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Hall Effect Measurement and Current–Voltage Features of Roselle Plant (*Hibiscus Sabigriffa*) Dye-Doped Nano Crystalline-TiO_2 and the Effect of Sensitization on Dye Sensitized Solar Cell

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ABSTRACT
Hall Effect measurement of thin films is one of the methods used to ascertain the electrical resistivity of thin film, sheet resistance of thin film, conductivity of the thin film, Hall mobility of the thin film, charge carrier density and type of charge carriers present in a particular cell or film. The thin films were developed using the screen printing technique to deposit TiO_2 on the substrate and the Chemical vapour deposition method to develop Fluorine doped Oxide layer on the substrates. The semiconductor (TiO_2) blocking band was developed by adding 0.1 mole of titanium isopropoxide and 0.4 mole of acetyle acetone to the substrate using spin coating method. The Hall effect analysis carried out shows the following results: mobility charge = 1.303 cm^2/Vs, bulk concentration= -5.274 $\times\ 10^{20}/cm^3$, sheet resistance =4.641 $\times\ 10^2\ \Omega/\square$, resistivity = 9,081E-3Ω cm, A-C cross hall coefficient = -2.092E-2 Cm^3/C, magneto –resistance = 6.729E-2Ω, sheet concentration = -1.055$\times\ 10^{16}/cm^2$, conductivity = 1.101E+2 /ΩCm, average hall coefficient = -1.184E-2 Cm^3/C, B-D cross hall coefficient = -2.757E-3 Cm^3/C and ratio of vertical / horizontal = 8.887E-1. We deduced that the charge carrier discovered in the developed FTO down to block band dyed semiconductor (TiO_2) films is a p-junction semiconductor type of charge carrier since the mobility charge value is positive with value of 1.303E+0Cm^2/Vs. When the mobility charge value is negative, it becomes n-junction type. Other characterization analyses were carried out.

Keywords:
Hall Effect,
Sheet resistance,
Conductivity,
Hall mobility,
Carrier density,
Spin coating.

INTRODUCTION

Hall Effect is one of the best methods of measuring the presence of magnetic field in a conductor. The Hall Effect method has been used to study the type of polarity that were present in the moving charges that form the electric current in a conductor (Okoye and Imosobomeh, 2024; Gerrit, 2019; Nwokoye and Okoye, 2020; Nguu *et al*., 2014; Hug *et al*., 2013; Okoye, 2022; Ugwu *et al*., 2015 and Kabir *et al*., 2019).

The Hall Effect measurement in semiconductors allow the particle size and band structure present in the semiconductor material to be discovered for both negative charge carriers or positive charge carrier or absence of an effective negative charge carriers (Fraser, 2011; Ananthakumar *et al*., 2019; Ekanayake *et al*., 2018 and Nazeeruddin *et al*., 2007). The Hall Effect measurements are very important in electrical analysis of TiO_2 materials and thin films because the polarity of charge carrier of the thin film, charge carrier density of the thin film and Hall mobility of the thin film need to be derived from the Hall voltage which are gotten from the Hall Effect measurement (Okoye, 2022; Ozuomba *et al*., 2011; Al-Rawashdeh *et al*., 2018; Andery *et al*., 2014).

The usefulness of Hall Effect measurement include; reference and motion tracking, tracking and measurement of magnetic fields for instance in cars, electronics, ignition systems and determination of polarity of the charge carriers in TiO_2 (Murakoshi *et al*., 1997 and Seigo *et al*., 2008).

The electrical analysis of TiO_2 and films prepared in this research were carried out using Hall Effect technique of measurement (Mehmood *et al*., 2014; Hagfeldt and

Grätzel, 2000; and Dai, 2002). The films were developed using the screen printing technique to deposit TiO_2 on the glass and using chemical vapour application technique to prepare fluorine doped oxide layer on the substrates (Furukawa, 2009; Lin *et al*., 2008; Macht *et al*., 2002; Brian et al., 2009 and Becquerel, 1839). The sol gel precursor was deposited on the substrate using spin coating technique to prepare block band of quantum dot solar cells (Calogero and Di-Marco, 2008 and Calogero *et al*., 2010). The aim of this paper is to investigate the Hall Effect measurement and current–voltage features of Roselle plant (*Hibiscus Sabigriffa*) dye-doped Nano crystalline-TiO_2 and to show the effect of sensitization on Quantum Dot Solar Cell.

