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Magnetic Field Effect on the Electrical Characteristics of a Monocrystalline n^+pp^+ Silicon Solar Cell

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ABSTRACT

In this paper, the effect of magnetic field on I-V characteristics of a silicon solar cell of n+pp+ structure is studied in dark and illumination modes. In dark, both the current and the voltage decrease with increasing the magnetic field in forward bias. However in reverse bias, the behavior is different. Under illumination, the effect of magnetic field on I-V characteristics of the silicon solar cell is studied experimentally and simulated using Neural Network Algorithm (NNA). Both short circuit current (I_{sc}) and open circuit voltage (V_{oc}) are measured under the influence of magnetic field. The solar cell efficiency and the fill factor (FF) are calculated without and with the magnetic field. This performance testing of the solar cell under magnetic field can be considered as one of the non-destructive reliability tools.

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1. INTRODUCTION

The increasing usage of solar cells for energy conversion has led to the need for reliable testing investigations. The trend in recent years in photovoltaic research and industry has been concerned with the non-destructive testing, i.e., reliability measurements. These tools have been deployed for single-crystal solar cells, GaAs solar cell and thin film polycrystalline devices of inexpensive substrates [1]. The reliability tools can be classified into temperature stress [2], and light induced junction modifications in solar cell construction [3]. One method for measuring all recombination parameters in the base region of solar cells has been presented in [4]. Magnetic field assisted bonding tool has been used for proper encapsulation of a thin-film Cu_2S-CdS solar cell. This was made possible by using a thin layer of nickel coating on the substrate as a back-electrode. Results dependent on the series resistance, short-circuit current, open-circuit voltage, shunt resistance, diode ideality factor and fill factor on the magnetic field have been investigated. Moreover, the time, the substrate temperature and the grid coating have been presented and discussed [5].

The effect of magnetic field on the photocurrent generated by a bulk heterojunction solar cell made of organic materials has been investigated in [6]. An increase in photocurrent of ~9% has been obtained under magnetic field less than 100 mT at the operating voltage. This increase in photocurrent was attributed to an increase in the rate of intersystem crossing, between the singlet and triplet states, leading to a higher net efficiency of exciton dissociation. Close to the open-circuit voltage, an increase of more than two orders of magnitude in the photocurrent could be obtained under the applied magnetic field [6]. In 2003, an observation of the change in current through an organic light emitting diode (OLED) under magnetic field, due to magneto resistance, was noticed [7]. The response of single-crystal Si solar cell, irradiated by spontaneous and stimulated light sources, under the effect of a high-intensity electric field has been studied [8]. It has been observed that the electric field has greater effects on the operation of the solar cell when irradiated by a white lamp. A significant change in the open circuit voltage, V_{oc}, value has been measured using a green LED compared to the other light sources. Their results suggested that the reduction in the V_{oc} value of the solar cell is related to losses due to bulk and surface recombination and ionization under high-intensity electric field.

Theoretical 3D study of a polycrystalline silicon solar cell in frequency modulation under polychromatic illumination and applied magnetic field has been studied [9]. The influence of the applied magnetic field on the diode current density, electric power-photovoltage and photocurrent-photovoltage characteristics has been discussed [10]. A numerical simulation for the determination of 2D current distributions from magnetic field measurements using some developed algorithm has been carried out [11]. These currents were generated experimentally in the thin layer of a solar cell (the emitter) under light and laser illumination. The three components of the induced magnetic field above the surface of the sample have been measured by sensitive magnetic field detectors.

In this paper, the performance characteristics of a n^+pp^+ silicon solar cell is studied in dark and illumination modes under the effect of magnetic field. Artificial Neural Network (ANN) simulation of the experimental I-V solar cell characteristics under magnetic filed is carried out in illumination mode using EasyNN-plus software. I-V characteristics of the solar cell, in dark and illumination, is presented in section 2. Section 3 is devoted to the experimental setup and measurements. The results and discussion are presented in section 4. Section 5 is devoted to conclusion.

