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Review of Photovoltaic Energy Production Using CdTe Thin-Film Modules

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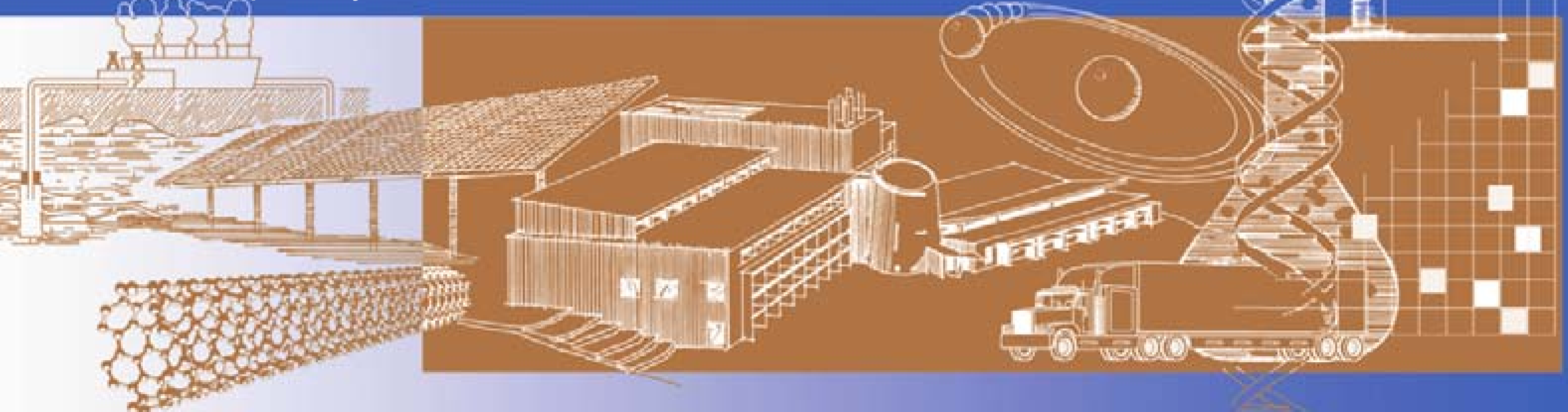

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Review of Photovoltaic Energy Production Using CdTe Thin-Film Modules

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Introduction

Thin-film photovoltaics (PV) modules that convert sunlight directly into electricity are viewed as important options for large-scale electricity production. If the ~35% exponential growth in module production observed since 2000 continues, PV-generated electricity could meet the majority of the projected new United States electricity needs by 2020 (0.19×10^{12} kWh new capacity required by 2020), surpass the energy currently generated by all U.S. nuclear power plants by 2030 (0.79×10^{12} kWh electricity produced by nuclear in 2004), and produce the equivalent amount of all energy presently consumed in the United States from all energy sources by 2040 (energy equivalent of 29×10^{12} kWh consumed in 2004).[1,2,3] To some, these projections may seem wildly optimistic. Nevertheless, the increasing concerns of diminishing cheap petroleum resources and expanding greenhouse-gas emissions related to combustion of fossil fuels could necessitate meeting or even surpassing these projections.

Many different criteria can be used to gauge advantages and disadvantages of thin-film PV technologies. Some that are often found useful include: a) demonstrated cell and module efficiencies under standardized conditions, b) perceived production advantages, and c) perceived materials abundance / low toxicity. Using these criteria, Table 1 suggests that technologies based on cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium

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diselenide (CIGS) each demonstrate a particular strength at this time of development. However, any of these technologies could acquire additional strengths as they mature.

Table 1. Comparison of thin-film PV technologies indicating present strengths of each.

	Demonstrated Efficiency	**Perceived Production Advantage**	**Perceived Materials Abundance/Low Toxicity**
a-Si			**Strength**
CdTe		**Strength**	
CIGS	**Strength**		

CdTe PV Technology

Thin-film CdTe PV devices are typically based on a heteroface design that uses p-type CdTe as the absorber layer and n-CdS as the window layer. All present commercial CdTe device fabrication processes use the "superstrate" configuration, starting with the CdS window-layer deposition onto a transparent glass substrate that has been coated with a transparent conducting oxide (TCO) top contact. The CdTe absorber layer is deposited onto the CdS, followed by an "activation" process and a back electrical contact. In the completed superstrate device, light enters through the transparent substrate. TCO top contacts for commercial CdTe devices are typically SnO_2:F, although In_2O_3:Sn (ITO) capped with SnO_2 has also been used. Higher-performance devices generally incorporate a high-resistance "buffer" layer between the high-conductance TCO and the CdS. The CdS layer can be deposited by aqueous solution growth or by vacuum deposition, but the device performance benefits from careful incorporation of oxygen when vacuum processing is used.[4]

CdTe deposition is typically performed at a substrate temperature between 550°C and 650°C for high-performance devices (i.e., 14%-16% efficiency). Nevertheless, several groups have fabricated ~12% devices at or possibly lower than ~400°C.[5,6] Because CdTe is a nearly congruent sublimator, deposition processes based on close-spaced sublimation[7] and gas-phase transport[8] can produce uniform, device-quality CdTe absorber layers at extremely high deposition rates (tens of μm/min). Following CdTe deposition, an activation process involving the use of a Cl-containing material (e.g., $CdCl_2$[7] and $CHClF_2$[9]) significantly improves the electrical properties of the CdTe layer. If the CdTe is deposited at high temperature (550°C-630°C), activation improves the electrical quality of CdTe grain boundaries; if the CdTe is deposited at lower temperature, activation can produce benefits of complete recrystallization.

The processing used to form a low-resistance electrical contact to the CdTe significantly affects junction functionality. Therefore, the specific elements of the back-contacting process are some of the most important components of CdTe PV device production. Highest-performance device designs diffuse Cu from the back contact into the CdTe by using various Cu-containing interface layers (e.g., Cu_xTe, ZnTe:Cu) placed between the CdTe and an outer metal. Insufficient Cu diffusion into the CdTe layer typically produces lower-performance devices, whereas excessive Cu diffusion may reduce device stability.[10]

Conclusions

Each of the major thin-film PV materials (e.g., CdTe, CIGS, and a-Si) embodies distinct advantages for continued large-scale deployment. Because of its near-optimum bandgap and advantageous deposition characteristics, this is especially true for thin-film polycrystalline CdTe. Although PV products designed for the terrestrial market represent a significant emerging industry, ultra-lightweight CdTe PV products will continue to be developed for high-value or military/aerospace applications. Because CdTe thin-film PV modules presently lead the other technologies in commercial production volume, improved understanding of its fundamental materials properties would be of significant benefit to accelerated deployment of this technology.

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