Progress in a-Si/a-Si Tandem Junction Thin Film Solar Modules

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ABSTRACT: SCHOTT Solar Thin Film has successfully brought her a-Si/a-Si tandem cell technology for ASI™ modules to full production. The production site in Jena with a capacity of 35 MW/a started end of 2007 and ramp up was completed in 2008. Due to continuous process improvements the initial power of the best module could be improved to 127 W which corresponds to 9.4 % initial aperture efficiency. Indoor and outdoor light induced degradation of the 1.4 m² modules is demonstrated to be reproducible around 18 %. Recently a new power class with stabilized 103 W could be introduced. Best small area development cells stabilize at 8.5 % which give the near term perspective of 110 W stable module power or 8 % module aperture area efficiency. A round robin comparison together with various institutes shows a high degree of reproducibility and accuracy for the power measurement of stabilized ASI™ modules within +/- 1 %. Long term monitoring of some of our early PV installations demonstrates an excellent stability over more than one decade. Schott ASI™ modules with thermally isolated rear side reveal a significant annealing effect and show an improved PR of up to 4 %.

Keywords: Silicon, Thin Film Solar Cell, Module, Long Term Stability

1 INTRODUCTION

Amorphous Silicon (a-Si) PV technology still attracts a lot of attention due to several attractive features like low energy consumption, use of abundant and heavy-metal-free raw materials, excellent manufacturability with very high production yield and most important for our customers high energy yields for a-Si based PV installations. Recently in Jena, Germany, a fully automated series production line was successfully ramped up to full production. The production fab which has an annual capacity of 35 MW/a of 1.4 m² ASI™ modules, was completely designed by Schott Solar procuring equipment from various suppliers.

Our cell design is based on an amorphous a-Si/a-Si tandem junction, which currently seems to be the best compromise between efficiency and production economy, if a-Si single junction, a-Si tandem junction and micromorph devices are compared [1]. Module efficiency of our ASI™ modules is about 15 % higher compared to state of the art a-Si single junction based modules. On the other hand efficiency is only 5 to 15 % lower as compared to micromorph modules where the cell is four to five times thicker.

The installation-friendly module design was chosen to help reducing BOS costs. The module combines high maximum system voltage with very low module voltage and therefore allows more than 30 modules with over 3 kW per serial string. The framed and low weight module is ideally suited not only for roof-top installations but also for multi-MW power plants.

SCHOTT Solar´s thin film R&D efforts focus on efficiency, cost and reliability relevant issues like light-management [2], up-scaling of the PECVD processes to larger substrate areas [3], and on economic solutions of highly efficient micromorph tandem-junction devices [4].

2 CELL DEVELOPMENT

The major limiting factor in achieving high efficiencies with a-Si based cells is the light-induced degradation (LID), caused by the Staebler-Wronski- effect [5]. In [1] we revealed the LID of a-Si pin single- junction cells with different thickness. A relatively small increase in cell thickness can create a significant enhancement of the LID. This disadvantageous situation is definitively improved in a-Si/a-Si tandem cells. Figure 1 shows the LID factor after 1000h light soaking for a series of

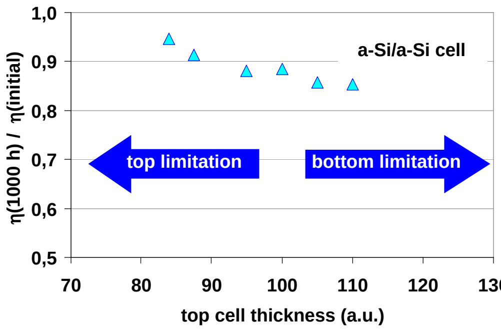

Figure 1: LID after 1000 hours for a-Si/a-Si tandem cells with different matching conditions

tandem cells with different current matching conditions for top- and bottom-cell. While typical single junction cells suffer from a LID factor of 22 % to 30 % or even more [1], bottom limited tandem cells show an LID of approximately 16 % and top limited cells lower than 10 % respectively. A relatively wide maximum of the stabilized efficiency can be found around the matching point, so that small cell thickness deviations would have a negligible effect on stabilized efficiency (Fig. 2). This is one of the key features of a-Si/a-Si tandem cells which help to minimize fluctuation of stabilized power output of production. Best stabilized cell efficiency is found to be around 8.5 %, while applying production relevant TCO, back contact and deposition rates for a-Si. Thus 8 % stable aperture area module efficiency is achievable in the near future.

