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Energy Production of Single Junction Amorphous Silicon Modules with Varying i-Layer Thickness

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Abstract: The energy production of a number of single junction amorphous silicon (a-Si) solar modules with different intrinsic layer thicknesses is investigated. This has been carried out through both indoor measurement and real operating condition monitoring outdoors. After 13 months of light exposure, the fully degraded and seasonally annealed states, can be seen. The results indicate that the thinnest devices do not necessarily have the lowest degradation. The thicker devices which have higher initial efficiency, however do suffer greater efficiency degradation. Experiment also shows that energy production does not follow the initial Standard Test Condition (STC) rated efficiency as the highest can be seen in thinner modules, which initially have much lower efficiencies.

Key Words: Amorphous Silicon, i-Layer Thickness, Energy Production.

1 Introduction

Amorphous silicon (a-Si) solar cells are a promising technology in today's world PV market. It is widely used in many photovoltaic (PV) applications as it has relatively low production cost and is easily up-scalable compared to its crystalline counterpart. However, one disadvantage that always limits the performance of a-Si devices is the light-induced degradation known as Staebler-Wronski Effect (SWE). This is directly influenced by the cell thickness as the transport mechanism of carriers in a-Si technology is heavily dependent upon the strength of the electric field. Since virtually all a-Si solar cells are produced in a p-i-n structure and optimised to standard test conditions (STC), this work focuses on the effect of the intrinsic-layer (i-layer) thickness on long term performance and realistic degradation-annealing, rather than artificial laboratory degradation. It will be shown that there are differences between indoor and outdoor experiments.

There have been several studies in this area which virtually exclusively have been carried out in controlled laboratory conditions, mostly on small, laboratory-scale devices [1, 2]. However, devices of larger size used for power generation, especially operating outdoors, will have additional effects related to the degradation, such as seasonal thermal annealing [3]. Thus, in order to study stabilised efficiency and energy production, there is a need for degradation studies on full-size a-Si devices under realistic outdoor conditions. This paper presents the results of full size, single junction a-Si modules of different i-layer thicknesses operated outdoors since July 2004. Data from the first 13 months of operation are reported in which the devices have seen the seasonally fully degraded state and the seasonally annealed state.

2 Experimental Details

Nine commercial a-Si (p-i-n) modules of the same area with 4 different i-layer thicknesses were investigated. Each module thickness was indicated by a number normalised to the thinnest i.e. relative i-layer thickness ($d_{i,rel}$) = 1.0, 1.3, 2.0 and 2.5. These modules have initially been measured in a solar simulator (SPIRE SPI-SUN 240A) which gives the I-V characteristic under controlled conditions.

After an initial simulator test, one of the samples ($d_{i,rel}$=1.3) has been taken as a control and stored in the laboratory. The remaining eight modules were mounted in the outdoor measurement system at the Centre for Renewable Energy Systems Technology (CREST) building, Loughborough University, UK. During exposure, the solar modules are open-circuited and connected automatically for I-V traces every ten minutes during daylight hours. The module temperatures and full environmental conditions (irradiance, spectrum and ambient temperature) are recorded. At frequent intervals (6-8 weeks) the modules are taken into the laboratory and measured with the simulator in order to determine absolute degradation. The average results of each thickness batch from both indoor and outdoor testing are reported in the following sections and then used to analyse the efficiency degradation and energy production of the modules with different i-layer thicknesses.

3 Initial Efficiency and Photovoltaic Parameters

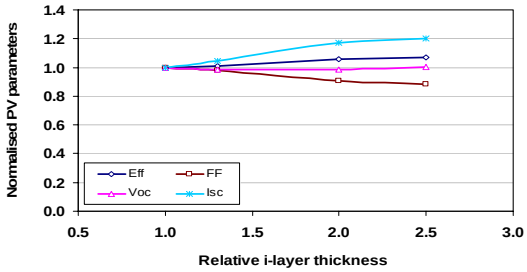


Figure 1 Normalised average initial efficiency, FF, V_{oc} and I_{sc} vs. Thickness.

Figure 1 shows the average initial efficiency, fill factor (FF), open circuit voltage (V_{OC}) and short circuit current (I_{SC}) of modules of different i-layer thicknesses normalised to that of the thinnest ($d_{i,rel}$=1.0). Thicker devices give higher initial I_{SC} and efficiency, with the thickest module ($d_{i,rel}$=2.5) having initial I_{SC} and efficiency of 20% and 7% respectively, higher than those of the thinnest module. This is due to better optical absorption in the thicker devices which results in the increase of I_{SC} and thus efficiency. Thinner modules do not absorb as much light because some incident light with longer wavelengths will pass through the cell without absorption. However, typically modules with a thicker i-layer will experience losses due to material quality (and thus are more prone to degradation). In addition, Figure 1 shows that the initial V_{OC} values of modules of different i-layer thickness are virtually identical. The devices are not benefiting from the typical logarithmic relation to the I_{SC}, which shows that

material quality, and thus the voltage-dependent current collection, is an issue for these thicker devices. The initial FF is 11.5% lower for the thickest modules with respect to the thinnest modules. This can be attributed to the reduced electric field within the thicker modules and thus a photocurrent more strongly dependent on voltage.

