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Utilization of Extracted Natural Dye from *Tectona grandis* (Teak) as a Sensitizer for Dye-Sensitized Solar Cell

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ABSTRACT
Cost and energy payback time in relation to solar cell performances is one of the key parameters considered for mass application. In this research work, a low-cost, easily fabricated, and the more eco-friendly photovoltaic device was successfully developed using the dye synthesized from teak plant leaves. The dye-sensitized solar cell (DSSC) is made up of photoelectrode and counter electrodes. The photoelectrode was prepared by depositing zinc paste on an active area of 1cm^2 of an Indium tin oxide (ITO) glass. The glass was annealed at a temperature of 450^{0}C for 30 minutes and stained in a beaker containing teak dye (a dye extracted using ethanol) for 24 hours. Another ITO glass was placed some centimeters above a candle flame to form the counter electrode; the effect was a dark-shaded ITO glass. To have working DSSCs, a binder clip was introduced to couple the two electrodes and three drops of iodine (as an electrolyte) were dropped in between the electrodes to complete the fabrication process. The ethanol-extracted dye has an absorption spectrum of 342 nm at a small peak and a broad absorption wavelength in the range of 412-664 nm. The power conversion efficiency (η) of 0.44% was achieved through the developed solar cell.

Keywords: natural dye; ruthenium dye (inorganic dye); DSSCs; the power conversion efficiency

INTRODUCTION
The world population is on the rise, likewise, there is an increase in electricity consumption. However, fossil fuel, which is a major source of electricity production being non-renewable, is decreasing at an exponential rate with the increase in population. Coupled with the fact that fossil fuels pose harm to the environment (global warming), then there is a need for man to look for an alternative source (which is renewable, sustainable, and eco-friendly). Utilizing the power of the sun to generate electricity is a promising alternative, but there is a need for a photovoltaic device to convert the sun's energy through the radiation of photons on the solar panel into electrical power through a photovoltaic effect.

Photovoltaic devices can be categorized into first generation, second generation, and third generation solar cells. But under the third-generation solar cells categories falls the dye-sensitized solar cell (DSSC) [1]. DSSCs became more popular among other generations of solar cells in the photovoltaic research world when O'Regan and Gräetzel reported an efficiency (η) of 7.1% using inorganic Ruthenium (II) dye as a sensitizer for the fabrication of DSSCs [2]. This paves way for several investigations to be conducted using a different technique to improve the DSSC performance [3-7]. Compared to other categories of solar cell generations [1], DSSCs are low-cost, more eco-friendly photovoltaic devices.

The main components of DSSCs are the electrolyte, counter electrode, sensitizer, and thin film semiconductor electrode. The sensitizer (inorganic and organic dye) plays a crucial role in the DSSC performance [8-10] because it is able to capture the incoming photons which excite the dye from its neutral form to the excited form from the HOMO to the LUMO of the dye. At the LUMO, the excited dye gets oxidized (to form redox cation) by injecting electrons into the conduction band of the semiconductor electrode. A DSSCs efficiency can be affected by the type and nature of the sensitizer used [11-13]. Due to the chemical stability, photon absorption, and broad spectral range, high-efficiency (11%) ruthenium complexes are seen as one of the most efficient dyes [14].

However, the presence of heavy metal (ruthenium) in Ru complexes can pose a threat to the environment [15], and taking into account its complicated synthetic route, scarcity, and high cost, it is disadvantageous as a sensitizer in DSSCs. Attention is now being shifted towards the use of natural dye-sensitized solar cells [16-20]. Unlike Ruthenium complexes dye, natural dye is easily available, does not pose threat to the environment, simple extraction procedure, and is of low cost. Various parts of a plant using different solvents for extraction can be employed to prepare the natural dye. For this work, *Tectona grandis* (Teak leaves) dye extracted using ethanol is used as a sensitizer.

EXPERIMENT
The natural dye was prepared by plucking teak leaves, rinsed with water, and sun-dried. The dried leaves were crushed into smaller particles using mortar and pestle. 15g

of the sample was weighed and immersed in a beaker containing 45ml of ethanol, the solution was mixed for 1 hour through the use of a magnetic stirrer. The top of the beaker was covered using aluminum foil paper and kept at dark room temperature for 72 hours after which the solution was filtered using Whatman filter paper.

