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Polycrystalline Thin-Film Solar Cell Technologies

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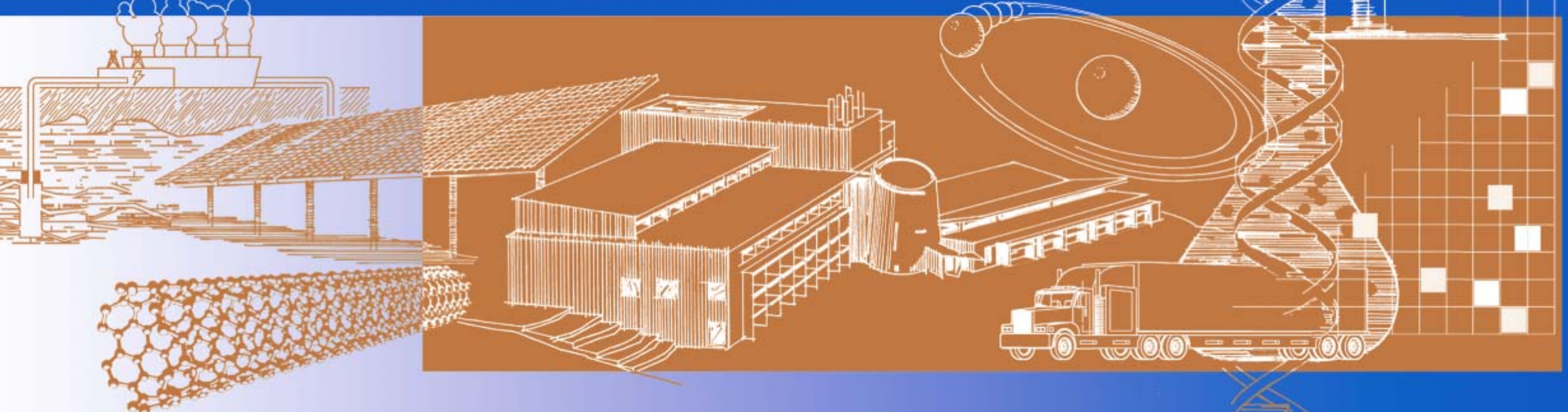

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Polycrystalline Thin Film Solar Cell Technologies*

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1.0 Introduction

In this paper, we report on the significant progress made worldwide by polycrystalline thin-film solar cells, namely, cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS). Polycrystalline thin-film PV technology status is also discussed in details. In addition, R&D and technology challenges in both areas are elucidated in this paper. The worldwide estimated projection for thin-film PV technology production capacity announcements (including a-Si/thin Si) which was estimated at 3700 MW in 2006 [1] is now estimated at more than 8000 MW by 2010.

1.0 Thin-Film Cadmium Telluride Solar Cell Technologies

Thin-film CdTe solar cells are one of the most promising thin-film PV devices. With a bandgap of 1.45 eV it has an excellent match with the solar spectrum. Since these are direct bangap semiconductors with high absorption coefficient, very thin absorber layer are needed to absorb the photons. Theoretical efficiencies for these devices are about 26%. Laboratory efficiencies of 16.5% for thin-film CdTe solar cell has been demonstrated by NREL scientists [2]. Historically, thin-film CdTe solar cells were referred to as the "dark horse" for thin-film PV devices. Subsequent concerted research effort by several groups worldwide has resulted in developing several deposition processes for the growth of the absorber layer. The processes are close-space sublimation, electrodeposition, vapor transport deposition, spray, screen-printing, sputtering, physical vapor deposition, laser ablation, metal organic chemical vapor deposition, molecular beam epitaxy, and atomic layer epitaxy [3]. Many of these processes has resulted in thin-film CdTe solar efficiency of 10% or higher. Five of these processes have demonstrated prototype power modules, namely, close-space sublimation, electrodeposition, spray, screen printing and vapor transport deposition.

For thin film CdTe technology, five key research, development, and technology challenges include: (1) standardization of equipment for deposition of the absorber layer, (2) higher module conversion efficiency, (3) back-contact stability, (4) reduced absorber layer thickness to less than 1 micrometer and (5) control of film and junction uniformity over large area for power modules.

