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The Role of Polycrystalline Thin-Film PV Technologies in Competitive PV Module Markets

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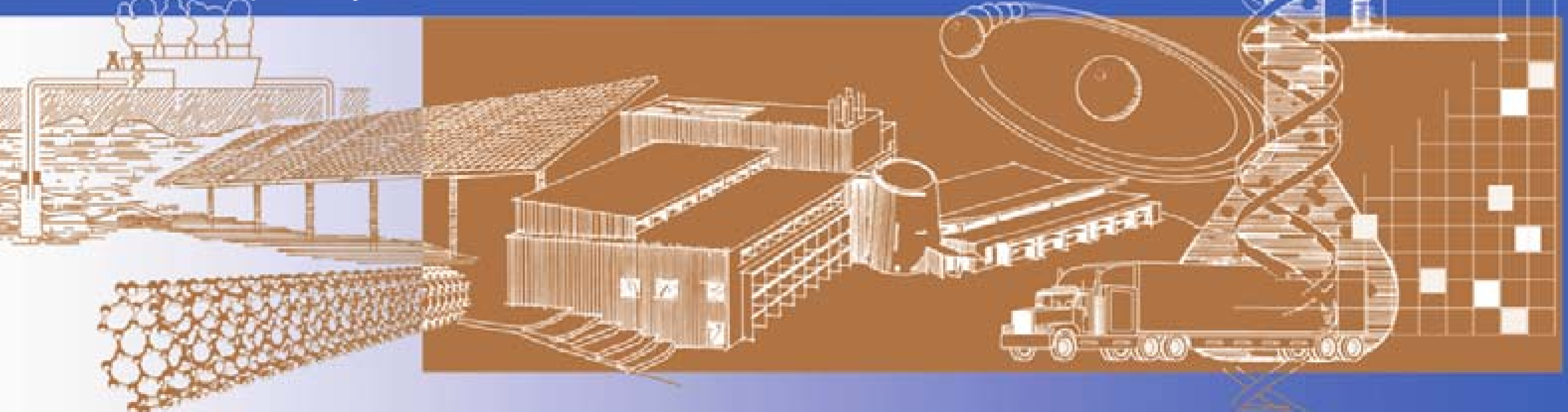

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The Role of Polycrystalline Thin-Film PV Technologies in Competitive PV Module Markets

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ABSTRACT

This paper discusses the developments in thin-film PV technologies. It provides an outlook on future commercial module efficiencies achievable based on today's knowledge about champion cell performance. It also provides a relative cost comparison of thin-film and wafer/ribbon based Si PV modules. In 2007, about 65% of the modules produced in the US were thin-film modules when amorphous silicon modules are also considered.

INTRODUCTION

This paper updates a methodology presented at the 31st IEEE PVSC Conference (2005) [1]. Different PV flat-plate technologies are compared on the basis of verified champion cell efficiencies; projections are made for commercial module efficiencies estimating that they will be proportional to verified best solar cell efficiencies. We will also review the technical issues affecting performance and commercialization of polycrystalline thin film PV modules.

We update our semi-empirical methodology of comparing verified stabilized best or "champion" solar cell data with performance achieved on commercial manufacturing lines [2], estimating the performance and cost developments for future successful PV module candidates. Table 1 is compiled from a survey of manufacturer's websites in April 2008. The 5th column in Table 1 indicates the c/c ratio, i.e., the ratio of respective module and best cell efficiency, where cell numbers given in Ref. 2 are used.

