Study of temperature on performance of c-Si homo junction and a-Si/ c-Si hetero junction solar cells

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Abstract- Silicon hetero junction (SHJ) solar cells, employing a surface junction, combine beneficial effects of c-Si and a-Si solar cell technologies. In this work, we have successfully developed large area (137 Cm^2), silicon hetero junction (SHJ) solar cells of efficiencies in the range of 16.0 to 16.5% and investigated variation with temperature of the electrical parameters of these as well as normal, diffused junction, c-Si homo junction solar cells. We have compared the temperature coefficients of parameters such as I_{sc}, V_{oc}, and P_{max} and have compared them for both types of devices as these would have direct impact on performance, in field, of modules made out of these cells. We found out that c-Si homo junction cells are more sensitive to temperature changes as compared to SHJ solar cells. Also the presence of intrinsic amorphous silicon layer between p type a-Si and n type c-Si does not affect the power temperature coefficients; however they do affect the performance of the cells.

Keywords- Silicon hetero junction (SHJ), c-Si homo junction cells, temperature effects, V_{oc}, I_{sc}, P_{max}.

1. Introduction

Silicon hetero junction (SHJ) solar cells comprising a-Si layers deposited on c-Si wafers are processed at low temperatures (< 250°C) which prevents lifetime degradation in c-Si substrates during solar cell process [1, 2]. This, together with careful surface preparation, has made it possible to achieve Voc in excess of 750 mV in the champion cell having an efficiency of 24.7 % [3]. The junction characteristics in these solar cells also come with reduced temperature coefficients which is beneficial for in-field applications. In this work, we have successfully developed large area, silicon hetero junction solar cells and investigated variation with temperature of electrical parameters of these as well as for normal, diffused, homo junction c-Si solar cells. In particular, the temperature coefficient of solar cell parameters like open circuit voltage (V_{oc}), short circuit current (I_{sc}) and efficiency (η) have been studied for silicon hetero junction and c-Si homo junction solar cells.

2. Experimental

Large area Silicon heterojunction (SHJ) solar cells, of size 12.5 Cm by 12.5 Cm pseudo square and area 137 Cm^2, used in the present study are fabricated by deposition of p-type a-Si:H layer onto n-type c-Si wafer with intrinsic a-Si:H in between resulting in a device structure of (p) a-Si:H/(i) a-Si:H/(n) c-Si/(n) a-Si:H. Before loading the wafers into Plasma Enhanced Chemical Vapor Deposition (PECVD) chamber, they are chemically cleaned using saw damage removal (SDR) process and are given 1% HF dip just before loading into the vacuum chamber, to remove the oxide layer. The wafers are given final DI water (6-10 M.Ω) rinse after treatment with hydrofluoric acid (HF) and immediately before loading them in the vacuum chamber for plasma deposition (PECVD) processes, so that the surface remains H-terminated at the time of deposition.

For PECVD deposition of a-Si layers, the vacuum system had a base pressure of the order of 10^{-6} Torr and the chamber is heated for a minimum of 4 hours. Further, the wafers are also heated for half an hour before deposition to ensure consistent heating for all the runs. The electrode size in the deposition chamber is 1‘x 3’ and the inter-electrode spacing is 13 mm. The variation in the plasma power at 13.56 MHz is between 26 mW/cm^2 to 33 mW/cm^2 and pressure is varied from 600 mTorr to 700 mTorr. All the depositions are done at the set temperature of 200° C which corresponded to the substrate temperature of 150° C, as confirmed with the temperature sensitive stickers. Also, the mass flow controllers (MFCs) are calibrated on absolute scale using displacement of water to ensure accurate flow values. P-type amorphous silicon layer at the front is deposited with 1% boron doping of silane and n-type layer at the back is deposited with 3% phosphene doped silane.

After amorphous silicon deposition, ITO layer is deposited by magnetron sputtering in oxygen mixed argon environment on both sides of the cell. The deposition rate for a-Si deposition for all the layers is ~ 1Å/sec. Finally low temperature curable silver contacts are screen printed on the front and rear of the cell.

