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Fabrication and Characterization of TiO_2-Roselle Dye Sensitized Solar Cell Cathode Using Gum Arabic

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Abstract

This paper proposed an alternative source of carbon material from Gum Arabic for the fabrication of TiO_2-Roselle dye sensitized solar cell. Traditional Arabic Gum-ink made with gum acacia used to fabricate the cathode part of 2 x 2cm^2TiO_2-Roselle dye sensitized solar cell using Doctor-Blade method. It is then tested using keithley 2400 source meter under AM 1.5 (100mW/ cm^2) illumination from a Newport class A solar simulator. The result shows that by using Arabic Gum-ink an open circuit voltage, V_{oc}= 0.83V, short circuit current density, J_{sc}= 50μA cm^{-2}, fill factor, ff = 0.13 and energy conversion efficiency, η = 0.006% was produced.

Keywords: Dye Sensitized Solar Cell, Roselle (Zobo), TiO_2, ITO, Carbon Soot, Gum Arabic.

1.0 Introduction

In today's society, it is becoming ever important to find alternative sources of energy that are both cheap and efficient. To date, fossil fuels, namely, coal, oil, and natural gas, which were formed millions of years ago from the fossilized remains of plants and animals are the main energy sources [1]. Even before the industrial revolutions human life quality is greatly affected by the availability of energy. The escalated and savage consumption of conventional sources of energy are leading to forecasted energy and environmental crises[2]. Renewable energy sources such as solar energy are considered as a feasible alternative because “More energy from sunlight strikes Earth in 1 hour than all of the energy consumed by humans in an entire year[3]. As international concerns about energy and climate change increase, solar cells have become one of the most widely-researched methods of obtaining energy in "greener" ways than burning fossil fuels [4].

One of the new variants on the solar cell that is currently being researched is the dye-sensitized solar cell (DSSC), which was invented by Micheal Gratzel in 1991, where conventional systems take advantage of the semiconductor to absorb light and transport charge carriers, DSSCs separate these two functions[5].DSSC Solar cell is a semiconductor device that converts solar energy into electricity. This conversion is called the photovoltaic effect, and the field of research related to solar cells is known as photovoltaics. Photovoltaic cells have gained widespread acceptance as a source of clean and renewable energy. Although the cost of crystalline silicon solar cells has dropped significantly over the past decade, these devices are still too expensive to compete with conventional grid electricity. A promising alternative to conventional silicon cells is given by the Dye Sensitized Solar Cells (DSSC). A sensitizer, which is anchored to the surface of a wide band semiconductor, absorbs sunlight. When light is incident on the dye, electrons are injected from the dye into the conduction band of the solid, accounting for the charge separation. The electrons are then transported in the conduction band of the semiconductor to the charge collector. Using sensitizers with a broad absorption band along with nanocrystalline oxide films (most commonly titanium dioxide) allows for the efficient capture of a large fraction of sunlight over a large spectral range.

First and second generations photovoltaic cells are mainly constructed from semiconductors including crystalline silicon, III-V compounds, cadmium telluride, and copper indium selenide/sulphide [3]. Low cost solar cells have been the subject of intensive research work for the last three decades[6]. Amorphous semiconductors were announced as one of the most

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promising materials for low cost energy production[7]. However, dye sensitized solar cells DSSCs emerged as a new class of low cost energy conversion devices with simple manufacturing procedures

Basically a solar cell, SC, consists of a junction of p- and n-type semiconductors. At the interface the Fermi levels of both semiconductors are the same, generating depletion region, and therefore, a charge separation[8]. When photons are absorbed in the p-type region, an electron-hole pair is created[9]. Each electron is then injected in the n-type region and the hole goes across p-type region. In the case of TFSCs the constitutes of material for the SCs production is considerably less, thus it reduces costs[10]. Some other advantages consist on the possibility of working with lighter materials and flexible substrates[11].

Most solar cell characteristics can be obtained from simple I-V measurements. Fig.1 shows the I-V characteristics of a typical solar cell under forward bias and illumination. The short circuit current (I_{sc}) is the current through the solar cell when the voltage across the solar cell is zero. The open circuit voltage (Voc) is the voltage across the solar cell when the current through the solar cell is zero and it is the maximum voltage available from the solar cell. The maximum power point (P_{max}) is the condition under which thesolar cell generates its maximumpower; the current and voltage inthis condition are defined as I_{max} andV_{max} (respectively). The fill factor (FF) equation (1) and the energy conversion efficiency (η) equation (2)are metrics used to characterize theperformance of the solar cell. The fillfactor is defined as the ratio of P_{max}divided by the product of Voc and I_{sc}.The conversion efficiency is definedas the ratio of P_{max} to the product ofthe input light irradiance (E) and the solar cell surface area A_c[12].

