TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS
Vol. 18, No. 2, pp. 70-73, April 25, 2017

Regular Paper

pISSN: 1229-7607 eISSN: 2092-7592
DOI: https://doi.org/10.4313/TEEM.2017.18.2.70
OAK Central: http://central.oak.go.kr

Improving Device Efficiency for n-i-p Type Solar Cells with Various Optimized Active Layers

Sk Md Iftiquar[a,†] and Junsin Yi[b,†]
College of Information and Communication Engineering, Sungkyunkwan University, Suwon 16419, Korea

Received April 4, 2016; Revised November 16, 2016; Accepted November 19, 2016

We investigated n-i-p type single junction hydrogenated amorphous silicon oxide solar cells. These cells were without front surface texture or back reflector. Maximum power point efficiency of these cells showed that an optimized device structure is needed to get the best device output. This depends on the thickness and defect density (N_d) of the active layer. A typical 10% photovoltaic device conversion efficiency was obtained with a N_d = 8.86×10^{15} cm^{-3} defect density and 630 nm active layer thickness. Our investigation suggests a correlation between defect density and active layer thickness to device efficiency. We found that amorphous silicon solar cell efficiency can be improved to well above 10%.

Keywords: Si thin film solar cell, n-i-p structure, High efficiency, Defect density, Simulation, Optimization

1. INTRODUCTION

The maximum electrical output from a solar cell is determined by its photovoltaic conversion efficiency. This has always been a key criterion for large scale commercialization. It is well known that conversion efficiency depends on various factors [1-5]. While these are easy to understand, it is difficult to improve the performance of a solar cell [6]. In an amorphous silicon solar cell, the energetic electron hole pairs are photo generated in the intrinsic type photo sensitive layer. Therein, the valence and conduction band tail states are exponentially distributed with photon energy. The transmitted light intensity through a layer of thickness *d* mostly follows Beer Lambert's exponential relation. Therefore, when an AM1.5G like broad band solar spectra falls on such a film, layer thickness is one factor on which the total optical absorption of incident light depends. Increasing the active layer thickness can increase the short circuit current density in a solar cell. It should be noted that the recombination loss of excess carriers opposes carrier generation. SRH (Shockley-Read-Hall) recombination [7] is one of the prominent routes through which the photo generated excess carriers can be lost. Amorphous silicon based semiconductors usually have significant mid gap defects [8] so increasing the active layer thickness may not always give a higher efficiency. Herein we investigate two parameters for solar cell efficiency; thickness and density of the cell's active layer. Since deposition conditions can affect electronic defect density, it is not always possible to reduce density. However, active layer thickness can be controlled as needed. We will show that a suitable combination of these two parameters can result in the best efficiency performance for a device.

† Author to whom all correspondence should be addressed:
E-mail: a: smiftiquar@gmail.com, b: yi@yurim.skku.ac.kr

2. EXPERIMENTAL DETAILS

Our investigation starts with a baseline n-i-p type solar cell without front surface texture and a back reflector. It was derived from a n-i-p type cell that was fabricated on a textured substrate [9], and we used AFORS-HET [10] simulation to get characteristics of the baseline solar cell (as given in the trace named "simu1" of Fig. 7(a) of reference [9]). The basic cell structure used in this investigation was: p-a-SiO:H (20 nm)/ i-a-Si:H (variable thickness)/ n-a-Si:H(25 nm), where p-a-SiO:H is boron doped hydrogenated amorphous silicon oxide, i-a-Si:H is i-type or intrinsic hydrogenated amorphous silicon, n-a-Si:H is phosphorus doped a-Si:H, with non-textured flat front and back surfaces. The intrinsic layer of this cell had a defect density, N_d = 8×10^{17} cm^{-3}. Details about this baseline reference cell are in reference [9]. The solar cells reported here were simulated from the baseline cell (using AFORS-HET simulation), with varying defect densities (within $N_d = 4\times10^{14}$ cm^{-3} to 8×10^{17} cm^{-3}) and thicknesses (within 25 nm to 3,500 nm) of the active layers.

3. RESULTS AND DISCUSSION

The efficiency of a solar cell is a complicated combination of optical absorption [9,11] and recombination of photo generated carriers [12]. With the help of the Beer-Lambert exponential relation, the optical absorption in the active layer (I_a) is expressed as [9,11]:

$$I_a = I_0[I - \exp(-\alpha d_i)] \quad (1)$$

where I_0 is light intensity at the front surface of the active layer, and α is the absorption coefficient. The SRH (Shockley-Read-Hall) recombination can be expressed as proportional to total trap density (N_t) as [12]:

$$R_{SRH} = k_{SRH} N_t \quad (2)$$

$$k_{SRH} = (np - n_i^2) v_{th} \sigma_t / [p + n + 2n_i \cosh(E_i / E_t)]$$

where n_i is the intrinsic carrier density, n & p are non-equilibrium carrier concentration in the material, v_{th} is the thermal speed of an electron, and σ_t is the capture cross section.

