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DA Oeba
Department of Physics, Kenyatta University, P. O. Box 43844-00100, Nairobi, Kenya., dukeoeba@gmail.com

CO Mosiori
Department of Mathematics and Physics, Technical University of Mombasa, P. O. Box 90420 -80100, GPO Mombasa, Kenya., dukeoeba@gmail.com

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Effect of Dyes Nano-Material Electrodes for Exploration of Dye-Sensitized Solar Cells

DA Oeba[1*] *and CO Mosiori*[2]

[1]Department of Physics, Kenyatta University, P. O. Box 43844-00100, Nairobi, Kenya.
[2]Department of Mathematics and Physics, Technical University of Mombasa, P. O. Box 90420 -80100, GPO Mombasa, Kenya.

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Abstract: The demand for suitable thin films and photoelectric electrodes for renewable and sustainable energy constantly grows. In the exploration of dye-sensitized solar cells (DSSC) recent and increased involvement in the application of nanomaterial-based electrodes and the effects of their unique electronic properties has grabbed the attention of several researchers. This was an attempt to contribute to the investigation by using different dyes on TiO nanoparticles.
Keywords: DSSC, Blocking Layer, TiO nanoparticle, Scaffolding layer, Ruthenizer, Photoanode.

1 Introduction

Photovoltaics have received growing attention in the research and industrial setting due to awareness of the effect of carbon emissions on the environment. A recent development in this field is the dye-sensitized solar cell (DSSC) which exploits the susceptibility of organic or organometallic dye molecules to visible-light-driven excitation processes. Excited electrons are transferred to a simple metal oxide semiconductor and then to a transparent photoanode to be used in an external circuit (Yu *et al.,* 2016). DSSCs are simple, inexpensive, and biodegradable. They also can be printed on flexible substrates (Rokesh *et al*., 2014).

The increased availability of carbon nanomaterials including nanotubes, nanostars, graphene sheets, and nano fibers has allowed the application of their unique electronic properties to assist in the advancement of DSSCs (Lee *et al.,* 2008). Several studies have focused on the incorporation of these materials in the photoanode, where they are composited with TiO_2 nanoparticles (Alhamed *et al.,* 2012). Fewer studies have investigated their use in the catalytic counter electrode, where electrons are transferred to the oxidized dye by an electrolyte solution. These studies have been limited to the use of pure graphene, pure carbon black, or pure carbon nanotubes. Few studies have addressed the use of a blend of these materials with other counter electrode materials such as silver or platinum.

In addition, various studies have investigated the relative performance of different natural dyes extracted from the leaves, roots, fruits, flowers, and seeds of different plants (Richhariya, *et al*., 2017). Although the efficiency of DSSCs based on such natural dyes is quite low, these dyes are more stable and less expensive with a higher extinction coefficient than the high-efficiency organometallic dyes (Shahid & Mohammad, 2013).

An additional area of active DSSC research is the photoanode material, design and morphology (Sengupta *et al.,* 2016) with an emphasis on developing a highly ordered surface area structure. One specific improvement in photoanode design is the employing of a blocking layer of compact titania particles to prevent contact between the electrolyte and anode which creates a short circuit or loss of forwarding current (Jang *et al.,* 2012). An additional improvement in photoanode design has been the use of scaffolding layers to tailor the active area thickness. For example, efficiency peaks at around 13 µm of built up P25 titania scaffolds (Alhamed *et al.,* 2012).

The present study aims to explore the effect of combining a variety of carbon nanomaterials with the catalytic cathode through spreading the particles on the surface of the platinum layer or blending them with the platinum precursor. Moreover, it investigates the use of numerous natural, synthetic, and blended dyes with different types of titania scaffold designs, including different blocking layer and absorbing layer combinations.

*Corresponding author E-mail: dukeoeba@gmail.com

2 Theories

An additional area of active DSSC research is the photoanode material, design, and morphology with an emphasis on the development of a highly ordered but high surface area structure (Jang et al., 2012). One specific improvement in photoanode design is the employment of a blocking layer of compact titania particles to prevent contact between the electrolyte and anode which creates a short circuit or loss of forward current. Currently, an additional improvement in photoanode design is the use of scaffolding layers to tailor the active area thickness.

