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IMPEDANCE SPECTROSCOPY APPLIED TO THE CHARACTERISATION OF a-Si:H SOLAR CELLS DURING LIGHT-DEGRADATION.

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ABSTRACT:

We have applied an impedance spectroscopy technique to study the performance and degradation mechanisms of a-Si:H solar cells to gain greater understanding of their fundamental properties and to achieve the production of devices with improved performance. Our results showed that over a limited range of frequencies and bias voltages the cell can be modeled as an equivalent circuit composed of a capacitor and resistor in parallel. Otherwise, one or more parameters of the equivalent circuit are functions of frequency. Preliminary results show that this technique is very sensitive to the changes that take place during the optical degradation processes. This technique provides complementary information about the production, transport and decay/recombination of the charge carriers.

Keywords: a-Si - 1: Impedance - 2: Degradation - 3

1 INTRODUCTION

The technique of impedance spectroscopy (IS) is widely used in electrochemistry to investigate electrode processes [1]. Since these processes proceed at different rates, by varying the frequency, fast and slow processes may be distinguished. This technique can also be used to study hydrogenated amorphous silicon (a-Si:H) solar cells, because of the similarities between a-Si:H photocells and electrochemical cells. Our results allowed us to determine the form and the parameters of the equivalent circuit consisting of a capacitor and resistor in parallel. There are other established techniques currently used for testing a-Si:H solar cells that provide similar information such as: fixed-frequency capacitance-voltage (CV) measurements, open circuit voltage decay (OCVD) and transient photocurrent measurement (TPM). The IS technique is very similar to the space charge spectroscopy (referred to as admittance spectroscopy) method described by Cohen and co-workers [2] which has its origins in electrical engineering methods.

The general form of complex impedance can be written as: $Z = Z' \pm jZ''$ where Z' is the real part of impedance ($Z' = |Z| \cos \Psi$), and Z'' is the imaginary part $Z'' = |Z| \sin \Psi$, $\Psi = \tan^{-1}(Z''/Z')$,

and $j = \sqrt{-1}$.

The identification of the effective parameters of the equivalent circuit and their interaction with the load in any system are crucial to analysis of that system. In this paper we report the IS measurements during the photo-degradation of a-Si:H solar cells fabricated by plasma enhanced chemical vapor decomposition (PECVD). The parameters of the equivalent circuit take values that depend on the modulation frequency and bias voltage.

2 EXPERIMENTAL

In this study the measurements were made on p-i-n photovoltaic cells fabricated on 100nm thick, un-textured TCO on glass substrates, prepared at a substrate temperature of 225°C, by plasma enhanced vapor chemical decomposition (PECVD). The p-layer was deposited from a mixture of pure silane and 1% diborane in argon, the i-layer from pure silane and the n-layer from a mixture of pure silane and 1% phosphine in argon. The i-layer was 0.4µm thick. The contact to the n-layer was provided by evaporated pure aluminum spots of 2.4mm in diameter. Light and dark IV characteristics were recorded before the impedance spectroscopy measurements commenced.

Measurements were made with the sample in an isolated light-tight box to avoid any possible external effects. The contact to the cell was made through a sample holder connected to the AC bridge analyzer (Wayne Kerr 6425 precision component analyzer) interfaced to a PC for automatic data collection. The AC bridge provides several features that permit accurate measurements; it has built-in bias voltage facilities and a frequency range of 20Hz-300kHz.

In this study measurements were made of the magnitude of impedance $|Z|$ and phase angle Ψ over the available frequency range at different bias voltages for dark and illuminated samples. These measurements were repeated after the samples had been exposed for up to 60 hours of light soaking under simulated AM1.5 illumination.

3 RESULTS and DISCUSSION

Figure 1 shows the AC equivalent circuit of a photovoltaic solar cell. CT: Transition capacitance, Cd: Diffusion capacitance, Rd: Dynamic resistance of the cell, Rp: Parallel resistance due to recombination in the transition region and r: Series resistance due to bulk and interconnects.

