Hydrogenated Nanocrystalline Silicon (nc-Si:H) Solar Cell

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Abstract

Hydrogenated nanocrystalline silicon (nc-Si:H) thin films have been deposited at different power by radio frequency plasma enhanced chemical vapor deposition (RF PECVD) technique. Single junction solar cells have been fabricated with nanocrystalline Si as absorber layer. The solar cell performances have been studied by varying i-layer thicknesses. The optimized solar cells show less than 1% degradation upto 50 hours of light soaking. Then the cells degrade upto 500 hours and thereafter they become steady. Using nanocrystalline silicon as absorber layer the solar cell efficiency degrades maximum 9% before stabilisation.

Keywords: Nanocrystalline Silicon, Light Induced Degradation of Photoconductivity, Solar Cell.

1. Introduction

In order to make silicon thin film technology cost effective, we need to improve the efficiency of solar cells and minimize the light-induced degradation of them. Among the different possible structures of silicon thin films, the material that presents very promising feature is hydrogenated nanocrystalline silicon (nc-Si:H), which consists of crystallites with sizes of the order of a few nanometers embedded in amorphous matrix. Nanocrystalline silicon films show stability under light soaking and thus have high potential as stable solar cell material. nc-Si:H films are generally grown from a mixture of silane and hydrogen with high hydrogen dilution. The H-atoms etches out some of the weak Si:H bonds and thus remove the cause of light induced degradation. Grain size and intermediate range order may also play important roles in improving stability. Ito et al.[1] has developed nanostructure tailored silicon where nano-sized crystallites are embedded in the amorphous silicon matrix homogeneously. Solar cells using this material as active layer show high stability against light soaking, with degradation ratio of around 5%. Currently huge interest has been drawn for the use of nano-crystalline silicon as intrinsic layer of solar cell. Moreover, the thickness of absorber layer is one of the crucial parameters for proper operation of p-i-n silicon solar cells because the cell parameters and solar cell stability i.e. the solar cell characteristic have a large dependence on the thickness of i layer. The effects of a-Si:H layer thickness on the performance of a-Si:H/c-Si heterojunction solar cells have been studied by Fujwara and Kondo[2]. The light induced stability of a-Si:H solar cells as a function of i layer thickness has also been investigated by Yang et al.[3]. Recently performance and spectral response of Si:H multilayer single junction solar cells have been investigated for various intrinsic layer thickness[4].

2. Experimental

Single junction solar cells have been fabricated using nc-Si:H films deposited at high power high pressure conditions as absorber layer. Solar cells with the structure Glass/ TCO / p (μc-Si:H) / i (nc-Si:H) / n (a-Si:H) / Al using different i-layers were fabricated in a multichamber RF PECVD system provided with a load lock and transfer arms. The p-layer was boron doped μc-Si:H material. The chamber pressure was kept at 40 W for i-layer, 25 W for p-layer and 4.4 W for n-layer deposition. All depositions were carried out at a substrate temperature of 250°C except for the p-type μc-Si:H layer which was deposited at 180°C. Electrode separation for the deposition of absorber layer is kept at a very low value of 1 cm to increase the deposition rate. The performance and stability under light illumination of the single junction solar cells have been investigated with varying the absorber layer thickness in a wide range (3000 Å to 11000 Å) and it has been found that the best cell is obtained under an optimum i layer thickness. The performance of the solar cells were evaluated by measuring the current and voltage under 100 mW/cm^2 light intensity (air mass 1.5 global) and degradation of solar cell parameters were also studied under a light intensity of 100 mW/cm^2

for 1000 hrs of light soaking. The spectral response has been measured under monochromatic light illumination.

3. Results and Discussion

Figure 1 shows the performance of the nc-Si:H solar cells plotted as a function of the intrinsic layer thickness varies from 3000 Å to 11000 Å. The thicknesses of p and n layer are fixed for all the cells. It is clearly observed from the figure that with the increase of i-layer thickness from 3000 to 4500 Å, V_{oc} increases sharply from 0.7 volts to 0.8 volts and then saturates at 0.83 volts at the i-layer thickness of 6500 Å. The value of J_{sc} increases initially up to 4500 Å and then saturates at 6500 Å. With further increase of the i-layer thickness of 9000 Å and above, J_{sc} decreases gradually.