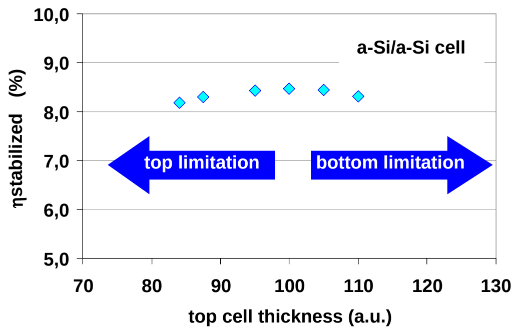

Figure 2: Stabilized efficiency after 1000 hours light soaking for a-Si/a-Si tandem cells with different matching conditions

3 PRODUCTION MODULES

Due to a well prepared process transfer from R&D to the production fab accompanied by continuous process optimization we were in the position to quickly

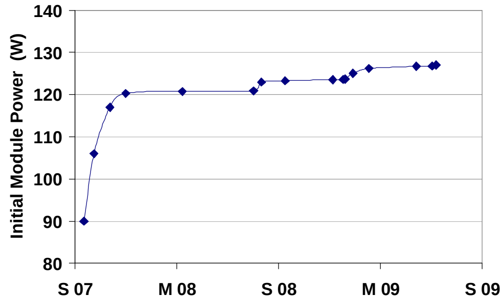

Figure 3: Improvement of the champion module power over the first two years of production

ramp up not only production volume and yield, but also module efficiency. Figure 3 shows the development of the initial power of the champion module from production start with 90 W up to a recent record with 127 W. The later corresponds to 9.4 % aperture area efficiency (Fig. 4).

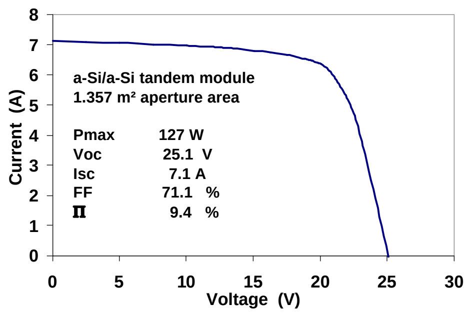

Figure 4: IV-curve taken from a 127 W (initial) production module

4 METROLOGY

At the end of the production process, completed modules are measured under STC condition in their initial power state, but labelled with their stabilized power output. Therefore both, a precise efficiency measurement of tandem junction devices and a LID factor as reproducible as possible, are the key features to fulfil our high quality level.

In a round-robin exercise within the EU-project PERFORMANCE only a high spread of +/- 7 % in determining the power output of a-Si/a-Si modules could be achieved [6]. Insufficient pre-stabilization of the modules was claimed to be one of the possible reasons for such severe deviations. As a consequence, we triggered a further round-robin procedure under the lead of Fraunhofer ISE, where stabilized SCHOTT Solar ASI™ modules were used. Our solar simulator in the production line is carefully adjusted by a calibrated and stabilized a-Si/a-Si tandem module and this adjustment is double-checked by unfiltered and filtered c-Si reference cells with +/-2.5 % accuracy. As a result we obtain performance measurements for four ASI™ modules, done by ISE, TISO, NREL and SCHOTT Solar, well within a +/- 1 % tolerance band (Fig. 5).

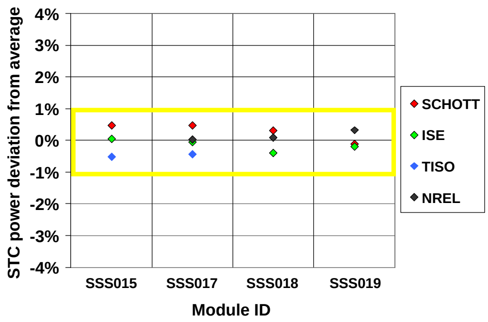

Figure 5: Relative power deviation for stabilized a-Si/a-Si tandem ASI™ modules obtained within a round-robin comparison between ISE, TISO, NREL and SCHOTT Solar

The second important issue, mentioned above, is to achieve a reproducible LID factor for all production modules and to demonstrate the correlation between indoor light soaking, which is done at Schott Solar over 1000 hours between 45 and 50 °C to obtain the stabilized state, and stabilization under real outdoor conditions Regarding the latter we must be aware, that cold locations cause higher LID and warm spots will do the opposite. Table 1 shows LID factors between 16.3 and 18.2 % extracted from five different modules being light-soaked indoor. It can also be seen that despite a significant improvement of initial module power from 102 W to almost 121 W (for ID 8-08 and ID 8-39) the LID factor stays in the usually found range from 16.9 to 18.1 %. Stabilization of our ASI™ modules under outdoor condition in Jena from October 2008 to June 2009 reveals LID factors between 17.3 and 18.0 %, thus being in good agreement with indoor stabilization data. As a consequence from the above shown precise performance measurement and reproducible LID factor we decided to offer our customers a positive sorting tolerance of the module power. Additionally a new power class with > 103 W could be introduced recently.