The I-V measurement set up has the provision to measure I-V characteristics of a solar cell in dark and under illumination. The solar cell to be tested is firmly held on a nickel-plated, temperature controlled vacuum chuck and the measurement of current and voltage are made with 4-wire arrangement (2 wires for current and 2 separate wires for voltage). For all measurements under illumination, first the light intensity is checked and adjusted to 100 mW/cm^2. Also, the temperature of the chuck is set at the desired temperature with tolerance of ±1 °C and monitored continuously using a PT100 probe inserted horizontally inside the gold plated chuck. Calibration of the intensity is performed with the help of the reference cell calibrated at NREL, USA in Dec 2007 (Make: PV Measurements Inc. USA, Model No.: PVM 230, 4 cm^2 area, Isc: 107 mA @ 25±0.2 °C, mounted on an Al block with BK7 glass protective window, with 4 wire contacts). The reference cell is certified for use to quantify or set the irradiance level of a light source used for testing solar cells and modules. When the short circuit current out put of the reference cell is equal to its calibrated value of short circuit current, it indicates that the irradiance reaching the reference cell is equivalent to the irradiance (usually one sun) that was present during its calibration. The I-V measurement system comprises a controller module which interfaces with a power supply / electronic load on one hand and a PC on the other from where the parameters of measurements are set. The system operates with the help of embedded data acquisition and analysis software to sweep the forward light I-V characteristics and forward dark log J-V curves.

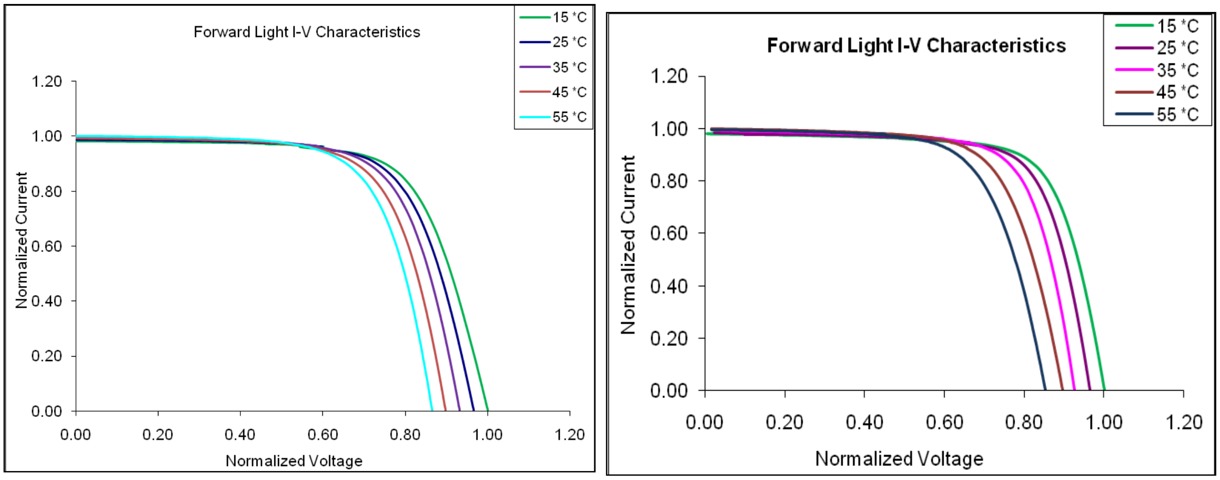
In order to understand the effect of intrinsic layer, one of the cells used in our study is processed without the intrinsic layer in between c-Si wafer and p-type a-Si:H layer. We have used three silicon heterojunction cells in our study, referred to as SHJ 1, SHJ 2 and SHJ 3 in our study. It is to be noted that SHJ 1 and SHJ 3 are pin like structure whereas SHJ 2 is a pn like heterojunction cell without any intrinsic amorphous silicon layer.

3. Results and discussions

The light forward I-V characteristics of these SHJ cells are measured and these cells measured efficiencies of 16.0 % and 16.1 % for SHJ 1 and SHJ 3 respectively whereas SHJ 2 cell measured efficiency of 15.1 %. The relatively low efficiency of SHJ 2 heterojunction solar cell is attributed to the fact that it was devoid of the intermediate a-Si intrinsic layer and thus is purported to have more interfacial defect states as compared to SHJ 1 and SHJ 3 [4]. In order to compare the temperature coefficients with silicon homojunction solar cells, a 16.3% n+/p c-Si homojunction cell is taken into consideration.