Table 1: Module Efficiency from survey of manufacturers' websites and "Performance Ratios [3]"

Eff. (%)	Module	T.coeff. (power)	Technology	Current c/c performance ratio cell/module
19.3	SunPower 315	-0.38 %/C	mono-Si, special junction (sp. j.)	78%
17.4	Sanyo HIP-205BAE	-0.30 %/C	CZ-Si, "HIT," sp. j.	70%
15.1	BP7190	-0.5 %/C	CZ-Si, sp. j.	61%
14.2	Kyocera KC200GHT-2	n/a	MC-Si, standard junction (std. j.)	70%
14.2	Solar World SW 185	n/a	CZ-Si, std. j.	70%
14.2	BP SX3200	-0.5 %/C	MC-Si, std. j.	70%
13.4	Suntech STP 260S-24V/b	n/a	MC or CZ-Si, std. j.	66%
13.4	Solar World SW 225	n/a	MC-Si, std. j.	66%
13.1	Evergreen Solar ES 195	*(up to)*-0.5%/C	String-ribbon-Si std. j.	65%
11.0	WürthSolar WS11007/80	-0.36%/C	CIGS	55%
10.4	First Solar FS-275	-0.25%/C	CdTe	63%
8.5	Sharp NA-901-WP	-0.24%/C	a-Si/nc-Si	70%
8.1	GSE Solar GSE120-W	-0.5%/C	CIGS	41%
6.3	Mitsubishi Heavy MA100	-0.2 %/C	a-Si, single-junction	66%
6.3	Uni-Solar PVL136	-0.21 %/C	a-Si, triple junction	52%
6.3	Kaneka T-SC(EC)-120	n/a	a-Si single junction	66%
5.9	Schott Solar ASI-TM86	-0.20%/C	a-Si/a-Si same bangdgap tandem	62%
5.3	EPV EPV-42	-0.19%/C	a-Si/a-Si same bandgap tandem	56%

In Table 2, we have listed expected future commercial module performance, multiplying current best cell performance by 0.8 (i.e., taking the future c/c ratio as 0.8 for all PV technologies) [4]. Future relative module performance was calculated by dividing future module efficiencies by the future standard Silicon efficiency number, because "standard Si" currently constitutes the prevailing PV technology ("standard Si" refers to cells fabricated by diffusion and screen printing processes). The last column of the table shows 1/relative-performance, if thin-film technology, hence avoiding the use of Si wafers, multiplied by 0.5 (the thin-film PV "advantage factor"). Anything in this column with a number <1 should show a manufacturing cost advantage over standard silicon. Manufacturing detail and cost control will affect the actual values, but the strength of our approach is to apply the same methodology to different flat-plate PV technologies. Compared to our last paper [1], we have increased the cost advantage of thin film modules over wafer Si modules from 40% to 50%. In the past, Si feedstock and wafer costs were largely determined using 'second-grade' electronic poly-Si feedstock, that may have established cost figures for wafers made from feedstock acquired below cost. Current analysis by Rogol indicates wafer cost to constitute about 60% of the cost of a wafer Si module [5]. Converting the cost figures into percentages (wafer-cost/module-cost) it is apparent that currently such percentage is near 60%; therefore, it appears likely that wafer costs could still make up approximately 50% of the cost of a crystalline Si PV module in years to come.

Table 2: Anticipated Future Module Efficiency and Relative Cost Based on Today's Demonstrated Champion Cell Performance

Technology	Future commercial module performance (80% of current record cell efficiency)	Future Relative Performance	Future Relative-cost (using a 50% thin film PV advantage)
Silicon (non-stand)	19.8%	1.18	0.85 (competitive)
Silicon (standard)	17.0%	1.00	1.00 (reference)
CIS	15.9%	0.92	0.54 (highly competitive)
CdTe	13.2%	0.78	0.64 (highly competitive)
a-Si (1-j)	8.0%	0.47	1.06 (about the same)
a-Si (3-jj), (or a-Si/nc-Si)	9.7%	0.57	0.88 (competitive)

It should be noted that in order to attain the relative cost given in the 4^{th} column of Table 2, module efficiencies given in column 2 will have to be achieved. As can be seen from the 5^{th} column of Table 1, many PV manufacturing schemes still show a c/c-ratio well below the value of 80% assumed for the data in Table 2, indicating that some progress with product performance is possible due to implementing better manufacturing methods.