MATERIALS AND METHODS

Experimental Procedure

Preparation of Blocking Layers of the quantum dot solar cell

The blocking layer is the dense titanium (IV) oxide (TiO_2) thin film. The precussor for the dense TiO_2 is a mixture of 0.1 mole of titanium isopropoxide and 0.4 mole of acetyl acetole (from sigma Aldrich >99% purity). The solgel precussor was applied on the substrate using spin coating method. The substrate was later annealed at 500^0C.

Development of Natural Dyes

The green leaves of Roselle Plant (*hibiscus sabigriffa)* were used to develop the natural dyes known as chlorophyll in plant. 5g of the leaves were weighed and measured out using weighing balance. 60 ml mixture of water and methanol (50:50 ratios) was measured using cylinder for the purpose of grinding this leaf. The 5g of leaf and 60ml of mixed solvent was grinded for 5 minutes using electrical grinder. When the grinding is completed, the liquid was filtered and the dye separated and transferred inside a cubic beaker.

Sensitization of Natural Dye and Nanocrystalline Blocking Layer of the Thin Film

The prepared natural dyes were used to sensitize the blocking layer substrate. The developed block band glass was immersed into the organic dye. After immersing the nanocrystalline glass inside the organic dye, the immersed glass was cleaned using the developed solvent (50:50 ratio of water and methanol). The glass was dried using REX – C400 hot plate machine under the temperature of 80ºC for 5 minutes. The UV spectroscopic data recording was carried out on Roselle Plant (*hibiscus sabigriffa)* dye using UV spectrometer to determine the absorbance level of each dye and that of TiO_2 glass. The recorded data was used to measure the absorptance spectra, transmittance value, energy band gap, Fill Factor FF, short circuit current Isc, open circuit voltage V_{oC}, maximum power point MPP, sheet resistance R_{sh}, serial resistance R_{send}, efficiency of the solar cell η, Tauc plot for energy band gap calculation and Beer-Lambarts law (Matt-Law, 1996).

Simulated solar irradiation was recorded using solar simulator, model 4200-scs semiconductor characterization machine under the irradiation of AM 1.5 9100mWcm^{-2} and the current voltage signal were captured by a digital keithley multimeter model 2400 coupled to a computer.

Hall Effect Measurement Procedures

The Hall Effect is the measurement of a voltage difference (the Hall voltage) of an electrical conductor placed in a transverse position to the direction of the movement of an electric current in the conductor and to an applied magnetic field which is placed in a perpendicular direction to the movement of current (Lee and Kang, 2010). The Hall Effect appears when two ends of a conductor are placed in a perpendicular position to the movement of current in magnetic field. When current is supplied to the conductive plate, the charges contained in the conductor will start moving in a cyclic form, positive charge (hole) aligned first followed by negative charge (electron). The dielectric particles are then positioned between positive charge (hole) and negative charge (electron) and the potential difference was recorded. The main important of Hall Effect is that we use it for the measurements and characterization of both new and old materials. The Hall Effect measuring apparatus includes high pressure gas, gas cylinder, filter, dryer, thermocouple machine, vacuum chamber, magnetic structure, vacuum pump, spring loaded probes and computer system. This Hall Effect has been used to identify the polarity of the moving charges that form the electric current. For semiconductors, the particle size and layer structure can give rise to both negative charge (electron-like) or positive charge (hole) or (absence of an electron) that form the effective charge carriers.

The current characteristics of the films were studied using a four point probes method. The circuit was designed in such a way that the voltage across the transverse distance of the films and the corresponding values of the current were captured using silver paste to maintain good ohmic contact to the film. The values of the resistance for the films deposited were measured by connecting the four point probe to a current supply and the inner probes to a volts meter, while the current flows between the outer probes, the voltage drop across the probes is measured. The average resistance of the film (the sheet resistance) and resistivity of bulk conductor is measured using eqtn (1).

$$\rho = RMt/I. \qquad (1)$$

Where

$R = V/I$ is the resistance, M is the Width of the conductor, t is the thickness and I is the length of the conductor.