Table 1: Initial and stabilized module power; ca. 1000 hours indoor light soaking at 45 to 50 °C

module ID	initial (W)	stabilized (W)	LID (%)
8-08	102.2	85.0	-16.9
8-22	117.0	98.0	-16.3
8-30	116.4	97.6	-16.2
8-39	120.8	99.0	-18.1
9-10	120.9	98.9	-18.2

Table 2: Initial and stabilized module power; outdoor test from Oct. 2008 to June 2009 in Jena

module ID	initial (W)	stabilized (W)	LID (%)
8-23	112.9	93.0	-17.6
8-27	113.9	94.2	-17.3
8-27	115.9	95.0	-18.0
8-27	116.6	95.6	-18.0

5 MODULE DESIGN

The installation-friendly module design was chosen to help reducing BOS costs. The module combines high maximum system voltage up to 1000 V with very low module voltage and therefore allows more than 30 modules with over 3kW per serial string. The module frame protects the glass edge during transport, installation and operation most effectively. As a result glass breakage can practically be avoided. Back foil encapsulation results in a low weight module which is ideally suited not only for roof-top installations but also for multi-MW power plants.

6 LONG-TERM STABILITY BEHAVIOUR

In order to investigate the long-term stability of our a-Si/a-Si tandem junction modules, produced in the Putzbrunn pilot line in 1996, a number of modules have

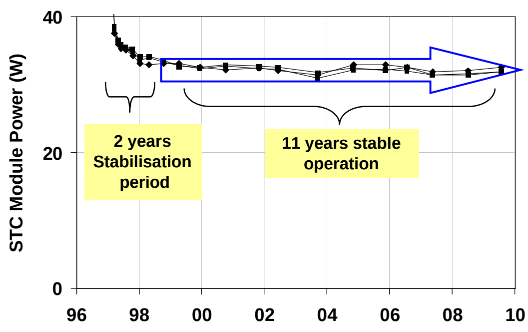

Figure 7: STC-power monitoring of 32 W a-Si/a-Si tandem junction modules for almost 13 years.

been deployed on the roof top of our production site in Munich. The power output of these a-Si/a-Si tandem modules was periodically measured with a calibrated solar simulator at standard test conditions (STC). This procedure provides a long-term performance monitoring without the influence of variation of temperature, solar irradiance and spectrum on the measurement. Figure 7 shows, after the initial stabilization period, a convincing stable behavior during the following 11 years of outdoor exposure.

A 2.4 kW roof-top PV-installation in Gaggenau, Southern Germany, also based on our a-Si/a-Si tandem modules, which started operation as early as 1994, has been partially monitored by Fraunhofer ISE since then.

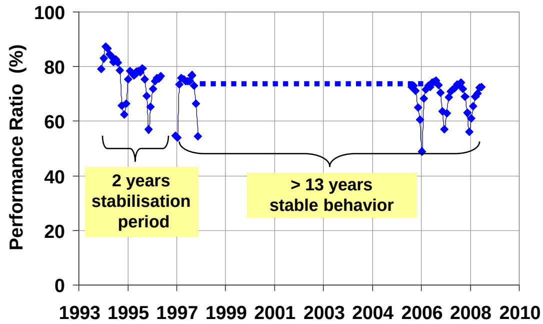

Figure 8: Monthly PR monitoring for the Gaggenau roof-integrated PV system from 1993 to 2009. Doted line interpolates missing data from 1998 to 2006. Monitoring done by Fraunhofer ISE

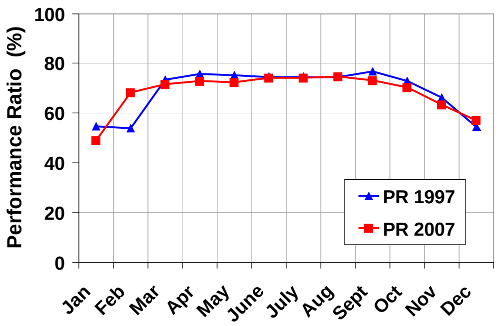

Figure 9: Monthly PR monitoring for the Gaggenau roof-top system for the years 1997 and 2007

For the monthly performance ratio (PR) we observe similar long term behaviour as for the modules shown in Fig. 8. After the initial stabilization period with an LID of about 19 % (decay of PR from approximately 90 to 73 %), beside of small annual fluctuations, we can not observe any indication for a performance degradation. Figure 9 allows an even closer look at the monthly PR for the years 1997 and 2007. Again, except of seasonal fluctuations, no decay of PR within 10 years seems to be detectable.

