
This item was submitted to [Loughborough's Research Repository](#) by the author.
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

The effect of cell thickness on energy production of amorphous silicon solar cells

PLEASE CITE THE PUBLISHED VERSION

PUBLISHER

PVSAT / © The authors

VERSION

AM (Accepted Manuscript)

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Vorasayan, Pongpan, Thomas R. Betts, Ralph Gottschalg, David Infield, and A.N. Tiwari. 2019. "The Effect of Cell Thickness on Energy Production of Amorphous Silicon Solar Cells". figshare. <https://hdl.handle.net/2134/5125>.

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.



For the full text of this licence, please go to:
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

The Effect of Cell Thickness on Energy Production of Amorphous Silicon Solar Cells

P. Vorasayan^{*}, T.R. Betts, R. Gottschalg, D.G. Infield, A.N. Tiwari

Centre for Renewable Energy Systems Technology, Department of Electronic and Electrical Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK

Abstract: Solar cells are currently evaluated under laboratory conditions and not under realistic operating conditions. Amorphous silicon (a-Si) devices exhibit a complicated dependence on operating conditions, with a major concern being the degradation of these devices in realistic operation. Optimising these devices for energy production of the stabilised state is dependent on many factors, with one of the main inputs being the overall thickness of the cell. In this paper, the effect of intrinsic layer (i-layer) thickness on the cell performance, the degradation and also the energy production under realistic conditions are investigated. It is apparent from the experiment that there has to be an optimisation of the i-layer thickness to maximise the light absorption and minimise the degradation, if higher performance and energy production is to be achieved.

1. Introduction

Amorphous silicon (a-Si) solar cells are a promising technology in today's world PV market. It is an extremely versatile material that can be made in different forms and structures and also has a manufacturing process potentially much cheaper than that of crystalline technology. Moreover, with a direct band gap, a-Si devices have a higher optical absorption leading to cells that can be made much thinner than their crystalline counterparts. However, one disadvantage that always limits the performance of a-Si devices is the degradation.

In a-Si solar cells, since the transport mechanism of carriers is heavily dependent upon the electric field, the thickness of the cell is crucial. If the i-layer is too thick, the electric field is weak, reducing the drift force. This will affect the collection of carriers, which have a diffusion length of typically only 100-200 nm in a-Si:H (Valizadeh, 2001) and in turn limits cell efficiency. The degradation normally known as Staebler Wronski Effect (SWE) (Staebler et al., 1977) occurs when the a-Si solar cell is exposed to sunlight. The light enhances the meta-stable defect density in the material structure which develops from the broken weak Si-Si bonds, driven by the energy released from the recombination of electrons and holes. These defects also decrease the electric field strength and increase recombination. However SWE will be limited at some state as shown in Figure 3, where all of the devices in this study are seen to nearly reach a stabilised state after 6 months of light exposure.

^{*} corresponding author: Tel.: 01509-228140, Fax: 01509-610031, email: P.Vorasayan@lboro.ac.uk

One of the factors that directly affects the degradation is the cell thickness because it changes the strength of electric field within the device and thus the likelihood of recombination. During the last twenty years, there have been several studies on the degradation of p-i-n a-Si cells with regard to the i-layer thickness, but most of the works have been done in the laboratory, i.e. using simulated light and small laboratory scale devices (Tanner et al., 1985 and Wyrsh et al., 1994). Devices of larger size will have additional effects on the degradation. Thus there is a need for degradation studies on full size a-Si devices under realistic outdoor conditions. Therefore, since solar modules are generally used outdoors, in this paper the effect of i-layer thickness on the electrical parameters that are key indicators of performance and degradation under outdoor conditions is investigated. More importantly, the energy production of each device is analysed because this is ultimately the most important feature of a solar cell in realistic operating conditions. It will be shown that the energy production cannot be inferred from the efficiency alone and closer consideration should be paid to maximisation of energy production. It is also shown that an initially high efficiency does not necessarily mean that the device will have a high efficiency in the degraded state.