RESULTS AND DISCUSSION

The UV-Visible Spectrophotometer has the TiO_2 film electrode attached to the slot and was read and recorded with a computer connected to the Perkin Elmer Lambda 35. The absorbance values of the film were read and it fall within the range of 230-1100nm. Figure 1 shows the spectra lines of the transmittance values of the dyes.

Based on the percentage of transmittance obtained from UV-Vis Spectrophotometer, absorbance of Roselle Plant (*hibiscus sabigriffa)* dyed TiO_2 were obtained according to eqtn (2)

$$A = 2 - log_{10}\%T \quad (2)$$

where A is defined as absorbance and T as transmittance). Hence to estimate the absorbance values of the sampled dyed TiO_2, we use eqtn (2). The Energy band gap graphs, transmittance graphs and absorption coefficient graph are shown in Figures 1-3.

The plot of transmittance (%) as a function of wavelength for Hibiscus Sabigriffa Plant synthesized on blocking layer is shown in figure 1.

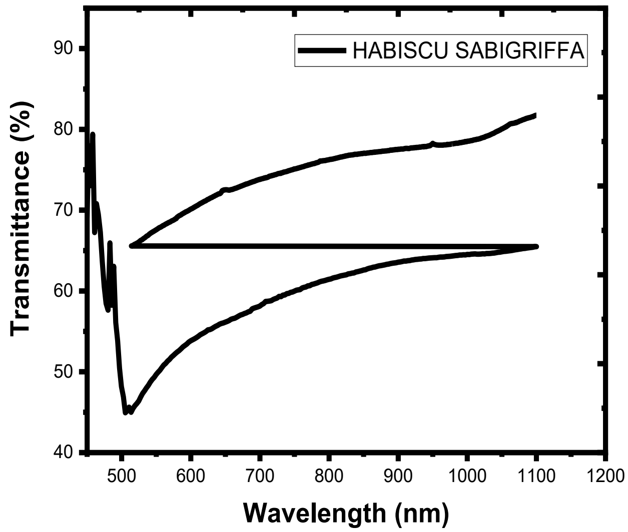

Figure 1: The graph of transmittance (%) as a function of wavelength for Habiscus Sabigriffa plant

The plot shows that the wavelength of incident radiation increases as the transmittance increases. The transmittance below 45% is in the ultraviolet region while the transmittance above 56% is in the infrared region. Films with high transmittance in the ultraviolet region is useful in photosynthetic coatings while films of low transmittance in the infrared region is used in the mass production of solar cells and for the fabrication of solar panel. Films with high transmittance in the ultraviolet region exhibit selective transmittance of photosynthetic active radiation (PAR) and also used as reflector and dielectric filter.

The band gap energy and transition types were determined mathematically by processing of the data obtained from the optical absorbance as a function of wavelength with the following relationships for near edge absorption as in eqtn (3)

$$\alpha = (hv - Q_g)^{\frac{n}{2}}, \quad (3)$$

where α is the absorption coefficient, ν is the frequency, h is the Planck's constant, Q_g is the band gap energy, while n carries the value of either 1 or 4. The band gap energy could be derived from a straight line graph of α^2 as a function of hυ; and by extrapolation of the straight line portion of the plot on the energy axis will also give band gap energy. If a straight line graph is obtained from n=1, it indicates a direct transition between the states of the semiconductor, whereas the transition is indirect if a straight line graph is obtained from n = 4 as shown in Fig 2.