7 ENERGY YIELD ASI^{TM} VERSUS c-Si

In order to monitor PR behavior and energy output of our a-/Si/a-Si technology, two small (0.8 kW) ASI^{TM} PV systems (ASI 1 and ASI 2), and a 0.6 kW c-Si based reference system were installed in Putzbrunn end of 2007. The energy output and thus the PR will not be not related to the name plate rating (as is usually done), but to the individual STC-power measurement of the individual modules used here. This measure will increase accuracy regarding characteristic differences between ASI™ and c-Si.

Figure 10 shows the PR of system ASI 1 and the c-Si from Jan 2008 to Aug 2009. Clearly the for amorphous Si typical "summer high" and "winter low" PR can be observed, while c-Si shows quite the opposite trend. Also a lower PR for ASI in 2009 compared to 2008 can be seen due to the stabilization effect. Feb and Mar 2009 were two snowy months where ASI™ unexpectedly outperforms c-Si. It is probable, that the c-Si PV-system suffers more from partial shadow and low illumination conditions coming from the snow coverage.

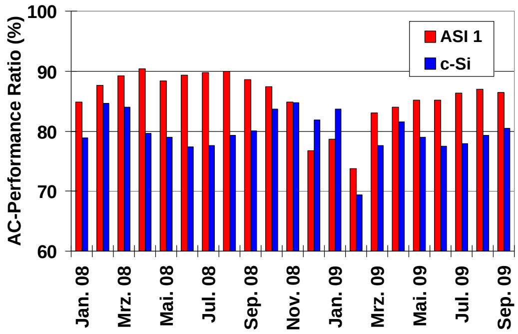

Figure 10: PR of two test PV systems based on ASI™ and c-Si modules

Table 3: Energy yield for the PV systems

	ASI 1 (kWh/kW)	c-Si (kWh/kW)	Delta ASI/c-Si
2008	1199	1091	+9.9 %
2009-09	883	824	+7.1 %

In the first year of operation (2008) the ASI system yields with excellent 1199 kWh/kW almost a surplus of 10 % as compared to the crystalline reference (Table 3). Due to the stabilization effect the advantage in the second year (Jan to Sep) is lower, but a 7 % higher energy yield can still be obtained.

As mentioned above, a second system ASI 2 is in operation as well since Jan 2008. During the course of the first 1.5 years it could be confirmed, that both ASI systems behave very similar. End of May 2009 the modules of ASI 2 were thermally isolated on their back side. By this measure the typical cell temperature under operation (NOCT) went up by about 10 K, thus from typically 50 °C to roughly 60 °C. This procedure should simulate the thermal situation of a roof-integrated system with no ventilation on the back side and a much warmer location like Southern Europe respectively. While according to the small, but negative temperature coefficient the power output at elevated temperatures should lead to lower energy yields, the annealing effect, which is only valid for a-Si, but not for other thin film technologies sustainably increases the module efficiency. Figure 11 shows the preliminary effect of the thermal isolation of system ASI 2 on the energy yield. With a certain delay of about one month the PR of the thermally isolated ASI 2 system improves to over 90 % as compared to about 86 % of the "normal" ASI 1 system. This demonstrates clearly, that the annealing effect over compensates the negative temperature coefficient. From this observation it can be concluded that ASI™ modules are ideally for PV installations in hot areas.

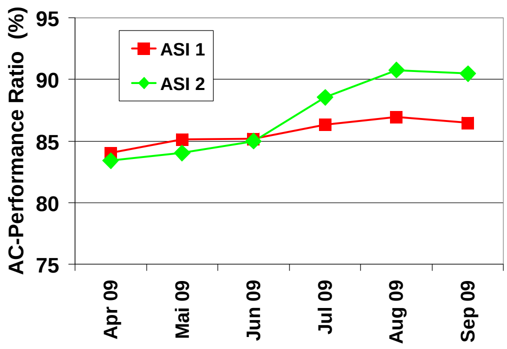

Figure 11: PR of the two ASI systems. ASI 2 was thermally isolated end of May 09

7 SUMMARY

SCHOTT Solar Thin Film has successfully ramped up its production in Jena. The best module shows 127 W initial power or 9.4 % initial aperture efficiency. LID is demonstrated to be reproducible around 18 %. Power measurement is in very good agreement with recognized calibration institutes. Various long-term monitored outdoor installations proof stable behavior without performance loss. Thermally isolated ASI™ modules reveal a significant annealing effect leading to an improved PR of up to 4 %.

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