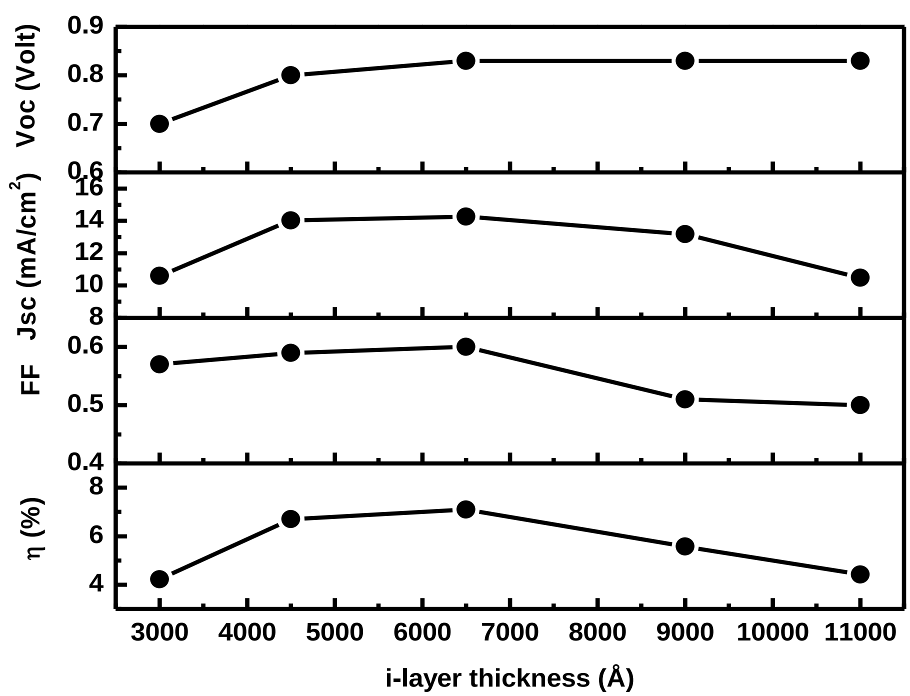


Figure 1: Solar cell parameters plotted against variation of absorber layer thicknesses.

FF increases slowly with the thickness of i-layer and reaches at a maximum value of 0.6 at the thickness of 6500 Å but it reduces sharply at the i-layer thickness of 9000 to 11000 Å. As a result, the solar cell efficiency increases up to 6500 Å and has been achieved the optimum value of 7.1 %. The increase of solar cell efficiency is mainly due to the improvement of V_{oc} and J_{sc} and also due to slight increase of the value of FF. In the case of thick nc-Si:H cells, the efficiency reduces by lowering of the values of J_{sc} and FF. Thus it has been observed that the quality cell has been obtained at an optimum i-layer thickness of 6500 Å. The spectral response of nc-Si:H solar cells have been investigated with various intrinsic layer thicknesses. Figure 2 shows the quantum efficiency (QE) spectra of all the solar cells. It is observed from the figure that the overall QE improves significantly with the increase of i layer thickness from 3000 Å to 6500 Å. The intensity of the QE spectra gradually decreases for the cells with i layer thickness of 9000 Å to 11000 Å whereas the two spectra are almost identical with a small reduction in intensity of the later cell in the lower wavelength region. It is also clear from figure 3 that both the shorter wavelength (400 – 600 nm) and longer wavelength (600 – 800 nm) responses improve much with increase of i layer thickness up to 6500 Å, but in case thick cells, the shorter wavelength response reduces. The reduction of QE in the shorter wavelength region for the thick cells (9000 – 11000 Å) may be due to light absorption within the i layer[2]. Another point may be noted that for all the nc-Si:H cells QE drops sharply at the wavelength of 800 nm, there is no spectral response at longer wavelength region (800 – 1200 nm) usually observed in case of microcrystalline solar cells. Similar type of spectral response of Si:H multilayer solar cells have been reported by Myong et al.[5]

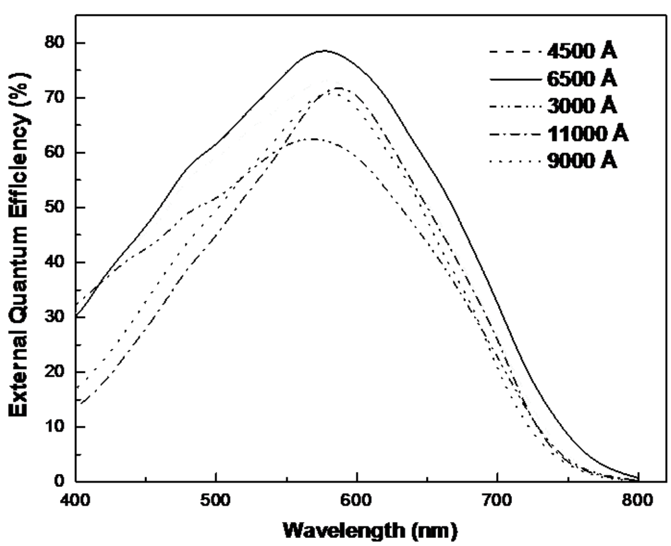


Figure 2: Quantum Efficiency of solar cells fabricated by varying i-layer.