An ITO glass was used as the conducting glass. At room temperature, the ITO glass was rinsed with ethanol and distilled water to remove any impurities and left for some minutes to dry. The conducting side of the ITO glass which was determined using a multimeter was taped down at the edges using transparent tape to mark out an active area of $1cm^2$. 1g powdered ZnO was mixed with 2ml nitric acid solution (0.1M) and 0.5ml mixture (of distilled water with ethanol in a ratio of 3:7) to prepare the photoanode. The mixture was stirred vigorously inside a mortar with a pestle until a lump-free thick substance (thin film) was obtained.

"Doctor blade technique" was employed to deposit a thin film on an ITO glass. After 10 minutes of deposition, the tape was removed. To enable the thin film to completely sinter on the ITO glass, the glass was annealed at a temperature of 450^0C for 30 minutes inside a muffle furnace. This was left in the muffle furnace for 10 hours as the sudden change in environment can result in the breakage of the glass. For 24 hours, the annealed glass with the conducting side facing up was dipped inside a beaker (containing ethanol-extracted dye) using a tweezer at dark room temperature for complete ethanol-extracted dye molecular adsorption onto the ZnO semiconductor thin film. The glass was removed and ethanol was used to rinse the glass to remove any of the extracted dye solution left on the ITO glass apart from the active area which was left to dry at room temperature. This process completes the photoelectrode

Another conducting side of an ITO glass was subjected to candle flame until the dark shade of carbon covered its entire surface and this made up the counter electrode. The stained-dye electrode (photoelectrode) and the dark-shaded electrode (counter electrode) were pressed against each other using a binder clip and leaving small space at both sides for the attachment of alligator clips (Figure 1). The fabrication process was completed by adding 3 drops of iodine solution (electrolyte) at the edges of the plates. The iodine solution flows between the two plates by capillary action.

FIGURE 1: Fabricated Dye Sensitized Solar Cell

RESULT AND DISCUSSION

- **Absorption spectra of the dye**

The ethanol-extracted dye absorption spectra were achieved using UV-V Spectrophotometer. It can be seen clearly from Figure. 2 demonstrated below that within the UV (ultraviolet) to V (visible) light range, a small peak is seen at 342 nm, indicating it can absorb in the near Ultraviolet region and a broad absorption wavelength in the range of 412-664 nm (which shows it can absorb light in the visible region and thus satisfies the fundamental criteria as a sensitizer).