2. I-V CHARACTERISTICS OF A SI SOLAR CELL FOR DARK AND ILLUMINATION MODES

For so many years, I-V measurements have been used to evaluate the electrical performance of photovoltaic cells and diodes. Since 1960's, both dark and light I-V measurements have been commonly used to analyze the effects of series resistance and other parameters on solar cell performance [12]-[14]. Recent work has described the distinction between light I-V and dark I-V measurements in the determination of the series resistance of solar cells [15]. When the solar cell is conducted under different temperatures, I-V curves provide many parameters of the solar cell, e.g., the temperature dependence of the shunt resistance, diode ideality factor, the energy and concentration of the dominant recombination center, the lifetime of the charge carriers. I-V relation of a solar cell is given by:

$$I = I_{01}\left[\exp\left(\frac{qV}{n_1 kT}\right) - 1\right] + I_{02}\left[\exp\left(\frac{qV}{n_2 kT}\right) - 1\right] + \frac{q(V - IR_s)}{R_{sh}} \tag{1}$$

Where $I_{0,}$ q, V, k, T and n are the reverse saturation current, the electronic charge, the applied voltage, the Boltzmann's constant, the temperature and the ideality factor, respectively. R_s and R_{sh} are the series and shunt resistances, respectively. The subscripts 1 and 2 indicate that two possible contributions to the diode current can be presented. The series resistance of large-area solar cells is small and can be negligible. Photocurrent - photovoltage (I-V) characteristic is obtained by the following equation:

$$J_u = J_{ou}\left[\exp\left(\frac{q}{AkT}\right)(V_u - J_u R_s) - 1\right] - J_d \tag{2}$$

Where R_s is the internal series resistance. J_u is the diode saturation current determined by material proprieties, electronic charge q and Boltzmann constant k. T is the absolute temperature and A is a dimensionless constant between 1 and 3. However, in most bifacial silicon solar cells, A takes values from 1.5 to 2.

I–V curve under illumination can be described as a superposition of dark I–V current and a voltage independent photocurrent. The principal power losses in a solar cell are that associated with the light absorption and recombination processes of the charge carriers. The diffusion effects in the junction region and electron–hole recombinations limit the fill factor (FF), so that FF value determines the maximum power point position. The observed fill factor, in silicon solar cells, decreases with temperature increase. This is attributed to the series resistance R_s and the shunt resistance R_{sh} of the solar cell that can be determined from the I–V dark characteristics.

The effect of the series resistance R_s on the fill factor can be described by:

$$FF = FF_0(1 - \frac{R_s I_{sc}}{V_{oc}}) \quad (3)$$

Where FF_0 is the fill factor for the ideal solar cell characteristic. There is also a relationship between the shunt resistance R_{sh} and the fill factor for a single silicon solar cell. Namely, the larger the R_{sh} value, the larger is the fill factor. Larger shunt or/and smaller series resistances provide a higher efficiency of solar cells [5].

A Double side silicon solar cell with n+pp+ structure has been studied under magnetic field [16]. Diffusion length and the diffusion constant of the excess minority carriers as well as the intrinsic excess minority carriers diffusion constant and their mobility are important parameters affecting the solar cells performance under a magnetic field. The excess minority carriers density profiles decrease with the increase of the minority carrier's recombination velocity at the junction. For front side illumination, the higher point of excess minority carriers is near the junction. The photocurrent density profiles decrease with increasing the magnetic field. The observed change in the photocurrent I_{ph} of the solar cells in response to a magnetic field can be caused by a decrease in the diffusion length of excitons.

3. EXPERIMENTAL SET UP AND MEASUREMENTS

Dark I-V measurements were carried out on the Si solar cell while covering it to eliminate the light generated current. A power supply was used to force the electric current through the solar cell from the positive to the negative contact. Current and voltage were simultaneously measured as the voltage of the power supply was increased from zero to a predetermined upper limit. The direction of current flow in dark was opposite to that when the solar cell was exposed to light, but the electrical configuration showed a forward biased solar cell.

