCs having organic metal complexes.

Generally, DSSCs represent a good compromise in terms of efficiency and cost, if compared to traditional but more expensive silicon cells. The main advantages consist in the fact that DSSCs are fully biodegradable, non-toxic and cheaper than traditional p - n junction solar cells, thanks to the absence of expensive purification processes, and thus they are more suitable for the large-scale production. However, typical conversion efficiency values of laboratory samples range from 10% to 12% [20–22], and even lower values (about 6%) are reported for large-scale production. Still, in recent years several technological advancements have allowed to improve DSSCs performance [23–28], up to a record efficiency of 15% reached in 2013 [29].

An interesting phenomenon that has been reported in the literature [30–34] on DSSCs is the increase (or recovery) in photocurrent and efficiency when exposed to a continuous period of illumination. This is the so-called “light soaking effect”, and has been observed both in small cells and in large modules. Therefore, this intriguing phenomenon has significant practical implications, going from improving the cell manufacturing process to stability tests of DSSCs. However, light soaking exact causes and explanations need further investigation as the results reveal somewhat conflicting [30–34].

A complete characterization of Ruthenium-based solar cells including a light soaking study is therefore useful to fully describe the behavior of such cells in different operating conditions. For this reason, in [35] we have already carried out different types of electro-optical characterizations, at varying incident wavelengths, irradiance levels, using the Laser Beam Induced Current (LBIC) technique and a preliminary study at increasing hours of illumination. In this work, we have performed an in-depth electro-optical characterization of such Ruthenium-based DSSCs, focusing on the measurements at varying temperatures and at increasing hours of light soaking. In particular, we have investigated on the light soaking process at the device level, producing a wealth of experimental data which can be very useful to better single out and quantify the underlying physical phenomena and the effects on the cell parameters. Finally, an ageing study has been carried out to analyze the long-term stability of the cells.

2. DSSCs structure and working principle

The structure of a typical DSSC cell is shown in Fig. 1.

The main constitutive elements are: a porous semiconductor sensitized with a dye and an electrolytic solution placed within two electrodes (anode and cathode) [19,36].

The anode is usually composed of a visible light-transparent material, with a thin layer of a transparent conducting oxide (TCO). The thickness of this element should be chosen as a trade-off between the electrical conductivity and the transparency to the incident light.

The most widely employed material for the semiconductor element in DSSCs is TiO_2 , thanks to low cost and high stability. The semiconductor is made porous and, subsequently, the dye molecules are injected into the pores. This porous structure allows to expand the useful surface in which the dye can be adsorbed, and thus the semiconductor can take a much greater amount of molecules. Lastly, the counter electrode (cathode) is usually made of glass or plastic and TCO, with a thin layer of catalyst material deposited on the surface that accelerates the redox reactions at the cathode surface, thus increasing the

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