2. Experimental Arrangement

The ten a-Si (p-i-n) modules used in the experiment have the same module area but different i-layer thicknesses. There are 4 different i-layer thicknesses indicated by a number normalised to the thinnest i.e. $d_{i,rel} = 1.0, 1.3, 2.0$ and 2.5 . In the following, the average results from each thickness batch are reported, with the exception of the thinnest cells, where the champion is reported separately ($d_{i,rel} = 1.0A$). This is done as this shows a slightly different trend and it appears that the other modules are affected by something else on top of straight-forward SWE.

The devices have repeatedly been measured in a solar simulator (SPIRE SPI-SUN 240A). This large area, multi-flash solar simulator gives a measurement of indoor I-V characteristic with the uncertainty of measurement of $\pm 5\%$ under controlled conditions. The module temperature measured by spring-loaded thermocouple in contact with the back of the module is monitored for data analysis. The module temperature is not controlled, it adjusts itself to ambient temperature.



Figure 1: Nine a-Si modules with 4 different i-layer thicknesses were installed in the outdoor measurement system on the CREST building

After an initial simulator test, nine of the modules were mounted on the outdoor measurement system at Centre for Renewable Energy Systems Technology (CREST) building, Loughborough University with an inclination of 52° , which is the latitude of Loughborough, and facing toward the south, allowing natural degradation as shown in Figure 1. One of the samples (an $d_{i,rel}=1.3$) has been taken as a control and stored in the laboratory.

During exposure, the devices are open-circuited and connected automatically every ten minutes for I-V traces and module temperatures to be recorded. Measurements are performed by a Keithley 2420 source measurement unit and the temperature sensors used are Pt-100 thermal resistors. In addition, the full environmental profiles are also taken every ten minutes, consisting of the irradiance, spectrum and ambient temperature. The irradiance is measured by two thermopile pyranometers, one installed horizontally and one in the plane of array (the mast used for the mounting can be seen towards the right corner in Figure 1). The spectrum is measured by a monochromator-based spectroradiometer. At regular intervals (about 6-8 weeks) the devices are taken into the laboratory and measured with the simulator in order to determine absolute degradation. The measurements from both indoor and outdoor testing are then used to analyse the degradation and energy production of the modules with different thicknesses. The outdoor measurements have been conducted since July 2004 and the first five sets of data measured with the solar simulator have been made.

3. Results and Discussion

3.1 Initial Efficiency and Electrical Parameters

The devices were measured with a solar simulator to indicate initial parameters before they were installed outdoors. Figure 2 shows an average initial efficiency, fill factor (FF), open circuit voltage (V_{OC}) and short circuit current (I_{SC}) of different thicknesses normalised to that of the thinnest ($d_{i,rel}=1.0$).

