Scale-Up at Global Solar Energy using Roll-to-Roll Processes for Thin Film CIGS PV

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ABSTRACT

Global Solar Energy (GSE) is the first company to overcome the technological hurdles for low-cost roll-to-roll production of thin film (CIGS) PV on flexible foil substrates, culminating in the 5 MW production facility in the original factory and the successful entry of the first, flexible CIGS PV product into the military and consumer markets. GSE has begun the development of rigid products and scaling all processes to 60 MW annual capacity for two new factories (Tucson and Berlin). Progress in the design and construction of plant and equipment, as well as continued effort for process advancement under the NREL Thin Film PV Partnership Program will be discussed.

1. Objectives: The objective of current work at GSE is to scale up the roll-to-roll processes GSE has pioneered for low-cost fabrication of thin film CIGS PV to a 60 MW capacity. Objectives during the scale-up include attainment of higher process rates, improved materials utilization, improved efficiency and production yields and the use of lower cost materials. Additional goals are the introduction of rigid PV using the large area, thin film CIGS cells on metal foil under glass for widespread deployment on rooftop and commercial installations, the demonstration of durable packages with 20-30 year lifetime. The above improvements, along with economies of scale attained with the 60 MW scale-up will enable PV costs of below $0.05/kwh.

2. Technical Approach: Significant attention has shifted recently toward PV as an attractive energy source. The economic viability of PV, earned through steady advances in technology, has driven accelerating production and widespread introduction of PV. These events, coupled with rising energy prices, have spurred consumer awareness and acceptance of PV, followed by increased government support. After 2 decades of compound annual growth exceeding 20%/year, with 42.8%/year growth from 1995-2005 and annual global PV revenue now exceeding the $10 billion mark, large investors and corporations have finally begun to take note. Continued acceleration and disruptive entry of PV into successively larger market segments now hinges on incremental cost reduction.

Technical approach is key to cost reduction. Crystalline silicon PV has benefited from an established knowledge base operating over many years to improve cost, but now faces a shortage of high-purity feedstock and the encroachment of fundamental limitations on further gains. Thin film technologies using several materials systems and novel deposition techniques have been proposed, from “printed” CIGS using feedstock formulated as ink, to organic or dye-sensitized absorbers. Despite claims made for particular approaches, the low cost potential of thin film PV stems from only 3 factors; i) greatly reduced use of materials, notably semi-conductors, ii) inexpensive deposition and processing methods, and iii) low cost substrate materials.

Continuous roll-to-roll coating of all thin film PV layers on flexible substrates was first initiated for CIGS by GSE in 1995 as perhaps the lowest cost deposition method available. Some proponents of ink-printed methods and organic PV have recognized the advantages of roll-to-roll coating, and have also advocated the use of non-vacuum deposition methods to reduce costs. However, at least 3 thin film layers are required in any of the thin film approaches (a front transparent contact, an absorber layer and a back contact) and vacuum-based methods are typically used for the front and back contacts regardless of the specific absorber or semiconductor. As for the absorber layer, vacuum deposition has provided the highest efficiency thin film PV. Particularly in the case of CIGS, vacuum deposition methods offer the greatest flexibility and control over semiconductor composition and morphology, and thus also conversion efficiency. Significantly, vacuum deposition of CIGS is not costly in a roll-to-roll format – the capital equipment cost for this step at GSE (amortized over the useful equipment life) amounts to about $0.0002/kwh cost in the product, yet the advantages are substantial.

3. Results and Accomplishments: GSE has successfully developed continuous roll-to-roll deposition as an inexpensive, high rate method for CIGS thin film PV, dramatically reducing the quantity of materials required over traditional PV, whilst using low cost, flexible substrates of stainless steel foil. PV efficiency, production rate, yield and cost have all been substantially advanced at GSE through process optimization, equipment modifications and the extensive use of real-time, in-situ controls for “intelligent processing”. Fig. 1 shows the efficiency of large area production cells taken randomly at representative

locations from a standard 1000-ft run made as a quality control check.

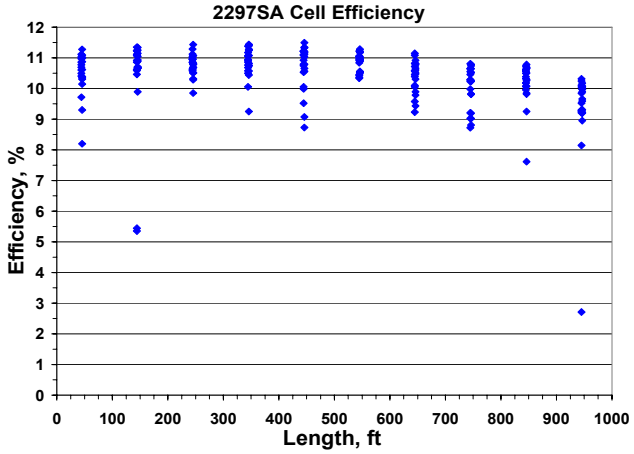

Fig.1 *Recent 1000-ft. run showing the efficiency of large area cells sampled at periodic locations for quality control purposes.*