RESEARCH AND DEVELOPMENT ISSUES

Our analysis above shows that module performance remains a significant factor for determining module cost. Since solar cell processing is often found to affect cell efficiency, it is important to assess (a) the true advantage of each process, and (b) how it can be handled in a manufacturing environment. It is also desirable to develop greater confidence and insight when chosen processes can be improved further by optimization, and when processes should be substituted or added.

In case of the CIS PV technology, manufacturing scale up issues have frequently prevented companies from successfully using high efficiency cell recipes for commercial production of modules with commensurate efficiency. This technology is in need to better understand the effects of deposition processes, choice of cell structures, and deposition rates on cell and module performance and device stability. In case of CdTe modules, development of improved device schemes that lead to high performance, low manufacturing cost, and good device stability have to be investigated.

Since 2006, DOE's new program to assist the development and deployment of photovoltaic technology, the Solar America Initiative (SAI) provides the means of developing PV technologies and advance PV manufacturing. Programs of interest to cell and module manufacturing include the Technology Pathway Partnership, TPP, geared towards larger and more mature entities, the PV Incubator program for small businesses, as well as the Future Generation and University programs geared at longer-term technology developments or in support of university driven R&D aspects, respectively. Among different PV technologies, the following thin-film PV companies are being supported: Uni-Solar (a-Si), and Nanosolar (CIGS) obtained TPP awards, and AVA Solar (CdTe), Primestar Solar (CdTe), SoloPower (CIGS), and Blue Square Energy (Si film) received SAI PV Incubator awards.

COMMERCIAL STATUS OF THIN-FILM PV

It seems reasonable from time to time to assess the impact of R&D developments on actual commercial product. In Fig. 1, we show the progress, broken down by technology, by averaging by technology best commercial module efficiencies as shown in Table 1 (such data have been compiled since 04/2004) [6]. For this period considered, the most impressive progress in module efficiency has been obtained for the CdTe technology by First Solar.

2007 has been considered a turning point for thin film PV at least for US-based PV manufacturing, with US thin-film shipments reaching a market share of about 65% [7]. First Solar and United Solar Ovonic became the number 1 and number 2 ranked US manufacturers, respectively. Using the breakdown provided by PV News [7], and only counting the thin-film PV “pure play” entities First Solar, United Solar, and Global Solar in the thin-film category (there may be a small amount of thin film PV within the “others” category, which constitutes largely wafer/ribbon Si flat plate technologies), we compiled Fig. 2. Estimates for 2008 production are taken as 2/3 of the PV News published capacity numbers for 2008. Projections for 2009 and beyond are currently difficult, because it is not known where in the world companies will expand manufacturing and when exactly some announced large capacities will come on line. Given the size of some announcements, even a 3-month delay in getting such factory to produce at capacity could make a significant difference in the amounts produced. Currently, First Solar has announced capacity expansion greater than 1000 MW_p annual capacity by the end of 2009, but those new factories are built (already under construction) in Malaysia.