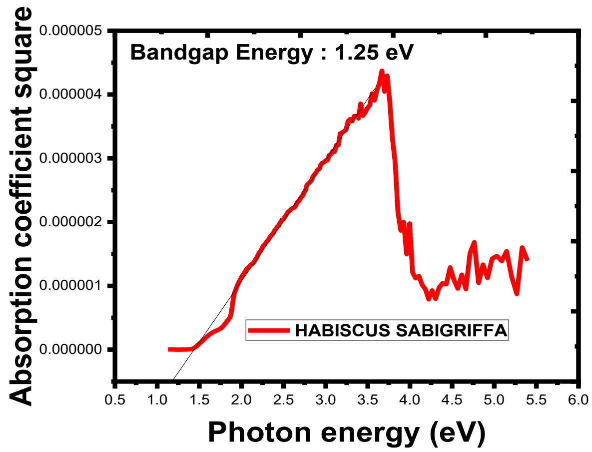

Figure 2: The graph of absorption coefficient square as a function of photon energy for Habiscus Sabigriffa

The band gap energy as plotted for Roselle Plant (*Hibiscus Sabigriffa)* synthesized on block layer is 1.25 eV. From Fig. 2, it was revealed that the absorption coefficient squared multiplies exponentially with photon energy. The range of the band gap energy makes the material useful for development of blue and green light emitting devices, photocell window layer and light emitting laser diode.

Absorption Coefficient analysis of dyed TiO_2 for the grown films were carried out. Fig. 3 reveals the plot of absorption coefficient as a function of photon energy. Absorption coefficient however gives direction on how far light that enters into a material of a particular wavelength can diffuse before it is absorbed.

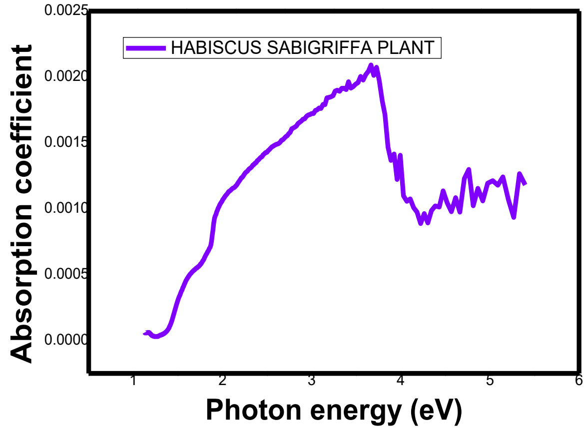

Figure 3: The graph of absorption coefficient as a function of photon energy for Habiscus Sabigriffa plant

The absorption coefficient spectra of the films revealed that the developed films have a sharp edge at the lower energies band. This is because light energies below the band gap (3.0eV and above) do not have enough energy to excite an electron into the conduction band from the valence band. However, the light was not absorbed. But as the photon energy multiplied enough to about 3.25eV, the absorption coefficient multiplies with the photon energy. A material with higher absorption coefficients is more readily absorbs photons, which excite electrons into the conduction band. Knowing the absorption coefficient of materials aids engineers in determining which material to use in their solar cell production.

The Hibiscus Sabigriffa Plant organic dye extracts have shown good absorbance qualities. The efficiency of a solar cell and incident power converted to electricity was determined using eqtn (4).

Normally, a good dye should absorb very well for all wavelengths below 920 nm. The quantum dot solar cells developed using these natural dyes gave overall photocurrent conversion efficiencies of η 0.235%. One of the greatest challenges to TiO_2 quantum dot solar cells is its ability to strongly absorb dye molecules.

The maximum power P_{max} and the efficiency η of a solar cell is calculated as the fraction of incident power which is converted to electricity are given by eqtns (4) and (5)

$$P_{max} = V_{OC}I_{SC}FF \quad (4)$$

$$\eta = \frac{V_{OC}I_{SC}FF}{P_{in}} \quad (5)$$

where *Voc* is the open-circuit voltage, *Isc* is the short-circuit current; *FF* is the fill factor, *η* is the efficiency and P_{in} is incident power.

The current density plots as a function of the power - voltage analysis for the quantum dot solar cells for hibiscus dyes is shown in Fig. 4.