Dark as well as light I-V measurements can be used to analyze the electrical characteristics of a solar cell. For modules composed of a combination of solar cells, the dark I-V measurement procedure is still valid, but it requires a larger power supply and a slightly different interpretation of the measured data. Such a system for dark I-V measurements can be used for three purposes: i) to diagnose changes in solar cell or module performance following field-aging or accelerated environmental testing, ii) to provide performance parameters used in numerical simulation of photovoltaic cells or arrays, and iii) to help in evaluating the production consistency of modules. The schematic diagram of the I-V characteristics in dark and illumination under magnetic field is shown in Figure 1.

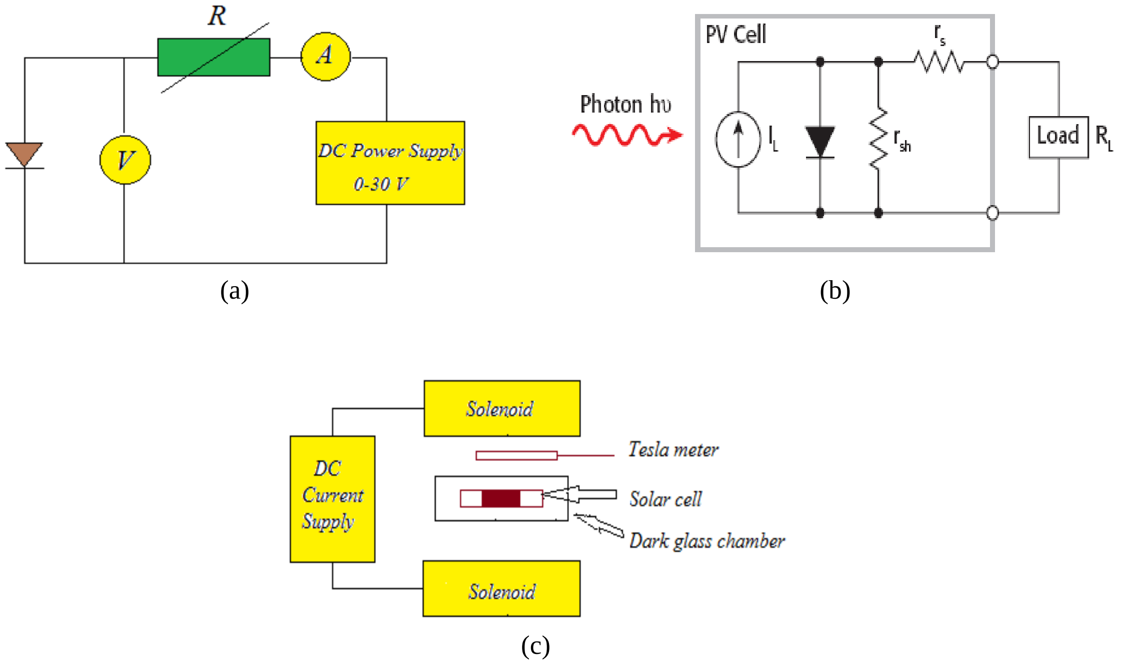

Figure 1. a) Circuit layout of dark I-V characteristics for 1.8 cm^2 Si solar cell, b) Equivalent circuit in dark and illumination modes. c) Experiment set up

The dark I-V circuit was constructed from an AC/DC power supply (0-30V) (Leybold company, Germany) and two digital multimeters (PeackTeck. No. 3695). In order to produce a suitable magnetic field, a circuit was built up from a constant current power supply (model DPS-50, Scientific Equipment, Roorkee, India) and a solenoid coils EMU-50 (Scientific Equipment & Services, Roorkee, India). Finally, a digital Teslameter with probe (No. 4060.50 of range 0-2000mT) was used for measuring the magnetic field. This circuit can produce a magnetic field of up to 1000 or 1100 mT. A Halogen Tungsten lamp of 50W/12V and a luxmeter have been used for measuring light intensity falling on the n+pp+ Si solar cell of area 1.8 cm^2. Under illumination, a suitable load resistance from 0-220 Ω (Leybold company-Germany) was used.