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \tag{1}$$

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{E \times A_c} \tag{2}$$

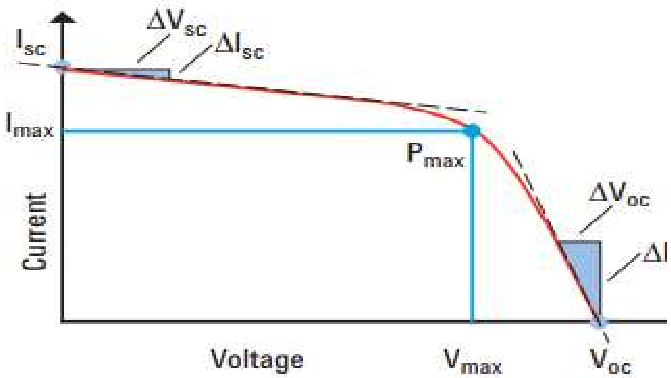

Fig.1: Typical I-V forward bias characteristics of a solar cell (Agilent Technologies, 2009) [12].

Although there are a variety of methods to obtain R_{sh} and R_s, one of the most straightforward techniques is to measure the slope of I-V characteristics as shown in Figure 1.

$$R_{sh} = -\frac{\Delta V_{sc}}{\Delta I_{sc}} \tag{3}$$

$$R_s = -\frac{\Delta V_{oc}}{\Delta I_{oc}} \tag{4}$$

R_{sh} and $R_s$can be obtained from Equation (3) and (4) respectively.

2.0 Experiment

2.1 Materials

Titanium Dioxide TiO_2 (79.89Mw, 99%), isopropanol, ethanol were procured from Tofel Ltd, Kano-Nigeria, Indium tin oxide coated (ITO) glass slide (25mm x 25mm with surface resistivity 10Ω/sq) obtained from Techinstro Ltd-India, silver paste from ENSON Japan Ltd. I^-/I^{-3} was prepared based on the Nanolab procedure. All these materials are analytical grade and used as received without any further purification.

2.2 Preparation of Gum Arabic

Gum acacia was obtained from Jigawa state, Nigeria. The samples were pulverized with the aid of mechanical blender (liquidizer). 20g of each pulverized sample was weighed using Adventure OHAUS Electronic weighing balance model AR2740 mixed with 50g of well blended powdered activated carbon soot and boiled with distil water for 3 hours. The extract of the sample were decanted to remove the residual part of the samples as shown in Fig.2.

Fig.2: Gum Arabic

2.3 Fabrication of DSSC

In this work, the deposition of our counter electrode on indium doped tin oxide (ITO) glass substrate was enabled through the doctor- blading method. The conducting side of a 2.5cm x 2.5cm ITO was identified and covered on each of the parallel edges with a single layer of sellotape to control the thickness of the TiO_2 film. The covered ITO edge measuring provided the electrical contact area. Before deposition, the glass substrates were cleaned with isopropanol, then Ethanol. The carbon paste (Arabic Gum) which was prepared through Doctor-blading method was applied at one of the edges of the conducting glass and distributed with a squeegee sliding over the tape-covered edges. The electrodes was kept on the safer side for about 24hours before removing the adhesive tapes. The edges were cleaned with ethanol. Nanocrystalline titanium (iv) oxide was used as photo-electrode. The same blade method was adopted in depositing the TiO_2 layer and the film was allowed to dry naturally for five minutes before removing the adhesive tapes. The edges were also cleaned with ethanol. The electrodes was sintered for 30 minutes at a temperature of 400^0C using the Vecstar LF2 MOD furnace. The contained liquid of the paste burns away, leaving the Titania nanoparticles sintered together. This process ensures electrical contact between particles and good adhesion to the TCO glass substrate[13]. The furnace was allowed to cool down before removing the annealed electrode. This is because a sudden change in temperature can cause the glass to break. The resulting nanoporous layer made from the sintered particles was stored in a sealed environment to avoid moisture absorption from ambient air. The TiO_2 photo-electrodes were immersed into a solution of the local dye for 15 minutes. The binder clips was cleaned with ethanol before it was rightly placed on the dyed working electrode. The conductive side of the transparent electrodes was gently placed on top of conducting carbonized side of the counter electrodes. We introduced 0.5ml drops of the electrolyte (Iodide/triiodide) through one of the gap left between the two glass plates by capillary action. Electrical contacts were made by applying the silver paste (ENSON, EN06B8) along the conducting side of electrode. The active surface area of *Roselle*-dyed cell was $4cm^2$ shown in (Fig.3).