AFORS-HET simulation was used to generate the J-V characteristic curves for solar cells and estimate efficiency (*Eff*) for each cell at the maximum power point. Figure 1 shows the efficiency of various cells with varying active layer thicknesses and defect densities. Cell efficiency was plotted for various thicknesses while its defect density (N_d) was kept constant, and lines were used to connect the data points for a particular N_d. The variation in efficiency shows that for a particular N_d a maximum efficiency can be achieved for a particular d_i. This implies that an optimized active layer thickness is needed to achieve the best efficiency from a device, and the thickness (d_i) is strongly dependant on the N_d. The maximum possible efficiency for a particular N_d is denoted as open star symbols in Fig. 1. If the stars are connected with a best fit curve (AB), we can divide the first quadrant of the *Eff* vs d_i plot into two regions: one above the AB curve that is dominated by optical generation (equation (1)), the other one below the AB curve is recombination dominated (equation (2)).

Now, collecting some of the cell results for particular di, we plot the efficiency with $Log_{10}(N_d)$, as shown in Fig. 2. It shows that for a particular d_i, the *Eff* always decreases with an increased N_d. This trend matches with the basic concept that when total optical absorption or carrier generation is constant, the maximum cell output power will reduce with increased N_d, or recombination loss

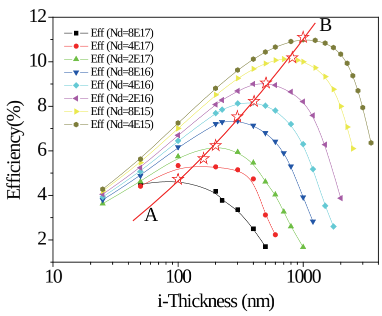

Fig. 1. Solar cell efficiency plot of active layer thickness for various defect densities.

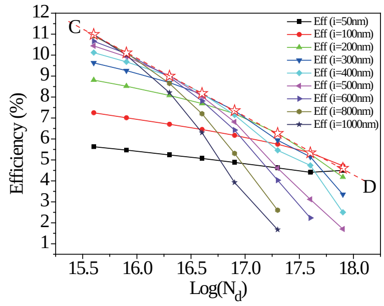

Fig. 2. Solar cell efficiency plot with $Log_{10}(N_d)$ of the active layer, for its various thicknesses.

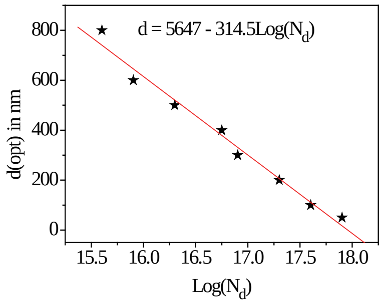

Fig. 3. The relation or plot between optimum active layer thickness, $d(opt)$, with the $Log_{10}(N_d)$. The symbols indicate simulation results, while the straight line is a best fit among the data points.

of carriers. The accessible solar cell efficiency is limited by the dotted line CD. The upper part of the line CD is inaccessible, while the lower part is accessible. Therefore, CD indicates the limiting device efficiency achievable for a particular combination of thickness d_i and defect density N_d. The open star symbols correspond to the solar cell structures for maximum possible efficiency. These data points are plottedin Fig. 3.

The best fit line obtained from the Fig. 3 is expressed as

$$d(opt) = d_0 - d_m Log_{10}(N_d) \quad (3)$$

where d_0 = 5,647 nm, d_m = 314.5 nm. Equation (3) outlines a type of relationship that might exist between active layer defect density and thickness for highest achievable device efficiency. In our case, the maximum device efficiency is achievable when $d_i = d(opt)$. In that case the efficiency can be expressed as :

$$Eff = Eff_{\max} - Eff_{factor} Log_{10}(N_d) \quad (4)$$

where Eff_{max} = 54.35%, Eff_{factor} = 2.781%. Again this is a typical relationship between the solar cell efficiency and defect density. It can also be noted that when the second term of expression (4), the Eff_{factor} $Log_{10}(N_d)$, is close to zero, or the N_d is close to 1 (with $d(opt)$ = 5.6 μm), the $Eff = Eff_{max}$ = 54.35%. This implies that the ideal limiting efficiency of the amorphous silicon solar cell is 54%. This is much higher than previously predicted. This is a theoretical prediction and may not be achieved practically (because defect density can never be zero or one). However, these results indicate that a very high solar cell efficiency is achievable with amorphous silicon material if active layer defect density and thickness are suitably combined.

It is to be noted that the term Eff_{max} in equation (4) implicitly contains the effect of parasitic optical absorption, although it was not included in this parameter explicitly. One parasitic effect can be described as the following. With increased thickness of the