Photo-electrochemical cells use semiconductor photo-electrodes (Jang *et al.,* 2012, Lee *et al.,* 2008) uniquely designed to convert energy from direct sunlight into storable chemical fuels or energy stores. Such semiconductor junctions as illustrated in figure 1 form a critical component of these cells. The carrier dynamics or system-charge separation and recombination mechanisms across their junctions fundamentally define their cell's performance (Rani *et al.*, 2015).

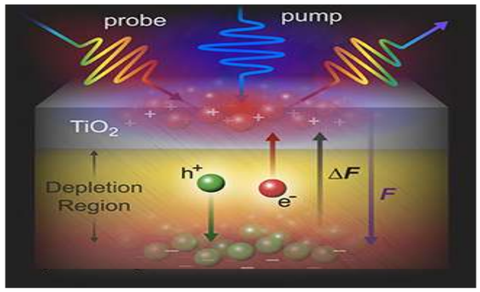

Fig. 1: electron-hole transfer.

3 Materials and Methods

3.1 Materials

3.2 Procedure

Ti-O nanoparticles were spin coated onto clean FTO glass to form photo-anodes. Then, they were annealed at 400ºC for 20 minutes under a closed spin coater. Next, another layer (constituting of an absorbing layer of TiO_2 nanoparticles) was spin coated on top and equally annealed at 400ºC for 20 minutes to keep annealing period the same. Blackberry, *Syzygium Cumini* fruits, and Blueberry juices were sensitized in Ruthenizer for 15 minutes followed by other 15 minutes in an equal-volume mixture of the fruit pulps of Blackberry. *Syzygium Cumini* fruits and Blueberry mixed with five dye variations that were allowed to combine with Solaronix photo-anodes electrodes (Cho *et al*., 2014). An absorber layer of TiO_2 nanoparticles was spin coated on top of Solaronix electrode and later annealed at 400ºC for 45 minutes. Then it was cooled to about 170ºC. Finally, it was heated to 230ºC in open nitrogen flowing gas to remove residual volatiles. The circuit was completed with Mosalyte, the device was sealed with Amosil sealing glue and measurements taken by 4-wire measurement Keithley 2450 Source Meter at 1 sun radiation employing the Abet Technologies solar simulator (Zhao *et al.,* 2017).

3.3 Characterization

3.3.1 Spectrophotometric Measurements

Absorption spectral measurements were carried out in the range of 380nm to 780nm which was within the visible spectra of the electromagnetic radiation.

3.3.2 Current-Voltage (IV) Measurements

The 4-wire measurement Keithley 2450 Source Meter was used to I-V variations of the fabricated solar cells at 1 Sun intensity employing the Abet Technologies solar simulator.

4 Results and Discussion

4.1 Absorption

The UV-visible absorption spectrum of the different dyes was measured. A strong absorption of Ruthenizer was at 420 nm and 520 nm. This was associated with the presence of the used dye. This indicated the excellent performance of the dye. Furthermore, natural dyes from the fruit pulp lacked strong absorption in the regions where Ruthenizer had very strong absorptions (420 nm and 520 nm) as shown figure 2.

It exhibits that the stain made on the photoanode by *S. cumini* pulp was much lighter in color than the other used dyes, indicating incomplete dye absorption (Leyrer *et al.,* 2016). The cells made by depositing a film of TiO_2 nanoparticles can also be seen in **Error! Reference source not found.** and **Error! Reference source not found.**. Figure 3 represents no blocking layer that serves as density-voltage characteristics from the reference DSSC. Figure 4 shows that

the onset of current occurs at a higher forward bias because of suppressing the rate of recombination of charge carrier. This is attributed to the reduced electron recombination without much loss of light transmittance through effective introducing of the TiO_2 blocking layer between the FTO substrate and the TiO_2 paste film (Rani & Tripathi 2015). Blocking layer in DSSC provides good adhesion and represses the electron back transport between electrolyte and FTO by breaking the direct contact (Jang *et al.,* 2012). Moreover, blocking layer, compared to bare FTO glass, offers a homogenous layer with improved crystallinity (Jang et al 2012). Figure 5 reveals that the current density improved when Blackberry Dye and Mixture of Dyes were used. The improvement occurred because electrons reduced recombination. Since the recombination mainly takes place at the surface, surface protection technique such as surface coated with Ruthenizer sensitizer reduced recombination of electrons (Maitani *et al.*, 2017). Figure 6 indicates that the quality of the DSSC improved because the film had higher charge collection efficiency. The efficiency was higher because the scaffolding layer improved photocurrent density because the confinement of the incident light by light-scattering particles gains more photons (Saxena et al., 2017). The most striking result associated JV curves with all the figures is the enhanced fill factor (FF). The FF improved because nanoparticles could provide a large surface area for the dye adsorption and scatter lighter to enhance the light harvesting (Oeba, 2019). The structure of this device and its associated JV curves for different dyes are shown in figures 3-6. Their power conversion efficiency (PCE) was quite similar to that of the "Ti-nanoxide BL/SC as well as nanoparticle and ranged in value between 0.514 and 0.661 (Chen et al., 2018).

