MEASUREMENT OF DIFFUSION LENGTH IN P-N JUNCTION SILICON SOLAR CELL

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Abstract

In this work, p-n junction silicon solar cells were fabricated using Plasma-assisted deposition technique, The minority-carriers diffusion length in the base region of a silicon solar cell has been determined by measuring the short-circuit current as a function of the wavelength of incident light. The incident light intensity required to produce a given short-circuit current is a linear function of the reciprocal absorption coefficient for each wavelength. and the extrapolation of this relation to zero intensity yields the diffusion length. The accuracy of this method appears to be greatly accepted.

Introduction

Crystalline silicon solar cells are nowadays well performing and reliable, commercially available and widely used in a variety of photovoltaic systems. However, their cost is still too high to be competitive with classical electricity production. Therefore, photovoltaic devices are mainly used in nice markets. It will not be possible that a substantial part (e.g. a few percent) of the electricity be produced by photovoltaic systems, until the cell and panel cost is reduced with a factor of about five. There is doubt that a larger production volume and normal technological evolution will eventually enable such a drastic cost reduction. The physical reason for the shortcomings of silicon as a solar cell material is its poor optical absorption coefficient a(λ). If no technological sophistication for enhanced light trapping is introduced, a silicon wafer of 200μm thickness is needed to absorb the sunlight almost completely. As a consequence, a minority carrier diffusion length larger than 100 μm is needed to collect the generated electrons and holes. The need for thick cells of high crystalline quality is inherent to silicon, and this is the main reason for the high cell cost [1]. In thin film solar cells the physical and chemical properties of the interfaces between the different layers mainly determine the electronic device properties [2].

The energy generation of solar cells is due to the photo-electric effect, which includes a photon interacting with matter by loosing its energy and using this energy to promote an electron to a higher energy level. If incident light hits a semiconductor it creates electron-hole pairs if the energy of the incident photons is higher than the energy band-gap of the semiconductor material. If the two carrier types are prevented from recombining, their increased electrical energy can be used for applications. Since the voltage depends on the band-gap, the output power is a compromise between low band-gaps for more current and high for more voltage. This sets a principle limit to efficiency of about 31% without concentration for a single band-gap cell.

The most common type of solar cells is p-n junction type. In an ideal case, the dark current (i.e. current-voltage characteristic in the dark) is given by the Shockley equation: .

$$I(V)=I_s[\exp(qV/kT)-1] \quad \text{....................(1)}$$

If light is incident on the solar cell, electron-hole pairs are generated as described before. Electrons drift to the n-type region and holes to the p-type region which leads to a negative external current in the forward bias case.

The minority-carrier diffusion length in a solar cell is the most important factor affecting the conversion efficiency and spectral response of the cell. The diffusion length in bulk semiconductors, epitaxial layers, and diffused junction solar cells has been measured by the surface photovoltage method (SPV) [3-7].

The Plasma-assisted deposition technique, the surface of a bulk semiconductor or a diffused junction is illuminated with chopped monochromatic radiation with energy slightly higher than the energy gap of the semiconductor. When the depletion layer thickness at the surface or the depth of the diffused junction (t) is much smaller than the diffusion length (L) (t«L) and the thickness of specimen (d) is much larger than the diffusion length (d>>L), then at «1, a d»1, where a is the optical absorption coefficient.

The incident light intensity required to produce a given surface photovoltage Vsp (or open-circuit voltage Voc in the case of a diffused junction) is a linear function of the reciprocal absorption coefficient when the carrier injection is at a low level. The extrapolation of this linear plot to zero intensity yields the diffusion length (L) as the negative intercept. The use of Voc is convenient for the measurement of the effective diffusion length in the base region of solar cells. The Voc of an illuminated solar cell is given by [8]:

Voc =kT/q ln[Isc/Is+1] ....(2)

Where Isc and Is are short-circuit current and saturation current, respectively. Low illumination levels are necessary to produce a Voc of 20 mV or less so that Voc is essentially a linear function of Isc and thus the light intensity. At high illumination levels, a small error in setting Voc may result in a large error in the light intensity.