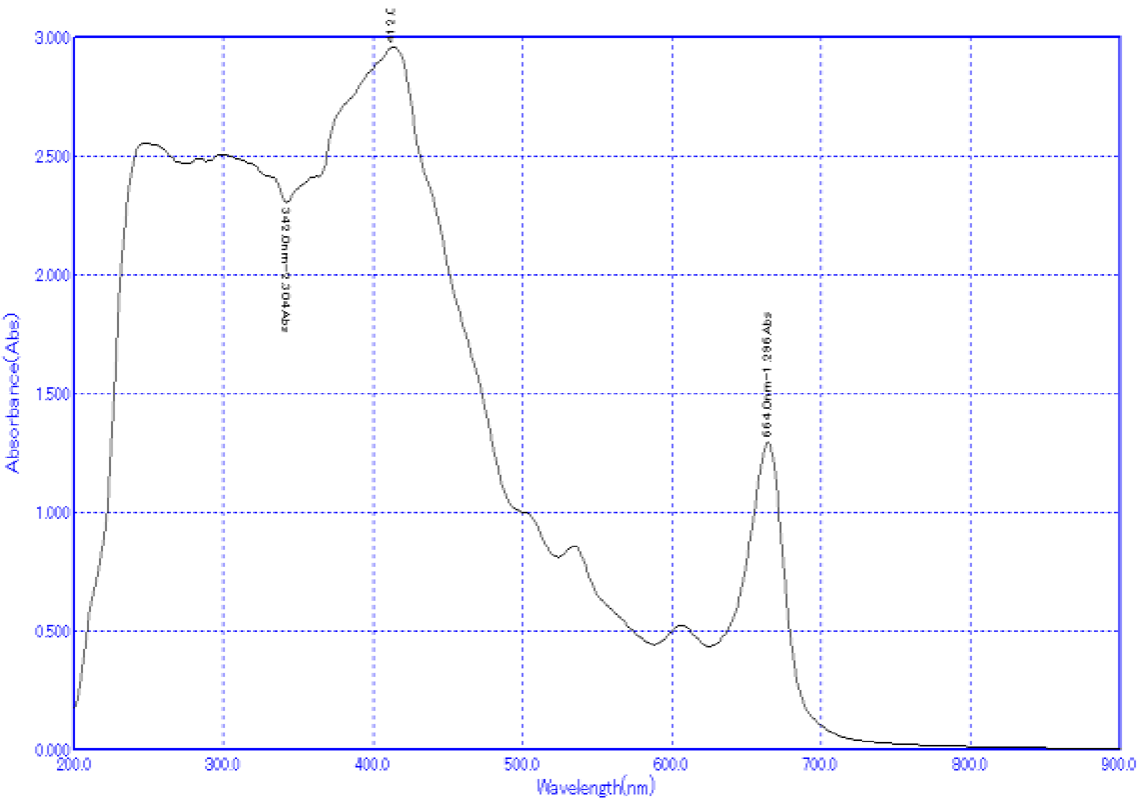

FIGURE 2: The absorption spectral of *Tectona grandis* (Teak)

- **Photoelectrochemical Performance of DSSC**

To determine the photoelectrochemical performance of the solar cell, the fabricated solar cell was exposed to a 100W white light bulb (1.5AM) source from a solar simulator connected to a source measure unit (Keithley 2400). Figure 3 shows the current density against voltage (J-V) graph curve for a better understanding of the photoelectrochemical performance of the developed DSSC.

In addition, other electrochemical parameters such as open circuit voltage (V_{oc}), Filled factor (FF), maximum power (W), short circuit current (J_{sc}), and efficiency (η) are well detailed in Table 1. Although the efficiency is as low as 0.44%. But then it is something that can be improved on from a research point of view since the dye source used was from a teak plant leaf.

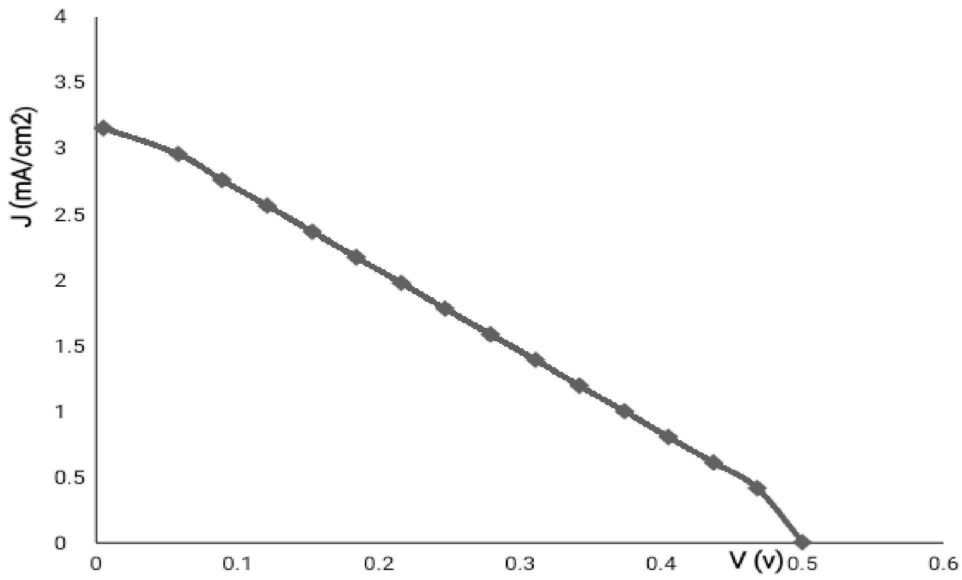

FIGURE 3: J-V (Current density against voltage) curve of *Tectona grandis* (Teak) used for the DSSC

The photoelectrochemical parameters obtained from the curve are summarized in Table 1 below.

TABLE 1: The photoelectrochemical parameters of Tectona *grandis* DSSCs

Natural Extract	J_{sc} (mA/cm²)	V_{oc} (V)	P_{max} (W)	FF	η (%)
Tectona grandis	3.155	0.5	4.422×10^{-4}	0.28	0.44

CONCLUSION

The dye-sensitized solar cell performance fabricated using *Tectona grandis* (Teak) as a sensitizer was successfully investigated. The absorption of the dye in the visible region spectrum confirmed its ideality as a sensitizer. The photoelectrochemical parameters efficiency of 0.44% is quite low compared to cells fabricated using inorganic dye. But the simple extraction procedure, availability, and environmental friendliness of natural dye are enough motivation to keep investigating the improving performance of DSSC using natural dye as a sensitizer.

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