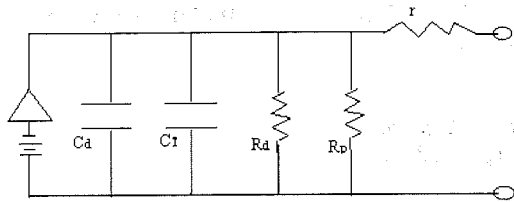


Figure 1: AC equivalent circuit for a-Si:H solar cell.

A typical set of results for a cell illuminated with simulated AM 1.5 light and for the same cell in the dark is shown in figure 2 and figure 3. The characteristic semicircular curves shown result when the imaginary part of the impedance is plotted against the real part in the complex plane. This can be modeled in terms of a simple equivalent circuit composed of a capacitor and resistor in parallel. The diameter of the semicircle corresponds to the value of dynamic resistance (R_d) of the space charge carriers in the depletion region as the parallel resistance (R_p) is very large and can be neglected [3]. The series resistance is represented by the distance between the origin and intersection of the curves with x-axis at maximum frequency. In figure 2, (dark), the transition capacitance is negligible because the charge carriers cross the p/i and i/n interfaces by diffusion processes while in figure 3, (illumination), the detected photocurrent in the out put circuit is due to transition of charge carriers to the interconnections. Hence, the transition capacitance is the dominant in this case and no more negligible. The impedance of the cell dramatically decreased when illuminated, as can be seen by comparing figure 2 and figure 3. The values of the dynamic resistance and impedance also decrease with increasing reverse bias voltage. These changes in the applied voltage suppress the holes close to the p-layer and the electrons close to the n-layer preventing recombination in the i-layer. The value of the capacitance increased significantly with the bias voltage, whereas, the change in series resistance was small. In figure 2, for 0 and 0.2v reverse bias, the curves appear to deviate dramatically from the semicircular shape. It is unclear at this stage whether these curves would ultimately become semicircular in form with large radii, or continue as straight lines. From the measured impedance $Z = Z' - jZ''$ near the maximum of Z''_{max} , C and R_d can be calculated by series to parallel transformation [4] as below:

$$R_d = \frac{(Z' - r)^2 \pm (Z'')^2}{(Z' - r)}, \quad C = \frac{1}{2\pi f Z''_{max}}$$

Another approach for presenting the results is shown in figure 4. This figure shows an alternative manner of presenting the results which highlight the change of the impedance with frequency. In this case we have plotted the real and imaginary components of the impedance as a function of frequency. The small change in the value of the impedance at low frequency indicating slow processes while the abrupt drop in the impedance which follows indicates fast processes.

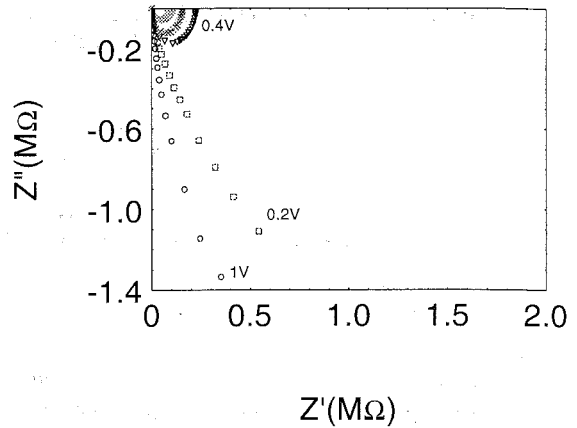


Figure 2. Imaginary part of impedance plotted as a function of real part for a-Si:H solar cell, in the dark.