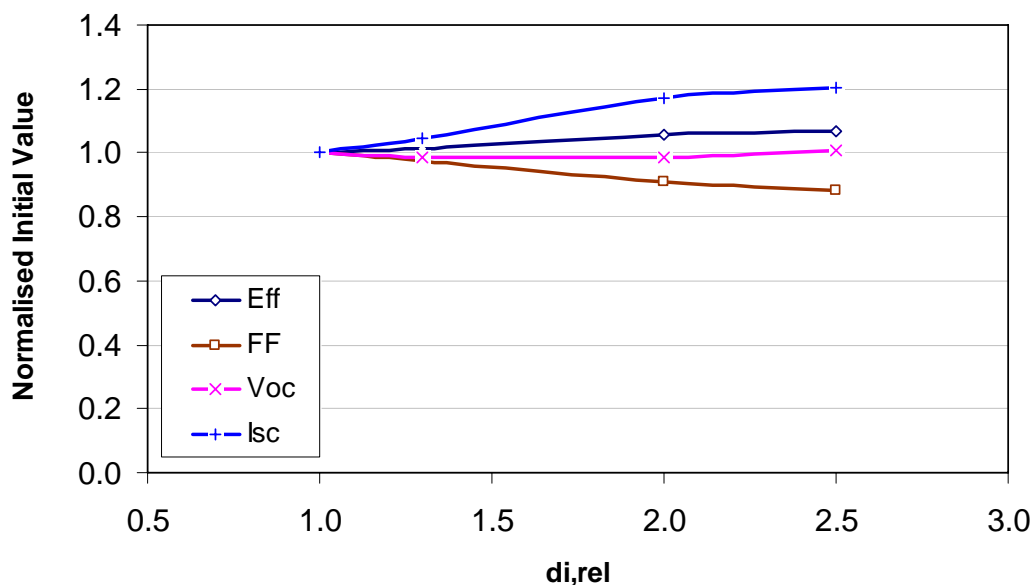


Figure 2: The normalised average initial Efficiency, FF, V_{OC} and I_{SC} vs Thickness.

As shown in Figure 2, thicker devices give higher initial I_{SC} and efficiency. The thickest device ($d_{i,rel}=2.5$) has initial I_{SC} and efficiency of 20% and 7% respectively higher than

those of the thinnest device. This is due to better optical absorption of the thicker devices which results in the increase of I_{SC} and thus efficiency. Thinner devices do not absorb as much light because some incident light with longer wavelengths (lower energy) will pass through the cell without absorption. However, typically thicker devices will suffer more degradation which will be described in the next section.

In addition, Figure 2 shows that initial value of V_{OC} of different i-layer thickness virtually constant which corresponds to work reported by Guha et al. (2003) that in some range of thickness, V_{OC} is constant. 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. For initial FF, an 11.5% reduction has been seen with a 2.5-fold increase of the thicknesses. This can be attributed to the reduced electrical field within the thicker devices and the thus more strongly voltage dependent photocurrent. Fantoni et al. (2002) reported a similar decrease in FF decreases with increasing thickness, making this a more general feature.

3.2 Degradation

The modules are taken into the laboratory at regular intervals to determine the absolute degradation by measuring with solar simulator under controlled conditions. Figure 3 shows the average efficiency normalised to the initial value obtained from these measurements. One of the results from the thinnest devices ($d_{i,rel}=1.0A$) has been shown separately in the graph, as the other devices behave slightly unexpectedly. All devices exhibit degradation around 30 to 45 % with respect to the initial efficiency, while the reference (the one kept in laboratory) shows a slight increase in efficiency of 2.1% from the initial value. This increase of the latter is due to a change in temperature of the laboratory between the solar simulator measurements, building works carried out in February and March 2005 resulted in the heating being switched off and thus the ambient temperature was about 8 degrees lower for these measurements (17°C). It is apparent that the average efficiency of all modules with different i-layer thickness installed outdoors decreases significantly in the first 2 months of outdoor exposure and after that they are nearly stable, with the $d_{i,rel}=1.3$ being virtually stable.

