Impact of Thin-Film Partnership on the Expansion of Amorphous Silicon Photovoltaic Production

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ABSTRACT

This paper reviews the impact of Thin-Film Partnership on the increasing production of triple-junction amorphous silicon (a-Si) photovoltaic products at United Solar Systems Corp. (United Solar). A roll-to-roll continuous deposition production line with an annual capacity of 5MW has been in operation since 1997 to commercialize the spectrum splitting, triple-junction structure developed under the Thin-Film Partnership program. Recent improvements in cell performance and manufacturing technology through continued support from the Partnership and the PVMaT programs are being incorporated into the design of a 25MW production line that is expected to be operational in mid-2002. Details of various innovations on the triple-junction structure and their impact on the large-volume production will be described.

1. Introduction

In November 1992, NREL established four a-Si research teams to facilitate and accelerate scientific and technological collaborations among industry, universities, and NREL. The team structure was designed to focus on the research and development of a spectral-splitting, triple-junction structure. The successful team effort laid a solid foundation for the Thin-Film Partnership. United Solar has participated in the team activities and the Partnership program since their inception. Highlights of the collaborations include the achievement of a 13% stable active-area cell efficiency [1] and a 10.5% stable aperture-area module efficiency [2]. The impact on manufacturing at United Solar is twofold. One is that the cell structure was changed from a same bandgap a-Si/a-Si double-junction configuration in 1991 to an a-Si/a-SiGe/a-SiGe triple-junction structure in 1997 [3]. The other is the production capacity is increased from a pilot production of 1 MW/year in 1991 to a 5 MW/year production currently operating around the clock, and a 25 MW/year plant under active construction. Major innovations on improving cell performance and manufacturing technology are described below.

2. Highlights of Innovation

• **Triple-junction Structure --** Our design of the solar cell is based on a spectral-splitting, triple-junction structure shown in Fig. 1. The top cell, made by a-Si alloys of an optical bandgap of ~1.8 eV, absorbs blue photons. The middle cell, made by a-SiGe alloys of an optical bandgap of ~1.6 eV, incorporates ~20% Ge and absorbs green photons. The bottom cell, also made by a-SiGe alloys but with a Ge concentration of ~40%, has an optical bandgap of ~1.4 eV, and absorbs red photons. In this design, each component cell absorbs a specific portion of the solar spectrum, ranging from 350 to 950 nm. The total thickness of the semiconductor layers is about half micron. An indium-tin-oxide $\lambda/4$ anti-reflection coating is deposited on top of the triple-junction to form the top contact and complete the solar cell structure.

• **Flexible Substrate --** We use a 'roll-to-roll' continuous deposition process in production. This necessitates the use of a thin, flexible, and continuous substrate. A 0.005-inch thick, 14-inch wide, and 2000-ft long roll of stainless steel (ss) is used as substrate.

• **Back Reflector --** The reflectivity of ss is relatively poor. A textured metal/oxide back reflector [4] is deposited onto ss to facilitate light trapping. Low energy photons that are not absorbed by the first pass are scattered back to provide multiple reflections in the solar cell.

• **a-Si Alloys --** The top cell incorporates high quality a-Si alloys. Recently, extensive studies have shown that intrinsic materials made using a hydrogen dilution method exhibit improved intermediate range order. Solar cells made near the amorphous-to-microcrystalline transition exhibits higher initial and stable efficiencies [5].

• **a-SiGe Alloys --** The middle and bottom cells incorporate a-SiGe alloys with different amounts of Ge. A novel bandgap profiling design was developed [6] to modify the absorption profile and aid the hole transport in the device, which, without profiling, was the limiting factor for obtaining high quality devices. Recently, we find that by hydrogen profiling concurrently with the Ge concentration, we are able to