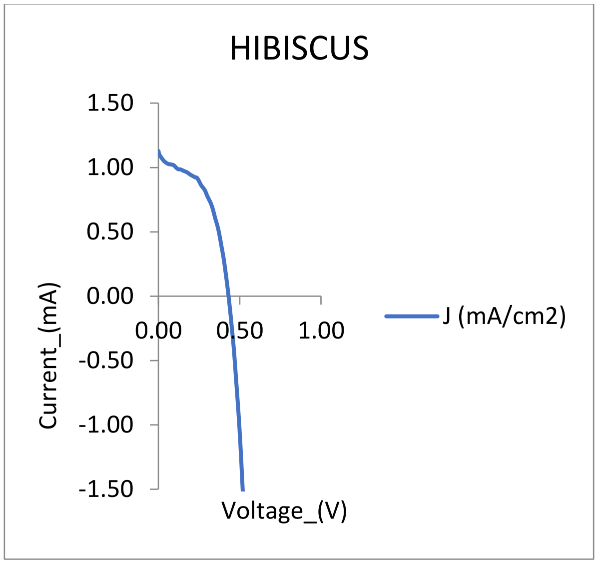

Figure 4(a): Current/Voltage

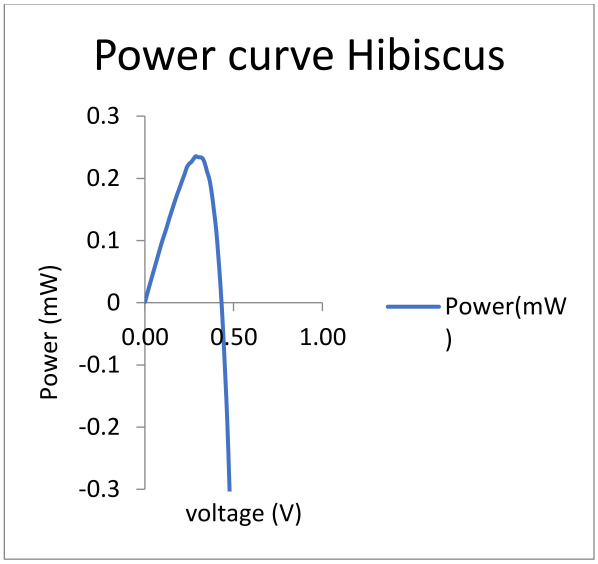

Figure 4(b): Power/Voltage

The solar simulation results of Hibiscus Sabigriffa dyed TiO_2 in fig 4.0 shows the following results; (I_{sc}) = 1.127 mA, (V_{oc}) = 0.427 V, FF(%) = 48.931 %, ɳ(%) = o.235 % and MPPT(Mw) = 0.235 Mw. These results is in agreement that the requirement for the production of quantum dot solar cells as confirmed in the works of some other researchers (Jewett and Serway, 2010).

Hall Effect Measurement and Result

The Hall Effect measurement results show that in equilibrium, the magnetic force (F_B) is equivalent to the electric force (F_E) and for a metal of width L, the developed Hall voltage (V_H) is given by eqtn (7)

$$VH = EH\ L = VnBYL \quad (6)$$

Where E_H is the calculated Hall electric field, V_n is the mean velocity of charge carriers, and B_Y is magnetic line in the Y- axis.

The mean velocity (V_n) of charge carriers is calculated from eqtn [6] and given by eqtn (7).

$$Vn = \frac{1n}{mdqLZ} \quad (7)$$

Where I_n is the electric current via the sample, m_d is the charge carrier density, (q) is the primary charge, L is the TIO_2 width and Z is the TIO_2 thickness.

The Hall voltage (V_H) and Hall coefficient (Q_H) is as in eqtn (8)

$$VH = \frac{1nBY}{mdqZ} = QH\frac{1n\ BY}{Z} \quad (8)$$

Where QH is the Hall coefficient given by eqtn (9)

$$QH = \frac{1}{mdq} \quad (9)$$

According to eqtn (9), the Hall coefficient (QH) varies indirectly with the number of charge carrier density (m_d). From eqtn (9), the Hall coefficient is represented in terms of measured quantities according to eqtn (10)