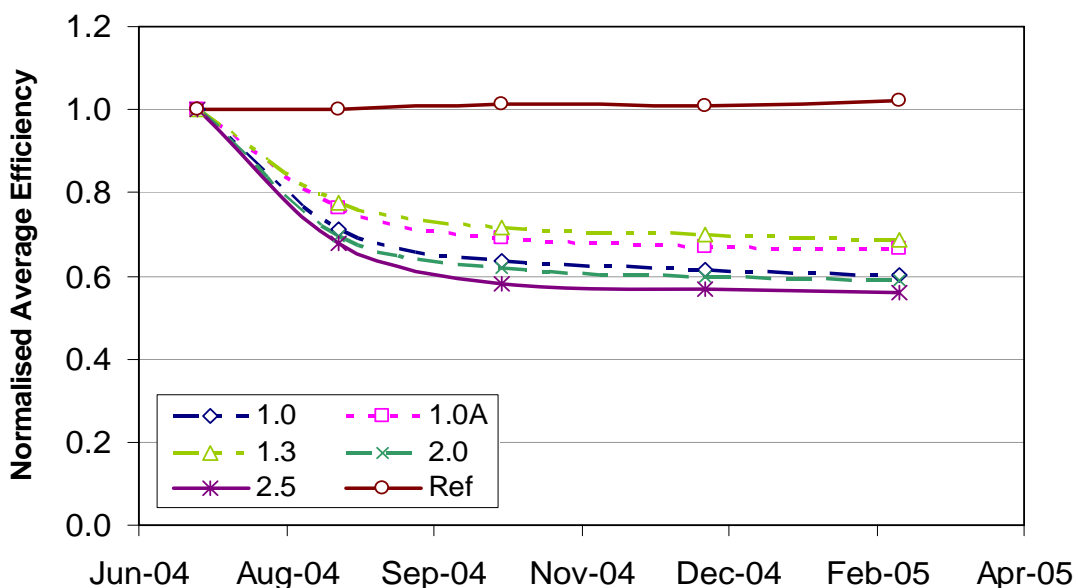


Figure 3: The average efficiency of different device thickness normalised to the initial value measured by the solar simulator during 6 months period of outdoor exposure

After 6 months of exposure, the thickest devices ($d_{i,rel}=2.5$) exhibit the largest reduction of efficiency of 44% relative to the initial value whereas that of the thinnest ($d_{i,rel}=1.0A$) decreases about 33%. This could be understood by 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 device is not the one that shows the smallest degradation, but the $d_{i,rel}=1.3$ modules which shows a reduction of 32%. According to Figure 3, it would be concluded that the thinner devices degrade less than the thicker ones, except for $d_{i,rel}=1.3$.

The parasitic resistances also affect the performance of the solar cells and in the case of a-Si can be an indication of the degradational state: the reduction in the lifetime-mobility product describing the charge carriers, which is associated with an increase of the voltage dependence of the photocurrent. This in return can be mixed up with changes in the resistances. Degradation will show as a reduction in the parallel resistance R_P and an increase of the R_S , because reducing the lifetime-mobility product of the charge carriers ‘flattens’ the I-V curve. The increasing of ‘ R_S ’ and decreasing of ‘ R_P ’ in the tested samples of the device lead to the reduction of FF and V_{OC} , which is an indicator that these are masking degradation. Truly resistive effects would not change the V_{OC} . Figure 4 shows the apparent R_S and R_P of the different device thicknesses during the outdoor measurement, normalised to the initial value. After having been measured outdoors, all of the devices show an increase of R_S but decrease of R_P . R_S increases with different rates corresponding to the thickness. The thicker the i-layer, the higher the rate of increasing R_S except for $d_{i,rel}=1.0$ and 1.0A, which is higher than $d_{i,rel}=1.3$. The R_S of the thickest device ($d_{i,rel}=2.5$) rises by more than twice the initial value.