Experiment

In this work, p-n junction silicon solar cells were fabricated. Single-crystalline n-type silicon wafers of 4×4 cm^2 surface and 0.5 mm thickness were used as substrates. Using the plasma-assisted deposition system with 10-6torr vacuum pressure and 750 W discharge power, a 200 nm indium thin films were deposited on the n-type substrate. Plasma-assisted deposition technique includes both depositing and consecutive heating processes, which induce the indium atoms to penetrate deeper in the n-type substrate. So, an In-doped silicon layer (p-type) was formed and hence a p-n junction was created. The indium layer was chemically removed from the central part of the sample and the surrounding. In layer represent front contact. A 200 nm aluminum layer thickness was deposited on the back surface of the substrate to represent the backside contact. The structures were then etched chemically with CP-4 solution to remove any residual oxides. The structure of the p-n junction solar cell is shown in Fig.(1). According to the conventional relations of p-n junction, the width of depletion layer is found to be (~200nm) and the absorption coefficient is 104 cm^{-1}).

Electrical measurements were carried out using a Farnell DC power supply and Keithly616 digital millimeter. A 120W maximum power halogen lamp was used for irradiation measurements. The power density of the lamp was adjustable within (0-230)W/cm^2.

Results and Discussion

Fig.(2) shows the conversion characteristics of the produced solar cell. It is shown that the maximum value of the short-circuit current (Isc) is (475 mA) and that of the open circuit voltage (VoC) is (2.2V). Therefore, the fill factor (F.F.) has a maximum of (50.3%) at maximum output current of (335 mA) and maximum output voltage of (L57V). as well, the maximum conversion efficiency is about (0.7%) at incident intensit of (75 W/cm^2).

The short-circuit current (Isc) is used to measure the collection of photogenerated carriers. Since Isc is a linear function of light intensity up to AM1.5 higher illumination levels, the accuracy for high light bias levels may be greatly improved the current produced by a solar cell under illumination is given by

$I=I_J-I_L$..(3)

where IL is the photocurrent and IJ is the junction current flowing in the opposite direction. At low voltages, l0 mV or less, the junction current is negligible. When a shallow junction n+/p solar cell is illuminated with monochromatic radiation of low absorption coefficient, such as that in the wavelength range (0.8-1.03)µm for silico6, the measured current is essentially the photocurrent from the p region and written as [9]:

$$I_{SC}=\frac{W_0 \alpha L}{\alpha^2 L^2-1}\Psi \qquad (4a)$$

$$\Psi=\left[\alpha L\exp(-\alpha t)-\exp(-\alpha t)\coth\left(\frac{d-t}{L}\right)+\exp(-\alpha d)\operatorname{csch}\left(\frac{d-t}{L}\right)\right] \qquad (4b)$$

where Wo is the intensity incident into the surface and symbols have the same meaning as defined above. Fig.(3) depicts the short-circuit current versus diffusion length according to Eq. (4). The short-circuit current is rapidly decreasing as the diffusion length increases by factor of 5, but it remain approximately as the diffusion length increases more. Hence, the short-circuit current is decreased by 25% of its initial value at L=2 µm. This decrease is mainly due to the role of specimen thickness (d) in absorbing the incident light intensity.

When d>2L and αL>1, the term {exp(-αd). csh[d-t/L]}becomes negligible (~0), and {coth[(d-t)/L_] } approaches unity (~1). Eq. (4a) can then be written as

$$I_{SC}=\frac{W_0 L\exp(-\alpha t)}{\left(\alpha^{-1}+L\right)} \qquad (5)$$

Fig.(4) shows the same relation of Fig.(3) but according to Eq. (5). The short-circuit current (Isc) is increased as the diffusion length (L) is increased~ a factor of (5 Above this, the increase in current (Isc) is very small as it will be determined mainly by the absorption process, which in turn is determined by the adsorption depth (α^{-1}). If the light intensity incident on the base region, $W=W_o\exp(-\alpha t)$, is adjusted to maintain a given Isc for all wavelengths, then Eq. (5) is reduced to

$$I=K(a^{-1}+L) \qquad (6)$$

where K is a constant and its value depends only on cell parameters and the value of Isc to be maintained. The effects of the back-surface field, trapping, etc., have not been considered. However, the SPV technique has been shown to be valid when the thickness of epitaxial layers is 4L or greater [6]. Thus, the back-surface field could be ignored if this condition is met.