4. RESULTS AND DISCUSSION

4.1. I-V Characteristics for Dark Mode

Figure 2 illustrates the dark I-V measurements at 17^0 C (room temperature) for available single-crystal silicon of 1.80 cm^2 area of n+pp+ construction. The shape and linearity of the measured curve at different current levels can be used to determine electrical parameters for the solar cell: such as, series resistance, shunt resistance, diode factor, and saturation current. For instance, the degree of curvature to the right at high current levels is an indication of the magnitude of series resistance (R_s). Similarly, large curvature at low current levels indicates low shunt resistance (R_{sh}). An inflection in the curve near mid current levels may indicate the presence of nonideal (n = 1) carrier recombination losses.

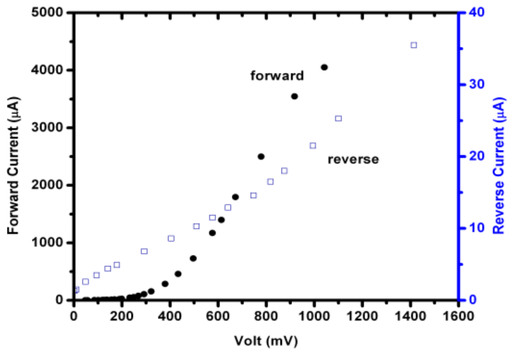

Figure 2. Dark I-V characteristics of a Si solar cell in forward and reverse direction

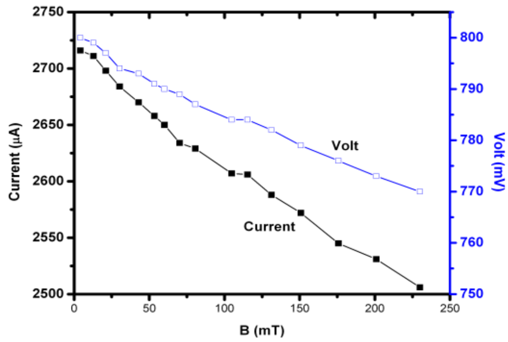

Figure 3. Dark current and voltage versus magnetic field for a n^+pp^+ Si solar cell in forward direction

For the solar cell shown in Figure 1, the typical operating current is approximately 20 to 30 mA, but measurements were performed to higher currents for better sensitivity in the determination of R_s.

When a solar cell, placed in a magnetic field, is biased in forward direction and dark conditions, a drop in the solar cell current as well as voltage occurs as shown in Figure 3.

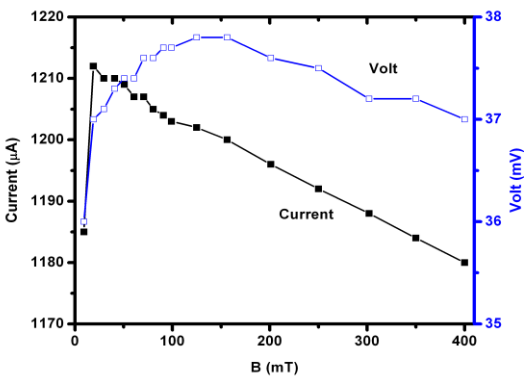

Figure 4. Dark current and voltage with magnetic field for a n^+ pp^+ Si solar cell in reverse direction

This is due to the creation of deteriorated areas in the solar cells that causes current losses. However, in reverse direction, the behavior is a little bit different. As the magnetic field increases, the solar cell biasing voltage and current slightly increase and then decrease as shown in Figure 4.

From the results, the solar cell voltage increases with magnetic field (B) until B is equal to150 mT. Then the solar cell voltage decreases. On the other hand, the solar cell current abruptly increases with B but after B = 25 mT the solar cell current decreases linearly. We can consider that the single crystal silicon solar cell under forward bias (or reverse bias) represents a capacitor and under the effect of a magnetic field a double exchange between the electrons and holes occurs. While the distance between the electrons and holes decreases, the diffusion capacitance of the solar cell decreases (i.e., solar cell resistance decreases while its conductance increases), and hence the solar cell voltage and current decrease. The magnetic field shape and strength affects the charged particle flux on the solar cell film and appears to have a strong influence on the final solar cell performance.