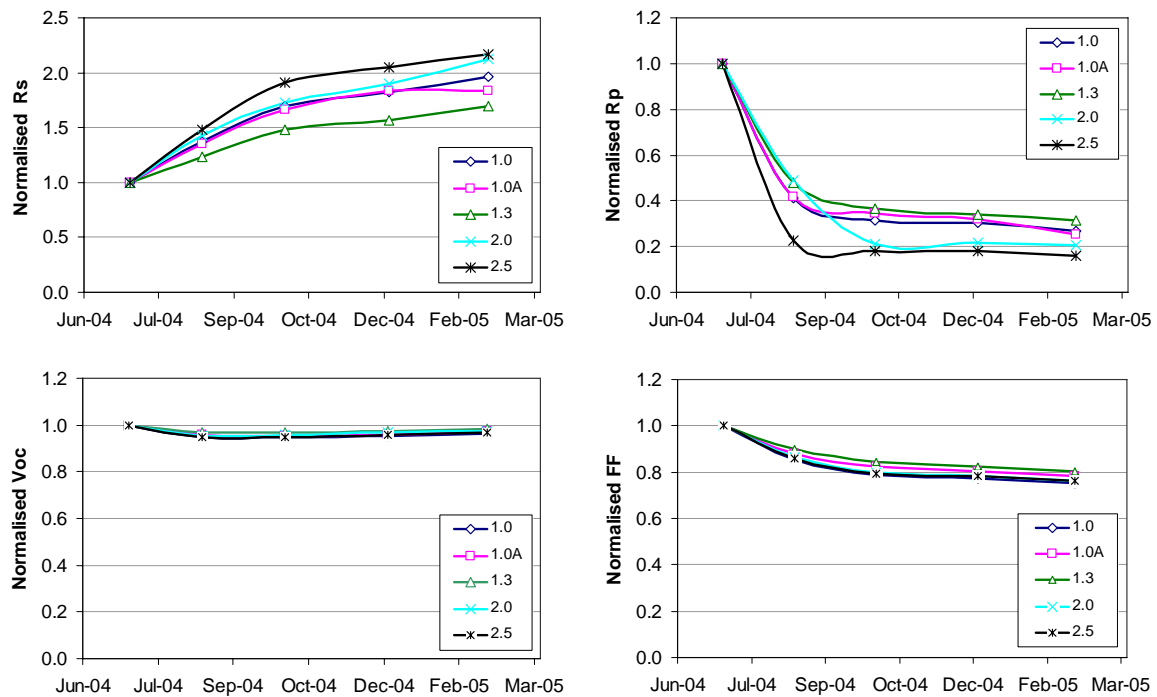


Figure 4: The average of R_S , R_P , V_{oc} and FF of each device thickness (top-left to bottom-right) normalised to the initial value measured by the solar simulator during the outdoor measurement.

The graph also shows that the apparent R_p of all devices significantly decreases during the first two months of outdoor exposure after which they seem to be stable, as can be seen in Figure 4. Nevertheless, there is some advantage in thicker devices. It has a lower probability of pin-holes occurring in the i-layer during the semiconductor formation. Such pin-holes form shunt paths (Roschier, 2002), which might be the reason for the rather high degradation of the $d_{i,rel}=1.0$ samples.

The changes in V_{OC} shown in Figure 4 are very small and can be attributed to some changes in the operating temperature during the later measurements. The shape of FF appears to follow the degradation most closely. The magnitude of this is amplified by a small reduction in the short circuit current (which is not shown here).

3.3 Energy Production

The energy production of solar cells obtained from outdoor measurement not only shows the performance degradation of each device but also directly relates to the environmental characteristics such as temperature, incident irradiance and spectrum that the device experiences at a particular site. Figure 5 illustrates the average outdoor energy production of the devices with different thickness, obtained from the outdoor measurements between July 2004 and January 2005. It is important to note that energy production in July was only about half of that in August due to the fact that the devices were installed in the middle of July 2004.

It can be seen from Figure 5 that there is an obvious difference of energy production between two distinct measurement periods, July to September and October to January. This could be understood by a seasonal variation. During the last 4 months of the measurement, the energy generation of each device was very low since it is a winter period that has shorter daytime and lower incident irradiance which are the keys indicator of energy production. The difference was somewhat amplified by missing the first few days of October, during which the modules were in the laboratory. Apart from those, the irradiance spectrum is another important factor that also affects the performance and energy production of a-Si devices as reported in work done by Gottschalg et al.,(2005b) and Ruther et al.,(2002).