Figure 3 shows I – V characteristics of the single junction solar cell of effective cell area 1 cm^2 in initial condition and after light soaking condition. Results of the solar cell parameters before and after light soaking conditions are given in the figure. Maximum solar cell efficiency of 7.1% is obtained using nc-Si:H films deposited at 40 W of deposition power. It is observed that for nc-Si:H solar cells open circuit voltage (V_{oc}) is 0.83 volts, which is like the V_{oc} of amorphous solar cells. The higher initial efficiency of solar cell for nc-Si:H films is due to lower value of defect density of these films.

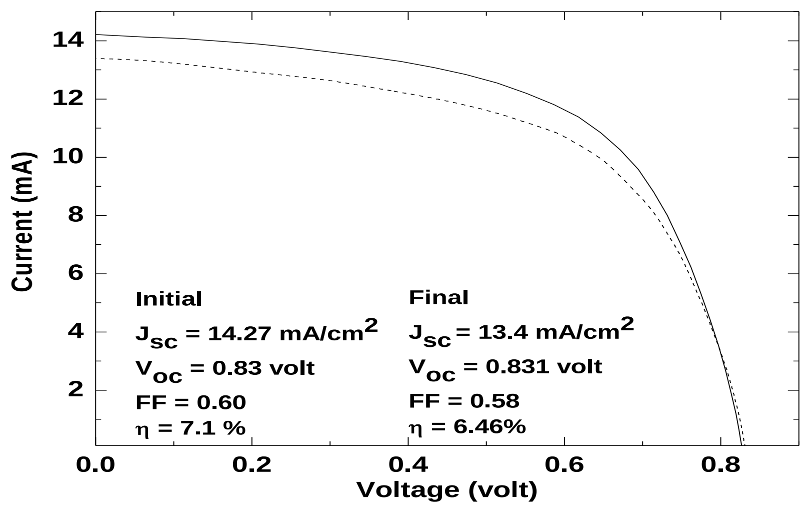


Figure 3: I-V curve for nc-Si:H solar cell before and after degradation. The solid line is used for initial state and the dotted line for the light soaked state. The Solar cell parameters before and after light induced degradation are given in the graph.

Light induced degradation have been done for solar cell made using nc-Si:H absorber layer deposited at 40 W having various i-layer thickness. The light induced degradation of normalized efficiency values of solar cells having a wide range of i-layer thicknesses after 1000 hrs of light soaking has been investigated. It is observed from the data that cells having less absorber layer thicknesses have much less degradation than that of having high thicknesses. The solar cell having 3000 Å of thickness degrades 5.9 % after 1000 hrs of light exposure, whereas the cells with thicknesses ≥ 9000 Å degrade ~ 14 %. As thickness increases the defect states in the absorber layer also increases which may cause the increase of dangling bonds and as a result degradation increases.