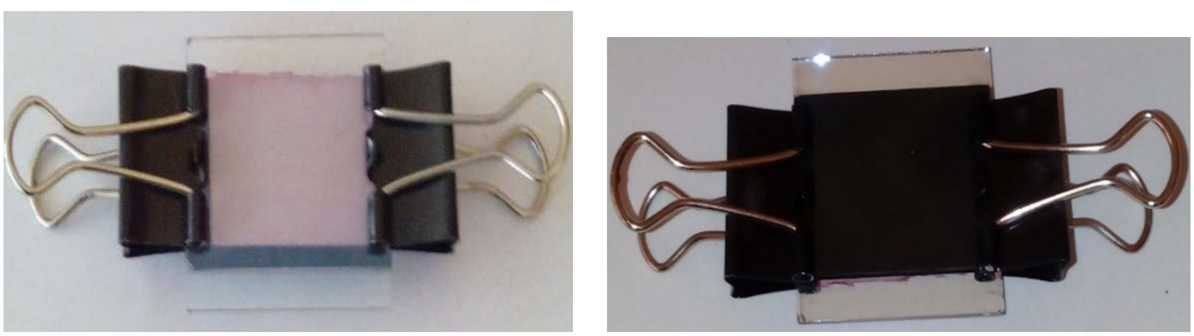

Fig.3: Typical picture of front and back view of Titanium Dioxide-Roselle DSSC

3.0 Photovoltaic Performance of DSSC

The performance of the DSSCs was determined using a calibrated AM 1.5 solar simulator Controller (Newport, Oriel instruments, Model: 69922) with a light intensity of 100 $mWcm^{-2}$ and a computer controlled digital source meter (Keithley, Model: 2400).

4.0 Results and Discussion

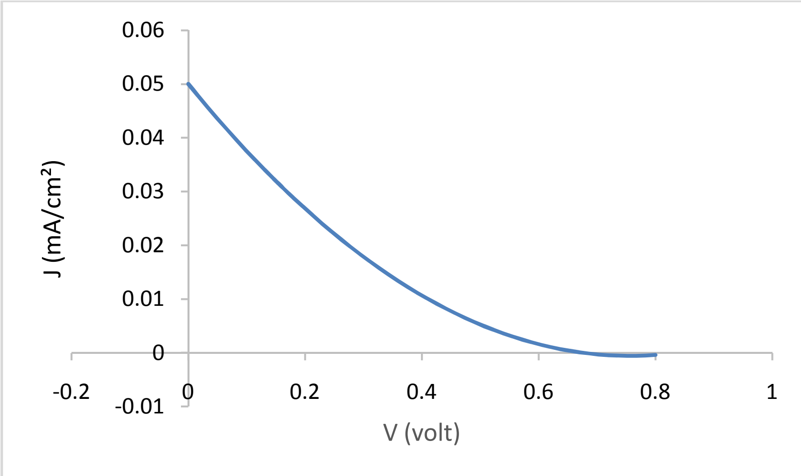

Fig. 4: J-V characteristic curve of TiO_2-Roselle Dye Sensitized Solar Cell

4.1 J-V Output Parameters of TiO_2-Roselle Dye Sensitized Solar Cell

The short circuit current density, open circuit voltage and the maximum output power density obtained directly from Fig.4 are;

$J_{sc} = 50\mu Acm^{-2}$ at $V_{oc} = 0$ and

$V_{oc} = 0.83V$ at $J_{sc} = 0$

$P_{maxoutput} = 5.529121 \times 10^{-6} Wcm^{-2}$.

Also, $A = 4.0cm^2 E = 1000Wm^{-2} = 100mWcm^{-2}, (PDensity)_{input} = (E \times A_c)/4.0cm^2 = (100mWcm^{-2} \times 4.0cm^2)/4.0cm^2 = 100mWcm^{-2}$

using equation (1) and (2)

$$FF = \frac{(Powerdensity)_{max}}{V_{oc} \times J_{sc}} = \frac{5.529121 \times 10^{-6}}{0.83 \times 0.05 \times 10^{-3}} = 0.13$$

$$\eta = \frac{(Powerdensity)_{max}}{(PDensity)_{input}} \times 100\% = \frac{5.529121 \times 10^{-6}}{100 \times 10^{-3}} = 0.0055\%$$

The results of this experiment includes short-circuit current density (Jsc), open circuit voltage (Voc), fill factor (FF) and energy conversion efficiency (η) for Titanium Dioxide-Roselle DSSC are listed in T able 1.

Table 1: J-V result of dye sensitized titanium dioxide solar cells using Arabic ink

Size of the cell	V_{oc} (v)	J_{oc} ($\mu A/cm^2$)	P_{max} ($\mu W/cm^2$)	FF	η
2 x 2cm^2	0.83	50	5.529	0.13	0.0055

In this research work the energy conversion efficiency DSSC, after annealing at 400°C generated its optimum value of, 0.005%, which is reasonably good when compared with work of [14] who investigated the performance of Hibiscuss sabdariffa (Roselle/Zobo) and Azardirachta Indica (Nimtree) TiO_2 DSSC with solar energy conversion efficiency; 0.002 % and 0.00017 %.

5.0 Conclusion

Dye-sensitized solar cells (DSSCs) are considered a promising future source of low-cost solar power[15]. At present, however, the most efficient DSSC designs utilize iodide-based electrolytes, which are highly corrosive and absorb strongly in some regions of the visible spectrum[16]. However, this efficiency (0.0055%) may appear to be low for any practical application, the cell performance is comparable to similar low-cost DSSC technology available today.

6.0 Acknowledgement

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7.0 Reference

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