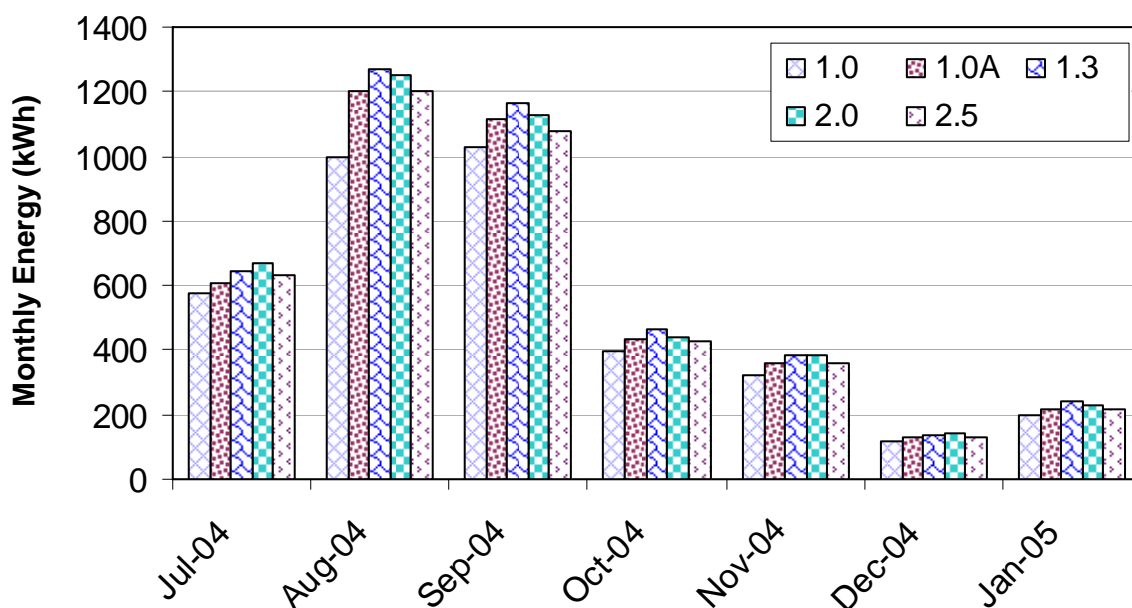


Figure 5: The average monthly outdoor energy production of device with different thickness obtain from outdoor measurements

In addition, in the first month of outdoor exposure, July 2004, the energy available from the devices corresponds to the thickness except for $d_{i,rel}=2.5$, as shown in Figure 5. The thicker devices generate higher energy since they had better initial efficiency according to Figure 2. However the $d_{i,rel}=2.5$ modules which had the highest initial efficiency do not give the highest energy production. Moreover, the $d_{i,rel}=1.3$ device which has the lowest degradation rate as shown in Figure 3 has obtained the highest monthly energy since August.