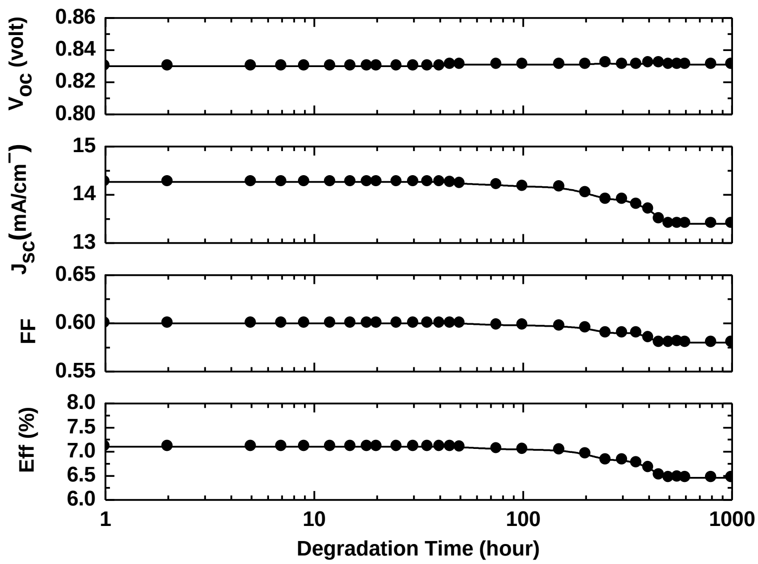
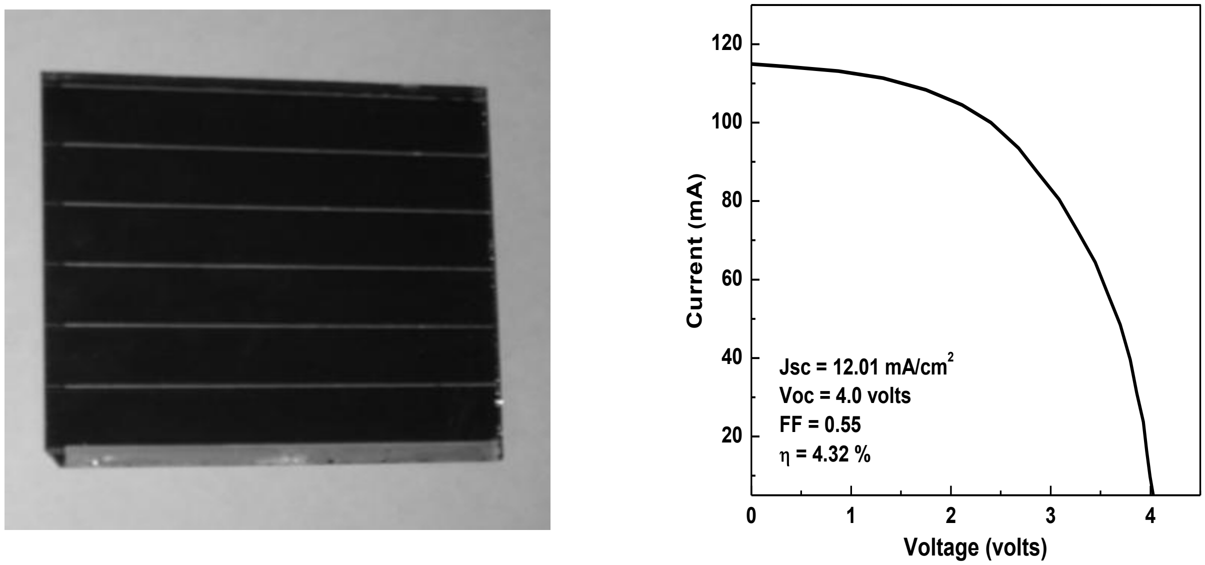


Figure 4: Light induced degradation of different solar cell parameters for optimized nc-Si:H solar cell.

Figure 4 shows degradation of different solar cell parameters of single junction nc-Si:H solar cell having absorber layer thickness ~ 6500 Å upon light soaking. There is a significant difference in the nature of degradation of the solar cell made using nc-Si:H with other μc-Si:H films. Solar cells made by nc-Si:H films shows less than 1% degradation upto 50 hours of light soaking. After that degradation increases upto 500 hours and thereafter it becomes steady as shown in figure 4. Using nc-Si:H as absorber layer the solar cell efficiency degrades by 9.1 % before stabilization. Solar cell module of effective area 80 cm^2 has been fabricated using nc-Si:H as absorber layer deposited at 40 W RF power. Figure 5 (a) shows one of the series integrated solar cell module made using nc-Si:H as intrinsic layer which are fabricated by laser scribing successively on the TCO, p, i, n layers and then the metal surface. The module comprises of 6 cells in series connection as shown in the figure.

The current-voltage characteristic of the optimum solar cell module is shown in figure 5 (b). The values of cell parameters are also given in the figure.



(a) (b)

Figure 5: (a) Solar cell module with nanocrystalline silicon absorber layer. (b) I-V Characteristics of solar cell module with effective area 80 cm^2.

Single junction solar cells and solar module were successfully prepared using nanocrystalline silicon as absorber layer. The optimum cell is 7.1 % efficient initially. Solar cells made by nc-Si:H films shows less than 1% degradation upto 50 hours of light soaking. It degrades by 9% before stabilization. The initial efficiency of the 80 cm^2 solar cell module developed using nc-Si:H absorber layer is ~ 4.3 %. Improvement in efficiency can be achieved by optimizing the doped layer/interface and using Ag back contact.

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