GSE has demonstrated commercial readiness in the current 5 MW plant and has begun execution of plans to further reduce product costs and expand production. Major facets of the plan include:

- Construct 60 MW capacity in new factories (Tucson and Berlin) with new equipment for the roll-to-roll CIGS thin film PV developed at GSE.
- Design, fabricate and install new equipment for the large factories, incorporating process advancements for higher production rates, capacities and improved material utilization.
- Continued product improvements and lower costs from further reductions in material usage, substitution of lower cost alternate materials, and lower cost processes for some production steps, increased yield and efficiency, and increased automation in product assembly.
- Extensive product testing for environmental durability, translating to expected product lifetimes of 25-30 years for rigid product.

Results to date include:

- Buildings and sites for the new factories have been selected in Tucson and Berlin with renovation and utilities installation in progress.
- Equipment for all major processes in the new factories have been placed under contract, with designs completed and fabrication started.
- Buildings and equipment at the new factories are on track to be in ramped production at the end of 2007.
- Evaluation of two lower-cost processes for the front contact has started. Process improvements have been introduced for the back contact. Increased deposition speed for the CIGS deposition has been shown (15 vs. 12-in/min) without loss of efficiency.
- Investigation of alternate materials and methods for rigid product packaging for durability and 30 year lifetime continue with good results. Shown in fig. 2 is product stability under accelerated testing (85 deg.C, 85% humidity) for some samples of rigid product. Fig. 3 shows the performance vs. time of an array of earlier GSE rigid CIGS modules under actual field conditions, including temperature and inverter losses.

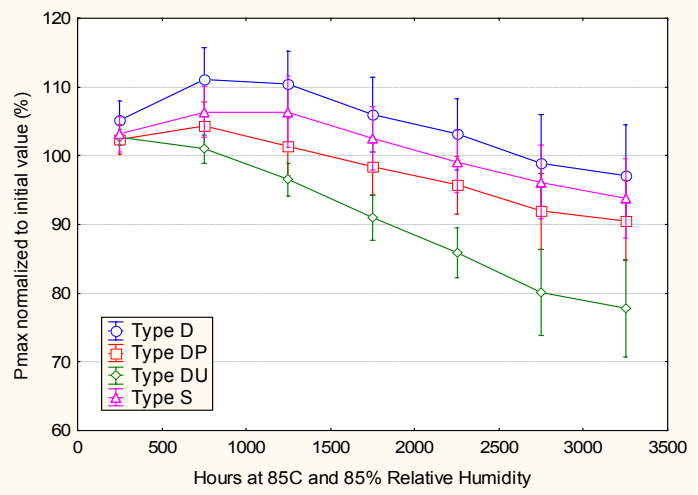

Fig.2 *Accelerated lifetime testing in damp heat for rigid CIGS PV product produced at GSE, showing good stability beyond 3000 hours under conditions that may correlate to 60 years under typical conditions for the impacted degradation mechanisms.*

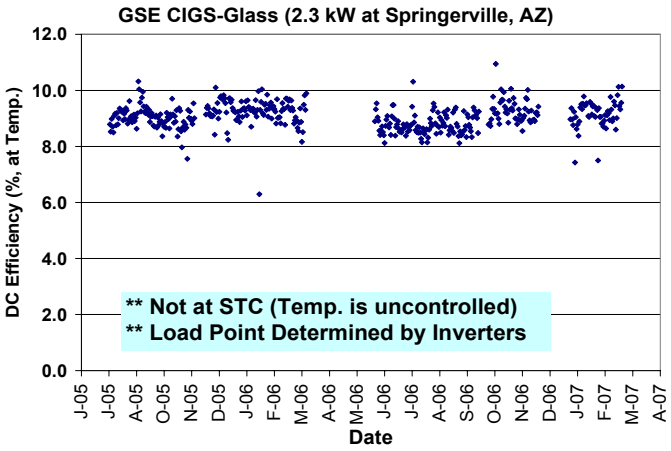

Fig.3 *Early GSE rigid product continues under actual field testing and does not yet appear to show any long-term degradation or instability. Missing data corresponded to times when the array, inverters or monitoring instruments had been inoperative, often due to lightening strikes. (deployed in Springerville, AZ).*

4. Conclusions: GSE is on plan to scale up its thin film CIGS PV capacity to 60 MW/year, incorporating economies of scale, process and equipment improvements to enable production of CIGS based thin film PV at a cost below the targets stated for the DOE SAI initiative.

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