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**ORGANIC AND NATURAL DYE IMPACTS ON SOLAR CELLS
SENSITIZED BY *LANTANA REPENS* DYE COMBINED WITH THIN FILM
SEMICONDUCTOR ELECTRODES**

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Abstract. *Dye-sensitized solar cells (DSSC's) have been considered as an alternative energy resource in recent years, due to low-cost fabrication and non-toxicity, compared to silicon-based and thin film solar cells. These cells were sensitized by a natural and organic dye extracted from Lantana repens flowers with high anthocyanin concentration, and it was analyzed by UV-spectrum. Photo-anodes and photo-cathode films with different nanostructured forms. The electrodes were morphologically and structurally characterized by atomic force microscopy and scanning electron microscopy. The Fourier Transform Infrared (FTIR) spectrum was obtained after the dye coating on a semi-conductive layer, to identify the light absorbance behavior according to the functional groups present in the dye molecules. The photovoltaic performance and electrochemical impedance spectroscopy studies were carried out to understand the effect of the different photo-anodes and the interaction with the dye molecules on the cell's efficiency. In this work, we present the results towards the construction, characterization, and integration of these DSSC's. The increasing of short-circuit current and chemical stability of the device, exhibit promising characteristics compared to other natural dyes, to extend the natural dye-based DSSC's fabrication for large-scale production.*

Keywords: *Dye-sensitized solar cells, natural dyes, nanostructured semiconductors*

1. INTRODUCTION

Alternative renewable energy resources are the major concern of recent decades. Because of the constant depletion of fossil fuels in the earth crust, there is a great demand for the creation of some devices that could increase energy demand. However, using renewable energy resources, that cannot be exhausted and do not affect the environment as seriously as the burning of fossil fuels is a great alternative to decrease the global warming. Amongst them, solar energy becomes an interesting choice considering that photovoltaic cells are used to convert solar energy into electric energy. From the array of solar cells, DSSC's are considered as a promising alternative for silicon-based solar cells because of the low manufacturing cost, non-toxicity and reasonably high conversion efficiency (Grätzel, 2003).

2. WORKING PRINCIPLE

The dye represents the core component of the DSSC's and has the function of photons' reception and anode sensitization. It must absorb as much as possible radiation throughout the solar spectrum, and strongly connected to the semiconductor surface, have a suitable redox potential and be stable for several years of Sun exposure. In fact, several natural pigments such as anthocyanin, betalains, chlorophyll, tannin, and carotene have been successfully used as photosensitizers in the DSSC's (Ferreira et al., 2018). Amongst of them, anthocyanins are found in a substantial amount of red-blue plant pigments, which naturally, occurs in all plants. Anthocyanins contains the functional group of (-OH)

to bind the semiconductor TiO_2 . The structure of the anthocyanins is shown in the Fig. 1, where R_1 and R_2 represents radicals, containing OH and OCH_3 , characteristic from the *Anthocyanidin petunidin*.

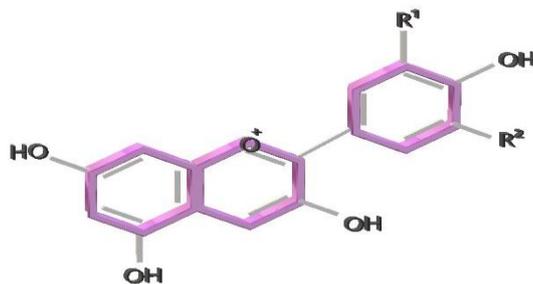


Figure 1. General structure of Anthocyanin molecule.