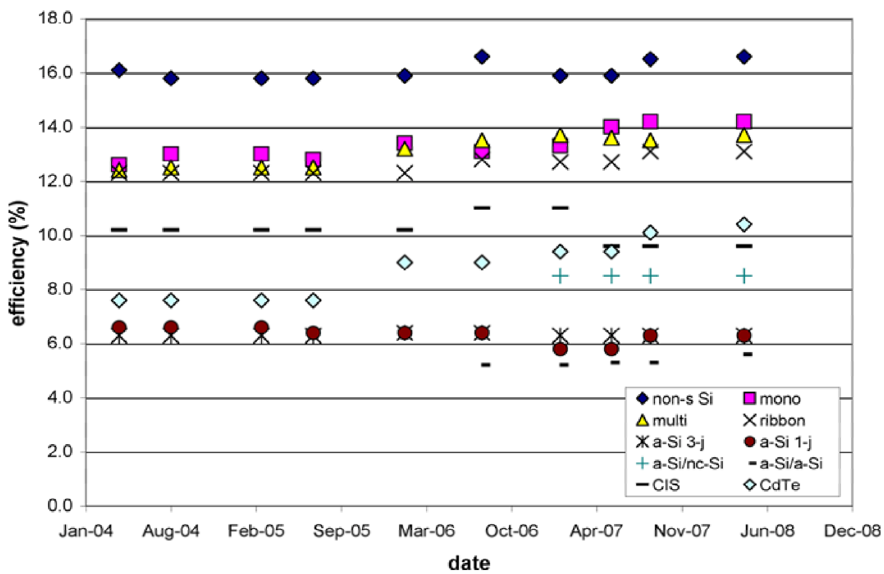

Fig 1: Development of Commercial Module Efficiency, from survey of manufacturers’ websites, broken down by PV Technology

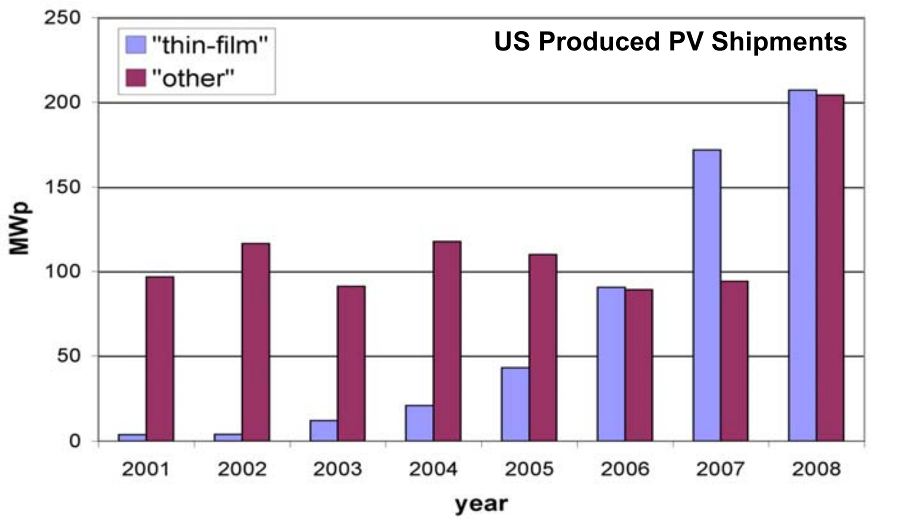

Fig 2: US produced Modules thru 2007, counting First Solar, Uni-Solar and Global Solar as “thin Film” PV and the rest as “other.” Projections for 2008 use 2/3 of PV News reported end of 2008 capacity figures.

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[1] Bolko von Roedern, Harin S. Ullal, and Ken Zweibel, ‘Polycrystalline Thin-Film Photovoltaics: From the Laboratory to Solar Fields,’ Proc. 31st IEEE PVSC (2005), p. 183.

[2] Martin A. Green, Keith Emery, Yoshihiro Hishikawa and Wilhelm Warta , “Solar Cell Efficiency Tables (Version 31),” Prog. Photovolt: Res. Appl. 2008; 16:61–67

[3] Some of the manufacturer’s spec sheet websites are given below. Note that product specifications can change, including the possibility of new modules becoming available or discontinuation of certain models.

[4] Bolko von Roedern, refocus magazine, (July + August 2006) p. 34.

[5] Michael Rogol, “Refining Benchmarks and Forecasts – Rogol’s Monthly Market Commentary,” Photon International, Jan. 2008, 84

[6] Older module specification sheets can currently be found on the NREL website http://www.nrel.gov/ by searching for it “spec sheet.”

[7] PV News, Greentech Media and Prometheus Institute, 03/2008 issue

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