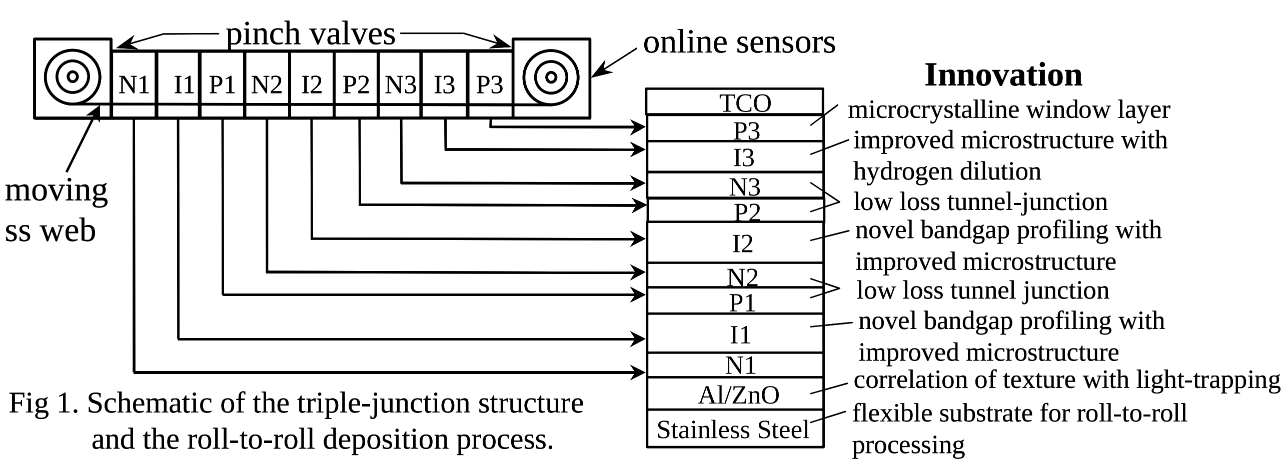

Fig 1. Schematic of the triple-junction structure and the roll-to-roll deposition process.

improve the a-SiGe alloy solar cell performance [7]. The effect of the improved a-SiGe alloy cell in a multijunction structure will be investigated.

• **Microcrystalline Window Layer --** A high conductivity microcrystalline *p* layer with low optical absorption was developed [8], resulting in a significant improvement in solar cell open-circuit voltage (Voc) and efficiency. Voc's of greater than 1 V have been obtained routinely for the top a-Si alloy cell.

• **Tunnel Junctions --** In a multijunction structure, the neighboring doped layers connecting the adjacent component cells form the tunnel junction, which is necessary for multijunction operation but causes electrical and optical losses. We have developed low loss tunnel junctions with reduced optical absorption and enhanced electrical conductivity, which improved cell performance [9].

• **Roll-to-roll Semiconductor Processor --** The roll-to-roll semiconductor processor is shown schematically in Fig. 1. A 2000-ft long thin ss web is loaded into the pay-off chamber, moving continuously at 2-ft per minute through the nine deposition chambers, and rolled up in the take-up chamber. A proprietary dynamic gas gate design is incorporated to eliminate interdiffusion of gases between adjacent chambers.

• **Pinch Valves --** A pinch valve design developed jointly with Energy Conversion Devices, Inc. under the PVMaT program [10] is installed between the deposition chambers and the pay-off and take-up chambers. The design eliminates the need of cooling the entire system after each run for changing the ss web. This reduces a significant amount of turn-around time and prevents the vacuum system from being exposed to air after each run.

• **Online Sensors --** Novel online diagnostic sensors were also developed under the PVMaT program [10] to monitor photovoltaic characteristics *in-situ*. A good correlation has been established with subsequently obtained solar cell characteristics. This allows us to monitor *in-situ* any abnormality during deposition and take immediate corrective measures if necessary.

3. Partnership Collaborations

United Solar has collaborated with more than ten National Team partners and published more than 30 joint papers. A list of examples is given in ref. 5 and 11-15. Scope of collaboration ranges from fundamental studies to jointly fabricating hybrid solar cells. In 1998, an R&D 100 award named United Solar and NREL Thin Film Photovoltaic Partnership as the joint recipient of the award.

4. Summary

We have developed and incorporated various innovations in a-Si alloy triple-junction cell structure and manufacturing technology with the support of Thin-Film Partnership and PVMaT programs. Our current 5 MW/year plant can no longer meet the demand of the expanding market. A 25 MW/year plant is being constructed, which will incorporate the state-of-the-art technology.

5. Acknowledgement

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