3. EXPERIMENTAL PROCEDURE

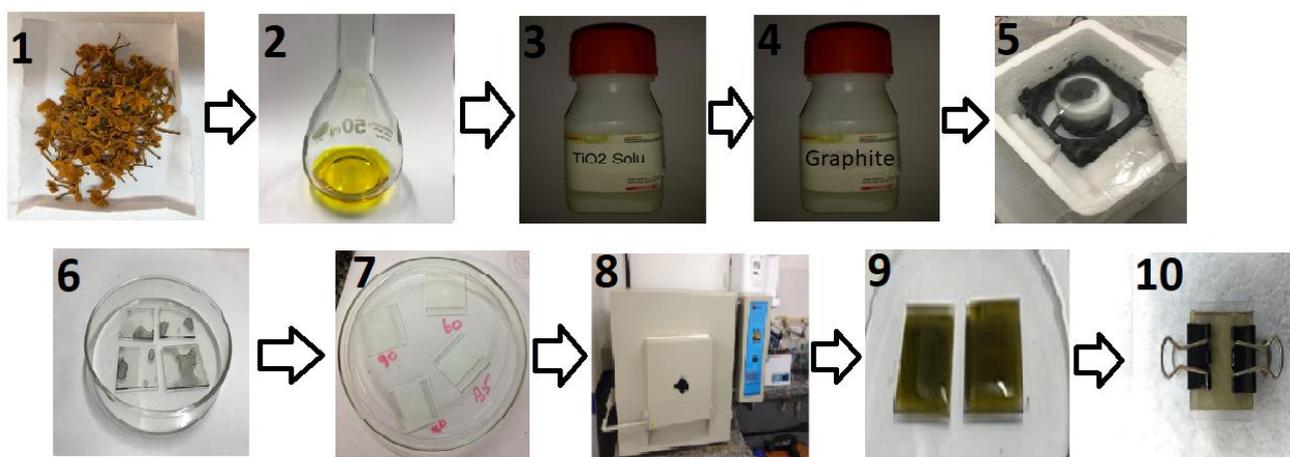


Figure 2. Flow chart of the full cell preparation.

Figure 2 summarizes the experimental procedure for this work:

- 1- *Lantana repens* petals were selected
- 2- The dye was extracted from the petals
- 3- The anode solution was prepared
- 4- The cathode solution was prepared
- 5- The anode and cathode solutions were deposited on an ITO plate by a spin coater method
- 6- Cathode after spin coater deposition
- 7- Anode after spin coater deposition
- 8- The annealing was performed after the deposition on a muffle furnace
- 9- The dye extracted was deposited on the annealed anode
- 10- The cell was completed when the anode and cathode were connected by the electrolyte on the middle

Initially, an indium-doped SnO_2 conducting glass (ITO film) was cleaned with double distilled water and Triton X-100. An ultrasound device was used for an additional 20 minutes for cleaning, and the electrodes were dried in the hot plate for approximately 10 minutes. The TiO_2 thin film was deposited over an ITO glass substrate (photoanode), that was prepared with 0.5 g of the semiconductor anode nano-powder (21 nm), 3 ml of distilled H_2O and 3 ml of acetic acid (CH_3COOH). The deposition of the prepared solution was performed by spin coating technique at 700 rpm for 10 seconds.

As a counter-electrode, a mixture of graphite powder, 5 ml of Triton X-100 and 1 ml of HNO_3 was coated. The deposition was made analogously to the anode deposition. Then, the solution was dried in a muffle furnace for 10 minutes at 60°C .

The electrolyte was prepared using an iodine-based redox electrolyte solution, consisting on the mixture of 0.5 M solution of potassium iodide (KI) and 0.5 M solution of iodine (I_2) (1:1) ratio solubilized in 20 ml of acetonitrile to obtain the tri-iodide/iodide redox electrolyte.

The dye was extracted from *Lantana repens* fresh flowers petals, collected from the Botanical Garden of Rio de Janeiro. The petals were removed and washed. A solubility test was carried, and ethanol shown up to be the best solvent option. The solution was mixed during 30 minutes on a magnetic mixer for the dye extraction.

4. RESULTS AND DISCUSSION

4.1 Dye's characterization

FTIR (Fourier Transform Infrared) spectroscopy was used to analyze the sample and identify the characteristics of the dye molecules. Figure 3 shows the FTIR spectrum of a TiO₂ anode with the dye extracted from *Lantana repens* and shows the characteristic peaks of anthocyanin present in the dye sample (Sampaio et al., 2016). As can be seen on the region between 3500 and 3000 cm⁻¹ a peak that indicates the presence of H-O-H, that can be credited to the water air contamination and ethanol used as solvent. The region 1700 to 1500 cm⁻¹ shows a characteristic peak of C = C bond, present on the aromatic structure from the anthocyanin. The subtle broadband in the range of 2800–2900 cm⁻¹ indicates the presence of the vibrational mode of stretching C-O-C, as well presented in the anthocyanin molecule (Ahlamed et al., 2012).