$$QH = \frac{ZVH}{1nBY} \quad (Cm^3\ C^{-1}) \quad (10)$$

The Hall effect results measured from the substrate developed using film doped with hibiscus dyes are written as follows; mobility charge = 1.303E+0cm^2/Vs, bulk concentration = -5.274E+20/Cm^3, sheet resistance =4.641E+2Ω/□, resistivity = 9,081E-3Ω Cm, A-C cross hall coefficient = -2.092E-2 Cm^3/C, magneto–resistance = 6.729E-2Ω, sheet concentration = -1.055E+ 16/Cm^2, conductivity = 1.101E+2 /ΩCm, average hall coefficient = -1.184E-2 Cm^3/C, B-D cross hall coefficient = -2.757E-3 Cm^3/C, ratio of vertical/horizontal = 8.887E-1. We deduce that the charge carrier present in the fabricated FTO down to block layer dyed TiO_2 films is P-Junction semiconductor type of Charge carrier since the mobility charge value is positive (1.303E+0Cm^2/Vs), when the mobility charge value is negative it becomes n-Junction type. The average hall coefficient (-1.184E-2 Cm^3/C) varies inversely with the number of charge carrier density, the result shows that the average hall coefficient ratio in the fabricated FTO down to block layer dyed TiO_2 films is negative. The magneto – resistance result (6.729E-2Ω) is equivalent to the electric force in the fabricated FTO down to block layer dyed TiO_2. The sheet resistance result (4.641E+2Ω/□) shows the resistance value of semiconductor devices through doping. The resistivity of the fabricated FTO down to block layer dyed TiO_2 is (9,081E-3Ω Cm) and it shows how strongly it resists electric current. A low resistivity indicates a material that readily allows electric current to pass through it. The conductivity of the fabricated FTO down to block layer dyed TiO_2 is (1.101E+2 /ΩCm) and it shows the ability of the electrolyte solution to conduct electricity. The greater the electrical conductivity within the material the higher the current density for a given applied potential difference. The bulk concentration of the fabricated thin film is (-5.274E+20/Cm^3) and it shows the concentration at the bulk solution away from the electrode surface. The A-C cross hall coefficient of the developed film is (-2.092E-2 Cm^3/C) and this shows the produced potential difference (the hall voltage) across an electrical conductor that is transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. The sheet concentration of the fabricated thin film is (-1.055E+ 16/Cm^2) and it shows the number of charge carriers in per volume of the electrolyte solution. The B-D cross hall coefficient is (- 2.757E-3 Cm^3/C) and it shows the ratio of the induced electric field to the product of the current density and the applied magnetic field perpendicular to the current. The ratio of vertical/horizontal line is (8.887E-1). The vertical line value shows the measurement of the line that is parallel to the vertical direction or a horizontal line shows the line normal to a vertical line which rises straight up from a horizontal line or plane. .

CONCLUSION

Electrical characterization of thin films was carried out through solar simulation of film or Hall Effect measurement to determine the electrical resistivity, sheet resistance, conductivity, hall mobility, charge carriers density and type of charge carriers present in a particular cell or film. The solar simulation and characterization of the cells took place here before encapsulation of the dye sensitized solar cells in various categories. I_{sc} = 1.127 mA, V_{oc} = 0.427 V, FF(%) = 48.931 %, η(%) = 0.235% and MPPT = 0.235 mW for *Hibiscus Sabigriffa* dyed TiO_2. The transmittance of above 56% in the infrared region and transmittance below 45% in the ultraviolet region was achieved for these plant; *Hibiscus Sabigriffa* Plant Synthesized On FTO. Films with high transmittance in the ultraviolet region is useful in photosynthetic coatings while films of low transmittance in the infrared region is used in the mass production of solar cells and for the fabrication of solar panel. Films with high transmittance in the ultraviolet region exhibit selective transmittance of photosynthetic active radiation (PAR) and also used as reflector and dielectric filter. Which meet the requirement as unique characteristics of an ideal photo-sensitize. The Hall Effect assessments include the assessments of the Hall voltage (V_H) and current (I_n) for steady applied magnetic field (B_Y). The Hall Voltage was picked in a perpendicular position to the magnetic field and to the position of an electric current flowing through the semiconductor using Hall Effect meters that provide current and magnetic fields and clamp meter which support the probes wires and the film. Using Hall Effect meters to study the electrical characterization enclosed in a developed film will help to reveal the old and new electrical properties that have been existing in a given developed nanostructure. The type of charge carrier present in the fabricated FTO down to block layer structure of the films were revealed using Hall Effect assessment.

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