4 Efficiency Degradation

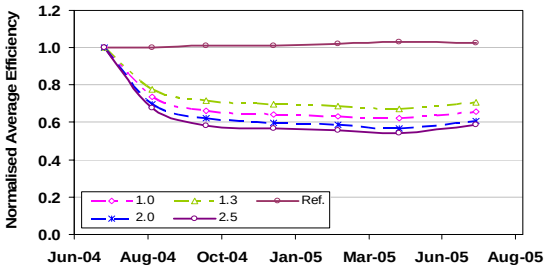


Figure 2 The average efficiency of solar modules of different i-layer thicknesses normalised to the initial value measured by the solar simulator during 13 months of outdoor exposure.

The modules are taken into the laboratory at frequent intervals to determine the absolute degradation. As can be seen in Figure 2, after 13 months of outdoor exposure, all modules show efficiency degradation with a significant decrease in the first two months, followed by a period of stability before a slight increase in the last two months. The efficiency has a minimum between April and May, with the thickest module ($d_{i,rel}$=2.5) exhibiting the largest reduction of efficiency of 45% relative to the initial value compared to a decrease of about 37% for the thinnest ($d_{i,rel}$=1.0). This could be explained as SWE, since there is a higher defect density in a thicker device, which leads to a greater reduction of electric field strength and higher recombination rate. However, the thinnest module is not the one that shows the smallest efficiency degradation, but the $d_{i,rel}$=1.3 modules, which show a reduction of 32%.

Interestingly, between May and July 2005, the normalised average efficiency was slightly increased. Because other environmental parameters are relatively stable as shown in Figure 3, this is believed to be caused by the increase of ambient temperature during summer, developing the seasonal thermal annealing effect [3].

The reference module (kept in the laboratory) shows a slight increase in efficiency of 2.7% from the initial value. This increase is believed due to a change in temperature of the laboratory during the solar simulator measurements - building works carried out in February and March 2005 resulted in the heating being switched off and thus the temperature was about 8 degrees lower for these measurements (17°C).

5 Energy Production

The operating efficiency of the modules obtained from outdoor measurements not only shows the performance degradation of each module thickness but also includes the effects of environmental characteristics that the module experiences at a particular site as shown in Figure 3 The efficiency pattern can be noticed as seasonal variations, as it improves during summer and decreases in winter. Apart from the irradiance effects, the irradiance spectrum and temperature are the other important factors that also affect the performance and energy production of a-Si devices [4]. The former effect can clearly be seen between December and February, as all modules start to improve slightly, corresponding to the decreasing airmass from its peak in December, where spectral mismatch is greatest. In this month, airmass reaches its peak, together with the degradation and lowest incident irradiance making December the least efficient month with the efficiency maximum reduction of 36% in $d_{i,rel}$=2.5. The temperature effect can be seen in summer 2005, as the operating efficiency increases in July and August 2005, corresponding to the high temperature in these two months and also to the indoor efficiency in Figure 2, as mentioned earlier.

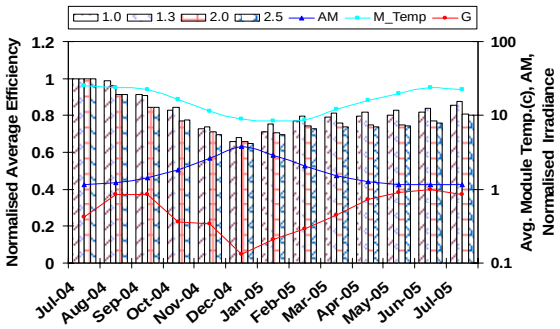


Figure 3 Normalised average monthly outdoor operating efficiency.

In addition, an energy production of each module can be implied from Figure 3, as the efficiency is the ratio of energy production to the incident irradiance. As with efficiency, there is an obvious difference of energy production between two distinct measurement periods, summer and winter. The module with a $d_{i,rel}$ = 2.5 which has the highest initial STC efficiency shows the lowest operating efficiency after a few months of outdoor exposure with the maximum reduction of 36% in December. The module with a $d_{i,rel}$=1.3 which has the lowest degradation rate as shown in Figure 2 has obtained the highest operating efficiency and thus energy production since October 2004.

6 Conclusions

The experiment confirms that the cell thickness greatly affects the performance of the a-Si solar cell. All of the devices show the expected degradation when exposed outdoors with the thicker i-layer modules having the highest degradation rate. The devices degrade significantly in the first few months of outdoor exposure and will saturate at some state. On the other hand the environmental factors of irradiance, spectrum and temperature also have a great effect which can either improve or pull down the module efficiency. The energy production under outdoor conditions cannot be inferred from the efficiency alone as an initially high efficiency of a-Si module does not necessarily mean that the devices will have a high efficiency in the degraded state.

7 References

[1] D.P. Tanner, S. Vasquez, D. Willett, Proceedings of the 18th IEEE PVSC, Las Vegas, 1985, 1301-1306.

[2] N. Wyrsch and A.Shah, Proceedings of the 24th IEEE PVSC, Hawaii, 1994, 583-586.

[3] R. Ruther, J. Livingstone, S, Solar Energy Materials & Solar Cells 36, 1994, 23-43.

[4] R. Gottschalg, T.R. Betts, D.G. Infield, M.J. Kearney, Solar Energy Materials & Solar Cells, 85, 2005, 415-428.