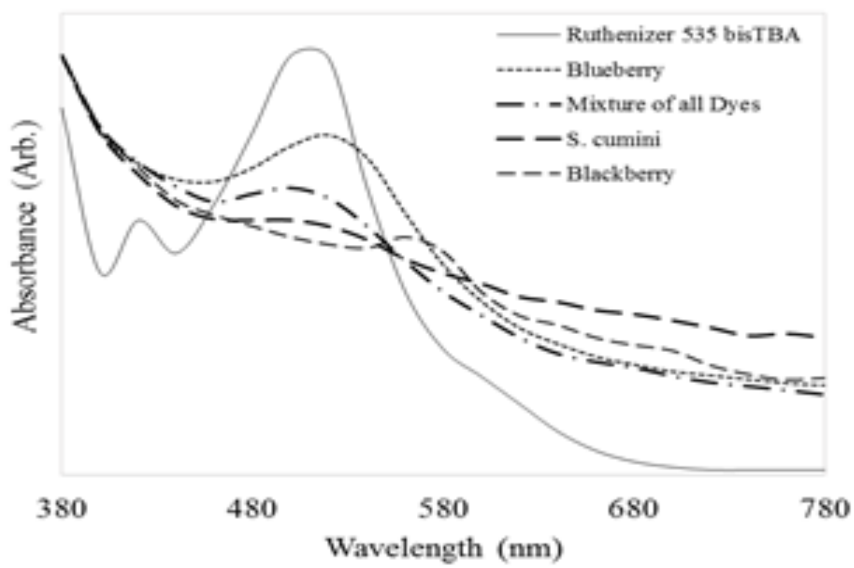

Fig. 2: Comparison of absorption spectra by various dye combinations.

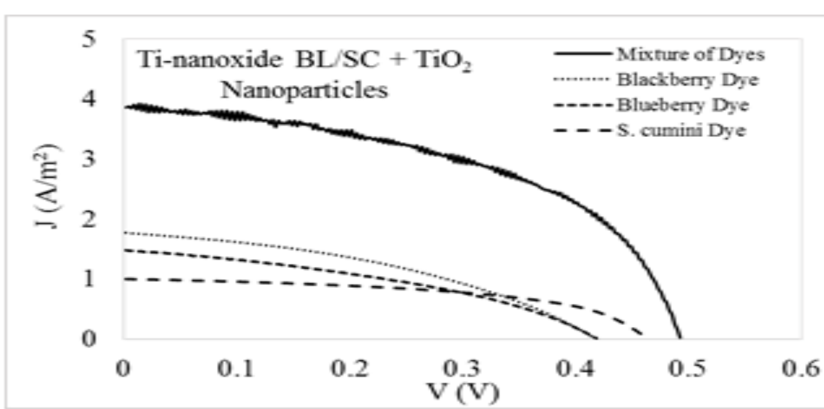

Fig. 3: I-V curve for TiO_2-nanoxide nanoparticles.