3.1. *Temperature Dependence of illuminated forward I-V characteristics*

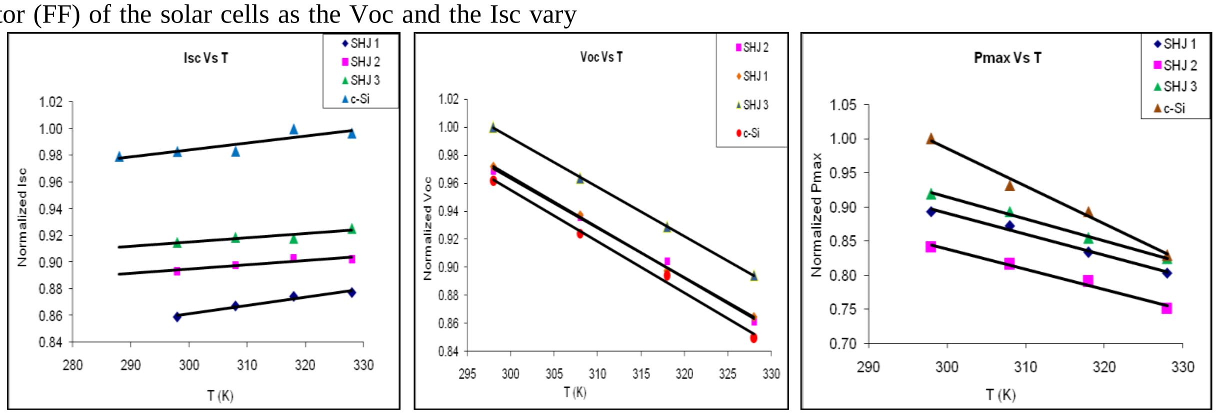
The temperature studies are conducted on three SHJ solar cells and one c-Si homo junction solar cell of efficiencies in the range of 15-16 %. Normalized Forward light I-V characteristics are plotted (Fig. 1) for all these cells at five temperatures between 15°C and 55°C at one solar intensity of 100 mW/cm^2.



(a) (b)

Fig. 1. Normalized Forward Light I-V characteristics at 15°C, 25°C, 35°C, 45°C and 55°C of a typical (a) silicon hetero junction solar cell and (b) c-Si homo junction solar cell

As can be seen from the normalized plots, the open circuit voltage (V_{oc}) consistently decreases for all the solar cells whereas the short circuit current (I_{sc}) increases marginally. The variation with temperature of V_{oc}, I_{sc}, and Peak Power (P_{max}) for all the cells is shown in Fig. 2. The corresponding temperature coefficients of the cells for V_{oc}, I_{sc} and P_{max} are shown in Table 1. It can clearly be seen from the table and Fig. 2 (c) that there is a large difference in the rate of peak power variation of SHJ and c-Si homo junction solar cells. The difference arises essentially from a difference in the variation of the Fill Factor (FF) of the solar cells as the Voc and the Isc vary almost at the same rate for the two types of solar cells (Figs. 2 (a) and 2 (b) respectively) [5]. This, in turn, relates to the dependence of the current transport mechanism on temperature indicating that the mechanisms are different. This is in line with the published reports elsewhere [6] as well as work reported earlier by this group [7]. Arguing on similar lines, one can explain the observed variation in efficiency - up to 2% absolute for SHJ solar cells and up to 3.2% absolute in case of c-Si homo junction cell when temperature is increased from 15°C to 55°C.



(a) (b) (c)

Fig.2. Variation with temperature of the normalized values of Isc, Voc and Pmax for the homo and hetero junction solar cells.

The value of temperature coefficient of peak power itself matches with the industry trend (~ 0.5 %) for c-Si homo junction solar cell but differs a lot for the silicon hetero junction solar cells (~ 0.2 %). This indicates that the SHJ solar cells used in this study have a lot of room for improvement in terms of the properties of individual a-Si layers as well as the interface properties. This is also corroborated by the actual value of Voc of the cells being in the range of 610-630 mV instead of the usual V_{oc} exceeding 650 mV. The other thing that needs to be seen from the data is that all three SHJ solar cells exhibit exactly similar behavior irrespective of the hetero structure, i.e. whether it is p/n or p/i/n. This possibly shows that the benefits of the i-layer are overshadowed by the defective interface which also needs to be improved.

Table 1. Temperature coefficients of Voc, Isc and Pmax for silicon homo and hetero junction solar cells.

Sl. No.	Cell ID	Temperature Coefficients in % per °C for		
		V_{oc}	I_{sc}	P_{max}
1	SHJ1	-0.37	0.07	-0.34
2	SHJ2	-0.37	0.04	-0.35
3	SHJ3	-0.35	0.03	-0.35
4	c-Si	-0.38	0.06	-0.55

The difference in temperature coefficients of the two types of solar cells has direct impact on the field applications, as it determines the performance of modules at elevated temperatures. The difference in power output between the two types of modules could be significant due to a large difference in the value of the temperature coefficients.

4. Conclusion

From the temperature studies of light I-V characteristics of silicon homo and hetero junction solar cells, it is concluded that temperature coefficient of peak power, the former is significantly higher than that of the latter. This suggests that c-Si homo junction cells are more temperature sensitive than hetero junction solar cells. This will have a significant effect on the performance of the modules in field. The study also shows that the presence of intrinsic amorphous silicon layer between p type a-Si and n type c-Si does not affect the power temperature coefficients; however they do affect the performance of the cells.

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