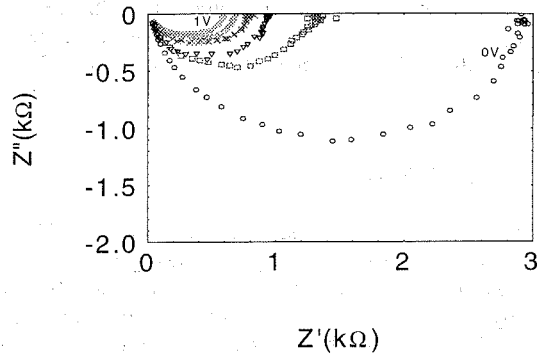


Figure 3. Imaginary part of impedance plotted as a function of real part for illuminated cell.

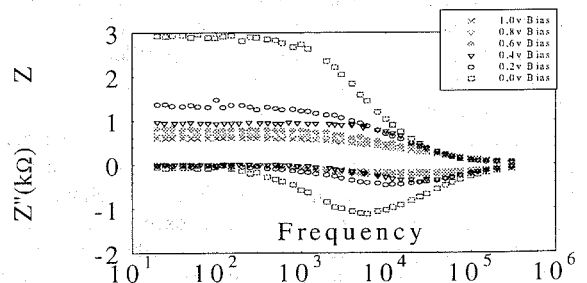


Figure 4. Real and imaginary parts of the impedance as a function of frequency for illuminated a-Si:H solar cell. The values of impedance as figure 3.

The effect of illumination on the impedance of the cell is dramatic as may be seen more clearly in figure 5 in which the impedance is plotted as a function of bias voltage, for illuminated and dark cells, at constant frequency. This figure shows that the photo-generated voltage has shifted the complete curve to higher bias voltages. The maximum impedance occurs at the bias voltage corresponding to the photovoltage. The value of the maximum impedance is, however, very much lower than the dark impedance. The values for the curve under illumination have been multiplied by 25 before plotting for comparison with the dark curve.

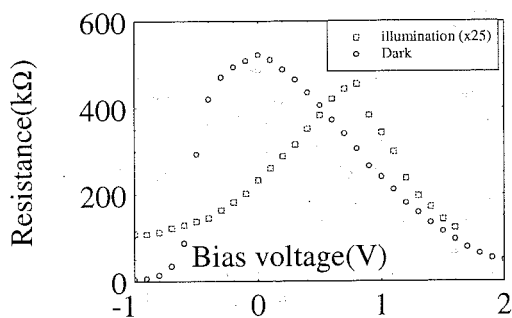


Figure 5. Resistance as a function of bias voltage for a-Si:H solar cell, at room temperature and for a modulation frequency of 10 khz. The open circles indicate the curve corresponding to dark and the squares the curve for AM 1.5 illumination.

The calculated values of C_d , R_d , r and time constant (τ) are tabulated below for a range of bias voltages. The diffusion capacitance shows frequency dependence at 0 and 0.2V bias voltages in the dark at very high frequency, Thus, the parameters could not be calculated for these values .

Bias(v)	C_d (nF)	R_d (kΩ)	r (Ω)	τ (μsec)	$R_d C_d/2$
0.0	---	---	---	---	---
0.2	---	---	---	---	---
0.4	1.87	220	100	205.7	
0.6	4.08	156	100	318.2	
0.8	5.8	104	70	301.6	
1.0	7.07	80	50	282.8	

Table 1: Calculated solar cell parameters for dark sample.

Bias(v)	C_d (nF)	R_d (kΩ)	r (Ω)	τ (μsec)= $R_d C_T/2$
0.0	23	2.9	56	33.35
0.2	33	1.37	39	22.6
0.4	38.5	0.93	39	17.9
0.6	54	0.82	31	22.1
0.8	96	0.69	22	33.1
1.0	100	0.6	22	30

Table 2: Calculated solar cell parameters for illuminated sample.

The values for the time constant are in the same range as the values of minority carrier lifetimes for similar material reported previously [5].