The degradation of solar cell efficiency often depends on the external load resistance and the illumination. In this study, both factors are fixed. But the electrical performance is investigated under an external variable magnetic field. The localization of the shunting areas is essential for further investigations of the current flow in solar cell under a magnetic field. Moreover, under a magnetic field, the drop in solar cell voltage may be due to the solar cell shunt resistance decrease. The resistivity in a particular direction decreases when a magnetic field is applied [17]-[19]. On the other hand, the I_{sc} under a magnetic field decreases, may be due to the decrease in the solar cell series resistance. Similar behavior is achieved at comparatively small fields in suitably strained manganite films. While the mechanism of these effects is not fully understood, it may arise from spin dependent scattering at interfaces between domains or within an individual domain.

4.2. I-V Characteristics for Front Illumination Mode

The results of I-V characteristics for front side solar cell illumination mode are shown in Figure 5. Without magnetic field, the I-V characteristics under illumination give normal values of the curve. The values of the photocurrent have normal open circuit position, which is suitable for the solar cell area and type. When a magnetic field is applied, we get a slightly lower I-V curve. The short circuit current I_{sc} and the open circuit voltage V_{oc} are near 31.5 mA and 510 mV, respectively. These values are related to the white light source which is a halogen tungsten lamp of 50mW/cm^2. On the other hand, under a magnetic field of 200 mT, both I_{sc} and V_{oc} slightly decrease as shown in Figure 6.

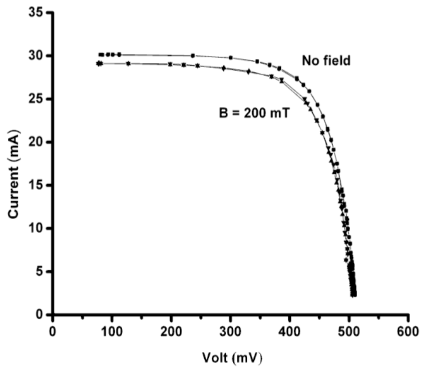

Figure 5. I-V characteristics of a n^+pp^+ Si solar cell with and without magnetic field (symbols) and with ANN simulation in front illumination mode (curve)

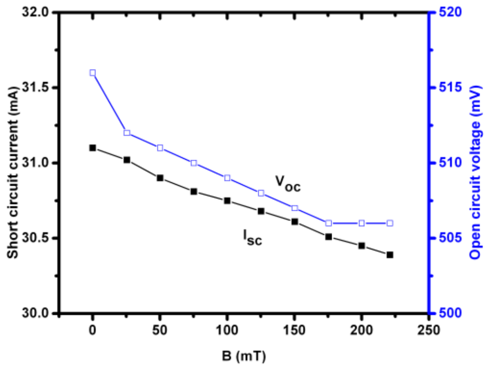

Figure 6. I_{sc} and V_{oc} under magnetic field, B (mT), for a Si solar cell of area 1.8 cm^2 at room temperature 17^{0}C

The I_{sc} under 200 mT decreased by 0.7 mA (i.e. 2.2%) while the corresponding value for V_{oc} shows a reduction by 1.93%. Figure 5 and 6 show that under magnetic field, the illumination I–V characteristics curve of n+pp+ single crystal silicon solar cell slightly falls where V_{oc} decreases in a different behaviour in comparison to I_{sc}. I_{sc} linearly decreases while V_{oc} does not. I-V characteristics simulation, under magnetic field, for front illumination mode is presented using EasyNN-plus software (as shown in Figure 5) [20]. The application of magnetic field results in degradation of both the efficiency and the fill factor values. It is observed that while the solar cell efficiency and the fill factor are 13.2% and 74%, respectively, without magnetic field, they are 12.27% and 71.8%, respectively, with magnetic field.

5. CONCLUSION

Without applying magnetic field, the dark I–V characteristic for a single crystalline silicon solar cell of n+pp+ structure yields a standard curve of semiconductor diode. However, under magnetic field, the dark forward I–V characteristics sustain a large variation, where a drop of the solar cell current and voltage profiles occurs. In dark reverse direction, both current and voltage increase up to a maximum and then decrease. I–V characteristics curve in front illumination mode has shown a slight drop in the solar cell photocurrent and photovoltage profiles when a magnetic field is applied. Moreover, the short circuit current and open circuit voltage are degraded. Consequently, the fill factor and the efficiency of the solar cell degrade when a magnetic field is applied.

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