To test the validity of Eq. (6), the minority-carrier diffusion length in a diffused n^+/p-single-crystalline silicon solar cells was measured by the standard SPV technique, the Voc of carrier collection, and the Isc method of carrier collection. The experimental arrangement is similar to the SPV apparatus used by other works [6, 10].

Fig.(5) shows the plots of adjusted intensity versus reciprocal absorption coefficient (d) for the three techniques (constant Isc, constant Voc and SPV). In each case, the diffusion length is obtained from the negative intercept on the α^{-1} axis, 19 µm, and the variation is within the expected experimental accuracy.

Conclusions

In concluding comments, the short-circuit current (Isc) of a solar cell may be used for the measuring the minority-carrier diffusion length in its base region. The linear dependence of Isc on the intensity of illuminations allows accurate measurements of effective diffusion lengths. The design of low-cost and high-efficient silicon solar cells is determined by the relations of diffusion length with all the other parameters such as thickness, absorption coefficient, depletion layer width and the sunlight level at which the solar cell is operated.

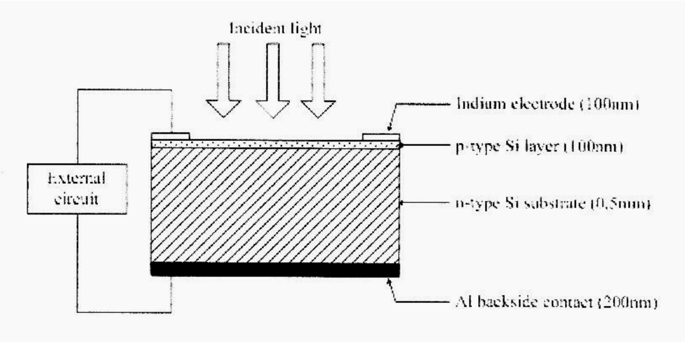

Fig. (1) : Schematic diagram of the p-n junction silicon solar cell.

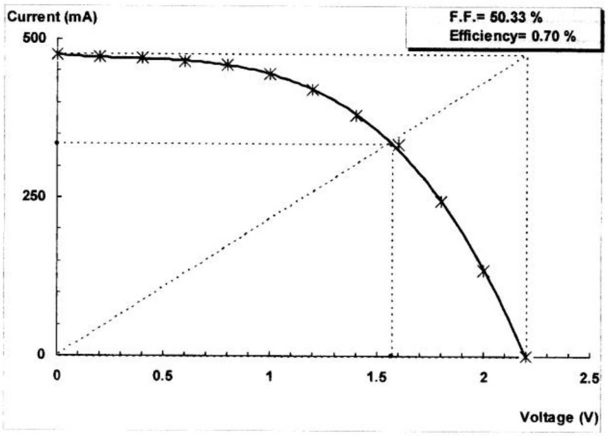

Fig.(2) : The conversion characteristics of the produced p-n junction solar cell the peak output current is 335mA and peak voltage is 0.157V.

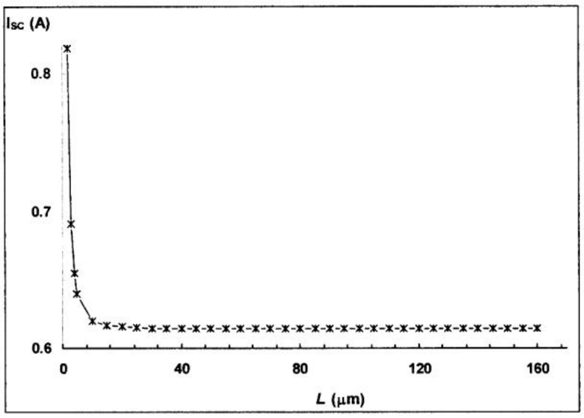

Fig.(3) : Short-circuit current (Isc) vr. Diffusion length (L) calculated according to Eq.(4).