Light-soaking was carried out on the a-Si:H solar cell sample number 123. This cell had a reasonably good initial efficiency and fill-factor. Degradation was measured and evaluated in terms of fill-factor and efficiency changes. The cell was exposed to light intensity of AM1.5 and kept at room temperature by cooling it with an air blower to prevent any annealing processes. After the first two hours a slight improvement was observed, following which the cell started to degrade. Both the short circuit current and the fill-factor (FF) dropped down to almost one third of their initial values after 60 hours of light soaking, as a consequence the efficiency dropped as well.

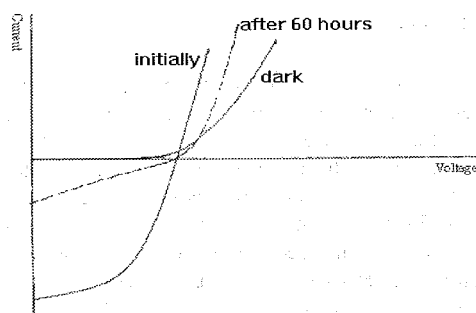


Figure 6. I-V characteristic curves for a-Si:H solar cell. The bottom curve is initially measured and the upper one was measured after 60 hours of light soaking.

Figure 6 shows the I-V characteristic curves for the as-deposited cell and after 60 hours of light soaking. The illumination has shifted the curves downward and the cell's characteristic in each case is dominated by the series resistance for voltages greater than the open circuit voltage, and by the parallel resistance for voltages less than zero. The effect of light soaking is more clearly seen in figure 7 and figure 8 where the imaginary part of the impedance is plotted as a function of the real part for the as-deposited cell and after 60 hours of light soaking. The bias voltage in both cases was 1V. The figures show a dramatic decrease not only in the impedance but, in the dynamic resistance of the cell (R_d) as well.

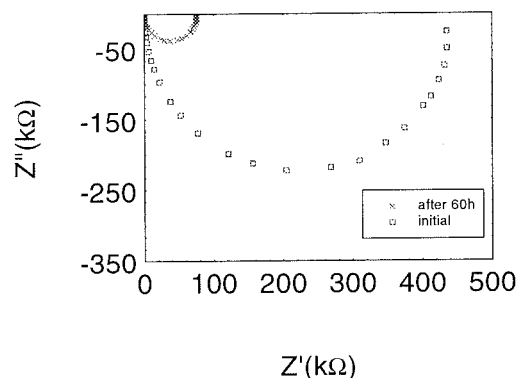


Figure 7. Imaginary part of impedance plotted as a function of real part at 1V bias voltage in dark.

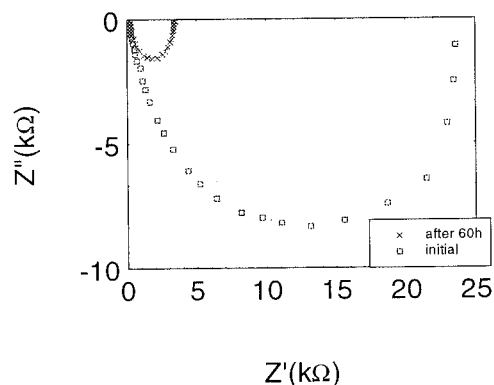


Figure 8. Imaginary part of impedance as a function of real part at 1V bias for the illuminated cell.

4 CONCLUSION

Impedance spectroscopy provides an accurate and different manner of presenting the results and permits the calculation of the parameters of the equivalent circuit for the a-Si:H solar cell. The effect of the light and photo-degradation of the sample is obvious as may be seen from figure 7 and figure 8 where the dramatic decrease of impedance can be noticed. We assume that the deterioration of a-Si:H solar cells is due to the creation of dangling bonds that result in mid-gap states. At 1.5 AM light intensity the effect of light soaking is slow and the effect on the IV characteristics and hence calculated values of efficiency and fill factor is small unless light soaking proceeds for long time periods. Under similar conditions, the change in the impedance is clearly evident.

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