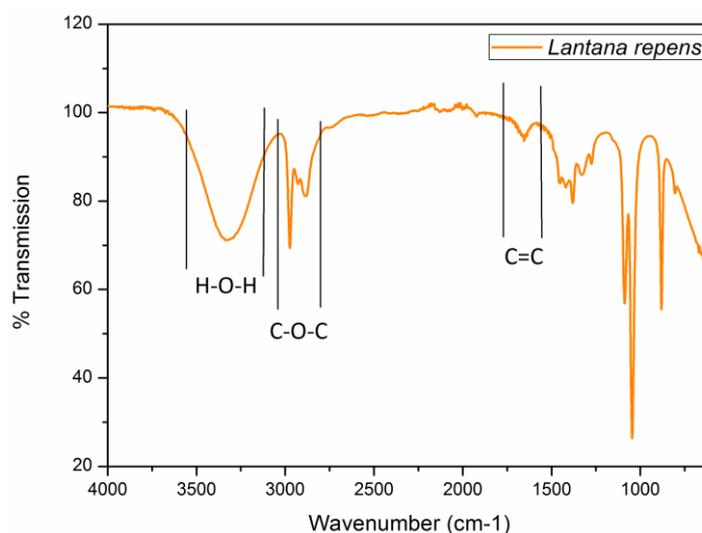


Figure 3. *Lantana repens* FTIR spectrum.

4.2. Structural characterization

The thin films structure and morphology could be verified with the use of 3D Atomic Force Microscopy (AFM) and Field Emission Scanning Electron Microscopy (JEOL® JSM-7100F). Figure 4 shows the AFM analysis of the deposited TiO₂ thin film surface. For good absorption of the dye in the substrate, it is necessary the presence of pores in the structure of the thin film, which must be uniform and mesoporous throughout the entire substrate. As indicated in Fig. 4, a range of 4 μm on the axis Z and low variation on the structure, confirm the desired surface for a good and efficient deposition of the dye molecules compared to the work of Sampaio et al. (2019).

The substrate surface can also be analyzed by SEM images (Fig. 5), which shows a uniform structure (Fig.5 A), correct granulometry of ~21 nm (Fig. 5 B) and confirms that the film has a uniformly scattered amount of nanoparticles facilitating the absorption of the dye from the prepared TiO₂ layer, settling the results obtained on the AFM result.