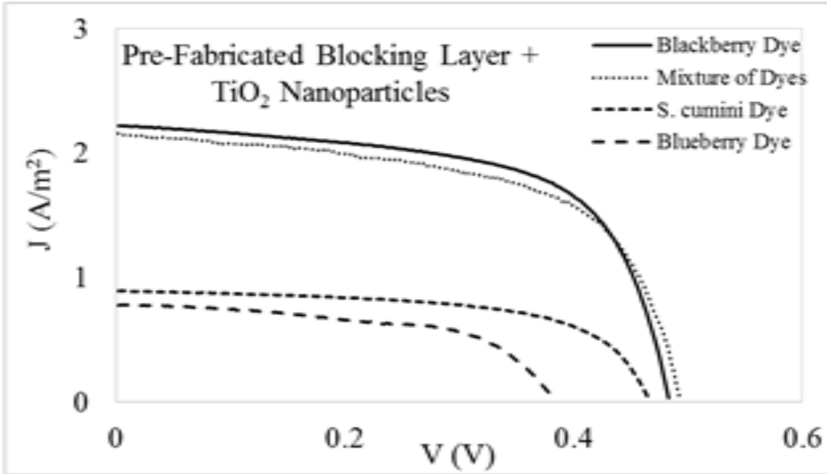

Fig. 4: I-V curve for TiO_2 NPs on a pre-fabricated blocking layer.

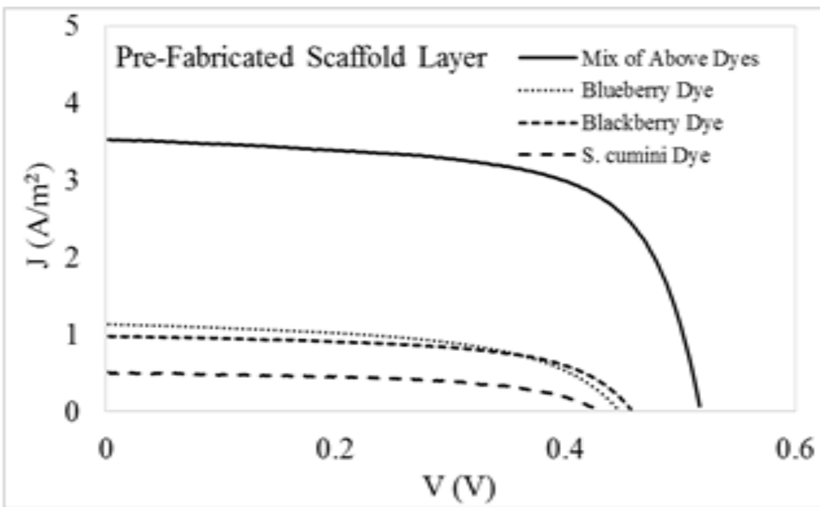

Fig. 5: I-V curve of spin-coated sensitized with Ruthenizer.

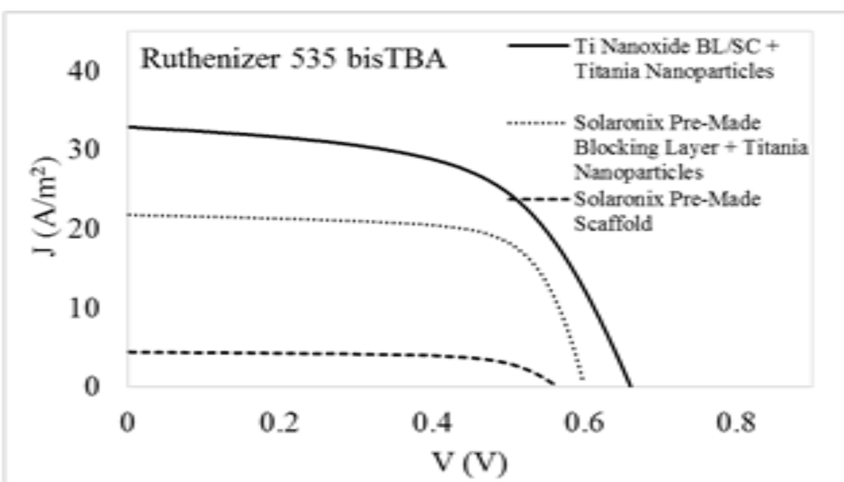

Fig. 6: I-V curve of pre-fabricated scaffolding layer photo-anodes.

Previous pieces of literature demonstrated that Fick diffusion is observed in DSSC sensitization. The present study demonstrates that Ruthenizer may have failed to penetrate sufficiently in the case of the mixed dye treatment in contrast with the case of pure Ruthenizer sensitization.

5 Conclusion

In the present study, a wide variety of DSSCs were fabricated and evaluated to explore the result of sensitizing dyes. Results indicated that applying a thin layer of nanomaterials enhanced performance. In addition, mixing the same particles into the platinum precursor reduced efficiency. Their PCE were quite similar to that of the “Ti-nanoxide BL/SC as well as nanoparticle and ranged in value between 0.514 and 0.66.

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