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The current status of the manufacturing technology is power modules with a conversion efficiency of 10.6% made by First Solar (FS). Their manufacturing cost is $ 1.08 per watt and installed system price is in the range of $ 4-5 per watt, the lowest in the industry for any PV system. Clearly, FS is the world leader in all thin-film PV manufacturing technology. They have an installed capacity of more than 140-MW in Perrysburg, Ohio. They have also installed a 192-MW manufacturing plant in Germany. In addition, they are installing more than 700-MW thin-film CdTe manufacturing line in Malaysia, which will be commissioned in phases in 2009 and 2010. Thus FS's target is to have a worldwide installed thin film manufacturing capacity of more than 1100-MW by December 2009. FS is also projecting cost to decline to $ 0.92 per watt by Dec 2009. To date, FS has installed 500 MW of thin-film CdTe power modules mainly in Germany and Spain for commercial roof-top and utility-scale applications. They are also working very closely with a system integrator -- Juwi Solar to install a 40-MW solar farm in Germany to be completed in December 2008. Like for all PV companies, the German and Spanish feed-in-tariff law has clearly helped in the market acceptance of the thin-film CdTe power modules. A few more emerging companies are AVA Solar, Colorado, USA; Primestar Solar, Colorado, USA; Calyxo, Ohio, USA; Calyxo, Germany; and Arendi, Italy.

3.0 Thin-Film Copper Indium Gallium Diselenide Solar Cell Technologies

Thin-film PV technology based on copper indium gallium diselenide is another attractive option for fabricating high-efficiency, low-cost, and reliable thin-film power modules. Thin-film CIS is also a direct bandgap semiconductor and has a bandgap of ~0.95 eV. When Ga is added to CIS, the bandgap increases to ~1.2 eV depending on the amount of Ga added to the CIGS film. This material has demonstrated the highest total-area, conversion efficiency for any thin-film solar cells in the range of 19.3% to 20.0%, fabricated by NREL scientists [4,5,6,7].

Several challenges still need to be addressed as emerging and new groups develop CIGS thin-film PV technologies. The following six challenges are critical for developing low-cost and reliable CIGS products: (1) standardization of equipment for the growth of the CIGS absorber films, (2) higher module conversion efficiencies, (3) prevention of moisture ingress for flexible CIGS modules, (4) improved processing for CIGS deposited by alternative process for high efficiency cells and modules, (5) thinner absorber layers of less than 1 micrometer or less and (6) CIGS absorber film stoichiometry, and junction and film uniformity over large areas for power module fabrication.

Worldwide, some 40 companies are actively involved in the technology development of thin-film CIGS products. Towards this end, ten deposition processes are being used for growing the thin-film absorber layers. In all cases, Mo is used as the back contact deposited by sputtering, while majority of the groups use ZnO as the front contact deposited by sputtering or chemical vapor deposition. Some companies use ITO instead of ZnO for the front contact. Six thin-film CIGS companies: Wurth Solar, Germany; Global Solar Energy (GSE), USA; Showa-Shell, Japan; Honda Soltec, Japan; Sulfurcell, Germany; and Solyndra, USA are in commercial production. The production capacity varies between 5 to 40 MW per year. GSE has recently installed a 40 MW CIGS manufacturing plant in Tucson, Arizona, USA and are installing a 35 MW manufacturing plant in Germany later in 2008. In addition, GSE is also planning an expansion of 100 MW plant in Tucson, Arizona that will be completed by December 2010. Thus, GSE will have a cumulative production capacity of 175 MW worldwide by December 2010.

The thin film CIGS absorber layers vary in thickness from 1.5 to 2.5 micrometer and are deposited by coevaporation or the two-stage process in which the first step is the growth of the precursors, Cu, In, Ga by sputtering followed by selenization in H_2Se gas for CIGS film formation.

4.0 Summary

Rapid progress is being made by CdTe, and CIGS-based thin-film PV technologies in entering the commercial markets. In the United States, market share for thin-film (includind a-Si) was about 65% in 2007 compared to less than 10% in 2003, and has surpassed Si shipments in the year 2007 [8]. Several critical research, development, and technology issues need to be addressed by emerging thin-film PV companies as they plan to enter the market. The projections for worldwide production capacity announcements for all thin-film PV (including a-Si) are estimated at more than 8000 MW in 2010, with First Solar's global target at 1000 MW by Dec 2009 and Sharp's target of 1000 MW by March 2010. These economies-of-scale production capacity should substantially reduce the manufacturing price of the thin-film PV products and potentially make solar electricity price-competitive with grid-parity electricity and met the U.S. Department of Energy's Solar America Initiative's levelized cost of electricity goals by the year 2015.

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