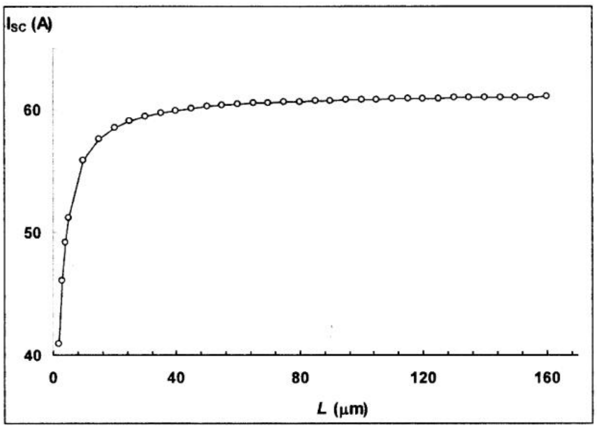

Fig.(4) : Short-circuit current (Isc) vr diffusion length (L) calculated according to eq.(5).

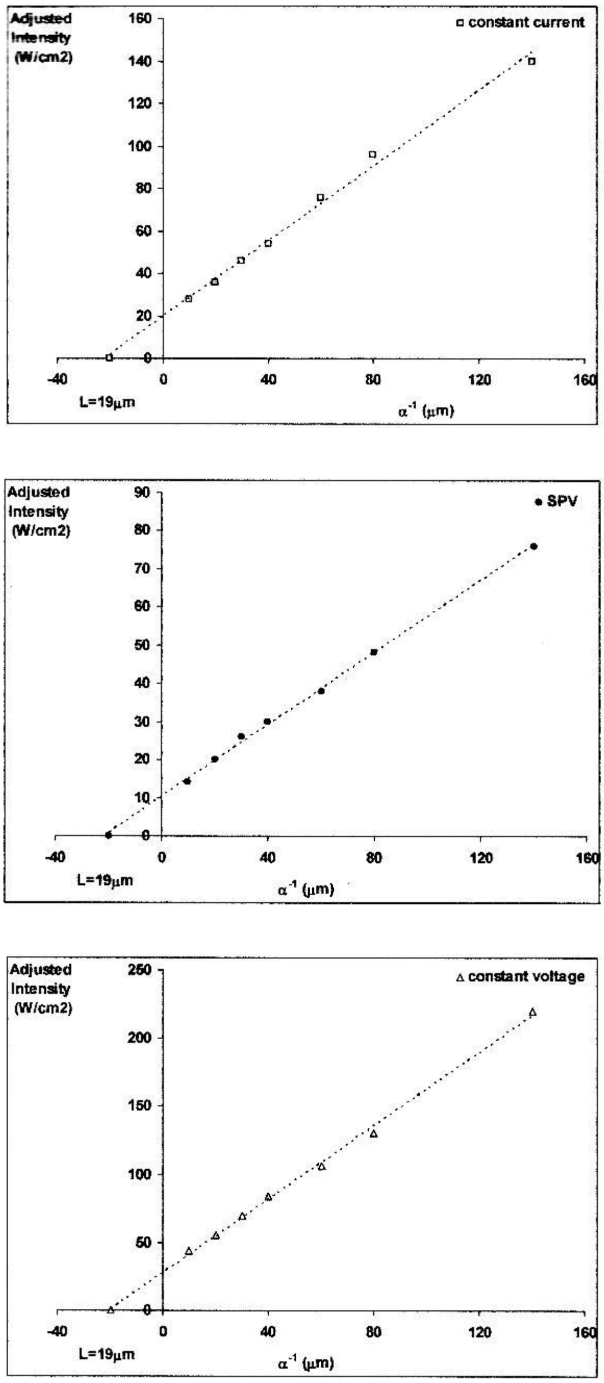

Fig.(5) :Relative intensity versus reciprocal absorption coefficient to determine diffusion length by three diffenet methods the diffusion length is 19=µm.

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الخلاصة

في هذا البحث ، جرى تصنيع خلية شمسية سيليكونية بنمط الوصلة الثنائية باستخدام منظومة الترسيب المعزز بالبلازما جرى تحديد طول الانتشار للحاملات الاقلية في منطقة القاعدة للخلية الشمسية المصنعة من خلال قياس تيار دائرة القصر كدالة للطول الموجي للضوء الساقط . كانت شدة الضوء الساقط اللازمة للحصول على قيمة معينة لتيار الدائرة القصيرة دالة خطية لمقلوب معامل الامتصاص لكل طول موجي ومن قيمة هذه الدالة عند الصفر يمكن الحصول على قيمة طول الانتشار . لوحظ ان هذه الطريقة في حساب طول الانتشار ذات دقة عالية .