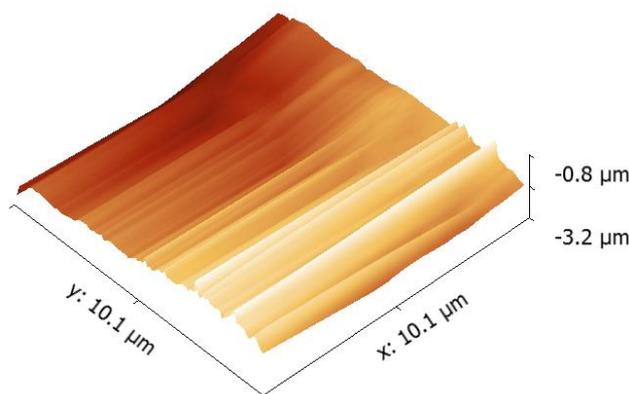


Figure 4. 3D AFM image of a TiO₂ film

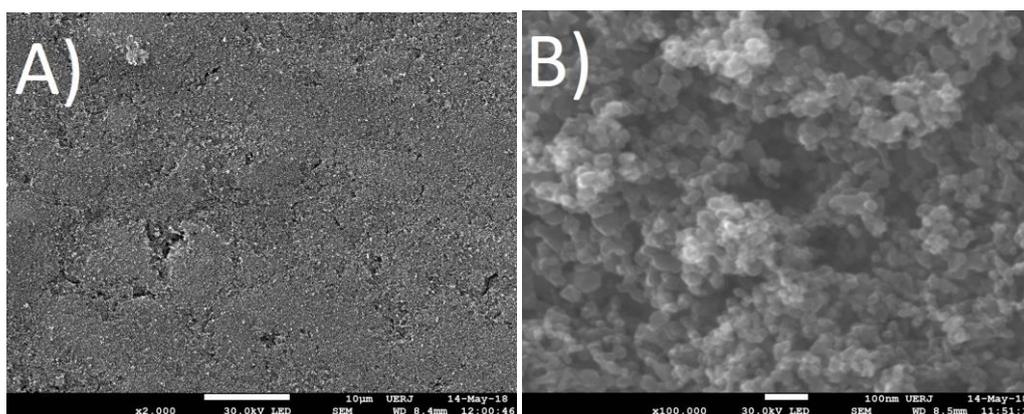


Figure 5. FESEM images of *Lantana repens* dye adsorbed TiO₂ electrode with different magnifications A) (x 2,000) B) (x 100,000)

4.3. Photovoltaic Performance

An artificial light, produced by a solar simulator (Ivisun®, IVIUM Technologies), was used for the *I-V* measurements. DSSC's performance was determined after 2 minutes of cell lighting. The irradiated area was about 400 mm² and data was processed by Labview® software.

Figure 5 shows the current versus voltage (*I* × *V*) curve for the sample sensitized by *Lantana repens* dye, using TiO₂ as anode and graphite as the cathode. From Fig. 5, it can be observed in the sample that the value of *V*_{oc} (open circuit voltage) was 485 mV and *I*_{sc} (short-circuit current) value was 0.4 mA, and a characteristic FF (Fill Factor) shape from *Anthocyanidin petunidin* radicals (Chang and Lo, 2010). The efficiency of light conversion reached was 0.76 %, which is a good result compared with anterior result of 0.13 % (Sampaio et al., 2019).

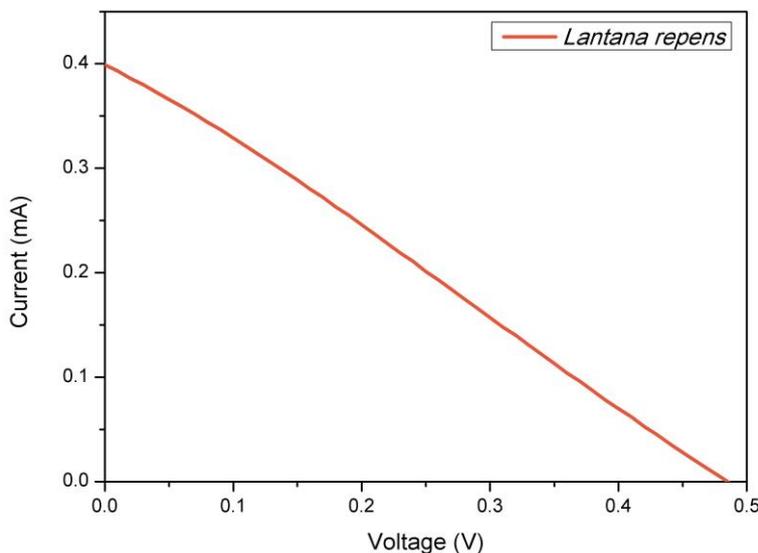


Figure 6. *Lantana repens* *I-V* characterization.

5. CONCLUSION

In this work, we have shown the nanostructured, morphological and electrochemical behavior of dye sensitized solar cells composed by spin-coated photo-anodes thin films, giving a desired uniform and mesoporous surface that facilitates the current flow and increases the dye absorption on the semiconductor film. The cell was sensitized by a new natural dye extracted from *Lantana repens* flowers petals containing *Anthocyanidin petunidin*, which increases the sun light absorption. The photovoltaic performance showed that the samples presented reasonably high *I*_{sc} and *V*_{oc} (0.4 mA and 485 mV, respectively), and good overall efficiency compared to the work of Sampaio et al. (2019), reaching 0.76 %. So, it is possible to verify the viability of the characterization system developed and the use of natural dyes as sensitizers, showing that the DSSC's work is promising as alternative to the current silicon based solar panels.

6. ACKNOWLEDGEMENTS

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