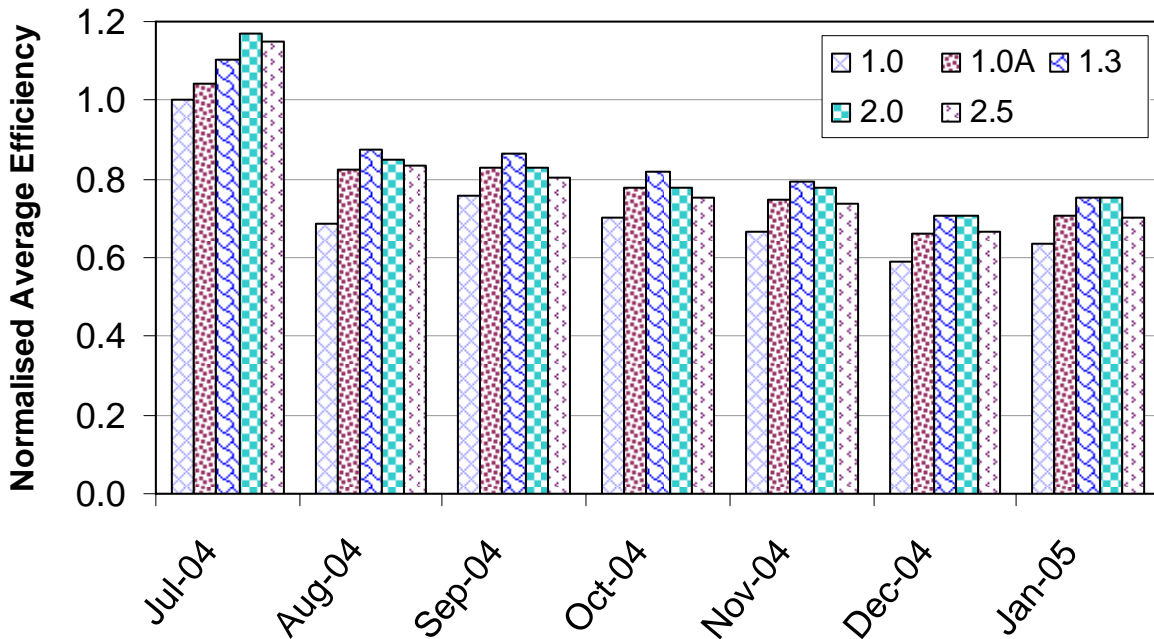


Figure 6: Normalised average monthly outdoor operating efficiency

The monthly operating efficiency remedies some of the variability of pure energy production as shown in Figure 6. The devices with a $d_{i,rel}=1.3$ seem to have the highest operating efficiency until January, together with the $d_{i,rel}=2.0$ devices. All devices start to improve slightly in January, as would be expected following the seasonal irradiance spectrum shift (Gottschalg et al., 2005a). The full evaluation of energy production can be carried out once a full year of data is recorded and the effect of seasonal annealing can be included.

4. Conclusion

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 having the higher degradation rate. In addition, the devices degrade significantly in the first few months of outdoor exposure and will saturate at some state. On the other hand the thinner device shows poorer optical absorption. Therefore, in order to optimise device performance, one must take the thickness of the i-layer into consideration where a trade-off has to be made between better absorption and reduced degradation.

5. References

- Dyk, E.E., and Meyer, E.L., 2004. Analysis of the effect of parasitic resistances on the performance of photovoltaic modules, *Renewable Energy*, 29, 333-334.
- Fantoni, A., Viera, M., and Martins, R., 2002. Influence of the intrinsic layer characteristics on a-Si:H p-i-n solar cell performance analysed by means of a computer simulation, *Solar Energy Materials & Solar Cells*, 73, 151-162.
- Gottschalg, R., del Cueto, J.A., Betts, T.R., and Infield, D.G., 2005a. Seasonal performance of a-Si single- and multijunction modules in two locations, presented at Proceedings of the 31st IEEE PVSC, Orlando, US.
- Gottschalg, R., Betts, T.R., Infield, D.G., and Kearney, M.J., 2005b. The effect of spectral variations on the performance parameters of single and double junction amorphous silicon solar cells, *Solar Energy Materials & Solar Cells*, 85, 415-428.
- Guha, S., Yang, J., Banerjee, A., Yan, B., and Lord, K., 2003. High quality amorphous silicon materials and cells growth with hydrogen dilution, *Solar Energy Materials & Solar Cells*, 78, 329-347.
- Roschier, S., 2002. Development of procedures for performance measurements and lifetime testing of thin film photovoltaic devices, Thesis(PhD.), Helsinki University of Technology.
- Ruther, R., Kleiss, G., and Reiche, K., 2002. Spectral effects on amorphous silicon solar module fill factors, *Solar Energy Materials & Solar Cells*, 71, 375-385.
- Staebler, D.L., and Wronski, C.R., 1977. Reversible conductivity changes in discharge-produced amorphous silicon, *Appl. Phys. Lett*, 31, 292-294.
- Tanner, D.P., Vasquez, S., and Willett, D., 1985. Thickness dependent of i-layer stability of thin film silicon: Hydrogen solar cells: A comprehensive study, Proceedings of the 18th IEEE PVSC, New York, US, 1301-1306.
- Valizadeh, P., 2001. Amorphous silicon solar cells: Efficiency and stability issues, Electrical Engineering and Computer Science Department, University of Michigan, Course report of EECS512.
- Wyrsh, N., and Shah, A., 1994. Degradation of a-Si:H solar cells: New evidence for a bulk effect, Proceedings of the 24th IEEE PVSC Hawaii 5-9th Dec, 583-586.