Efficiency and throughput advances in continuous roll-to-roll a-Si alloy PV manufacturing technology†

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ABSTRACT

Energy Conversion Devices, Inc. (ECD) and United Solar Systems Corp. (United Solar) have been developing, testing, and implementing new technology to increase the performance of United Solar's 5 MW production equipment. The 5 principal areas in this research and development program are: (1) improved web heating and temperature monitoring systems; (2) new online diagnostic systems; (3) testing and implementing reactive ZnO sputtering from Zn metal targets; (4) improved rf PECVD cathode designs; and (5) the development of new pinch valves. Items (1) and (3) have been discussed elsewhere[1]; progress in the other 3 areas is summarized in this report, with the emphasis on operational results.

INTRODUCTION

ECD has developed and built 6 generations of roll-to-roll amorphous silicon PV production equipment. A metal/oxide backreflector, a 9 layer a-Si/a-SiGe alloy triple junction solar cell, and top transparent conductive oxide coating are deposited onto 125 μm thick stainless steel webs in a series of three roll-to-roll deposition machines[2]. In the PVMaT 5A research program we have developed technology that increases the efficiency and throughput of this production process. These new technologies are now well along in their development; most have been successfully tested or implemented in the present 5 MW production line, and all are being implemented in the new 25 MW production equipment that ECD is building for United Solar, scheduled for turn-on in early 2002.

ONLINE DIAGNOSTIC SYSTEMS

United Solar's production machines are very highly instrumented and automated. Control, however, is open loop in the sense that measurements of the process inputs are the principal source for feedback. We are now developing a new set of online diagnostic systems that measure PV device characteristics. These systems will allow immediate recognition of production problems and enable the operators, and eventually expert systems, to continuously optimize the process. We expect that these new capabilities will significantly reduce the commissioning time of the new 25 MW equipment.

The systems being developed include a scatterometer for backreflector surface texture measurements, reflection spectrometers for film thickness measurements, and PV Capacitive Diagnostic (PVCD) for online measurements of the PV cell electrical characteristics.

The Backreflector Scatterometer has been installed in the 5 MW production backreflector machine since May 2001, and has been previously described[1]. This system measures the specular and the diffuse reflection as a function of angle from the backreflector.

The scatterometer has been proven to be a useful online QA/QC device: changes in online measurements from the scatterometer correlate with changes in offline PV device characteristics (e.g. V_{OC} and R_S) [see Fig. 1]; the device is sensitive to changes in process parameters (e.g. sputtering power and target changes), and it has demonstrated the ability to detect non-conforming material (e.g. material produced when there was a small vacuum leak). An updated version is planned for the new 25 MW production equipment.

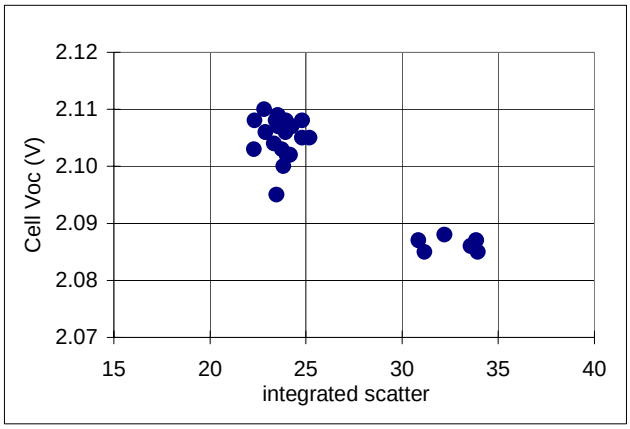

Fig. 1. Observed correlation between increased back-reflector scattering and decreased V_{OC}.

The PV Capacitive Diagnostic (PVCD) is a is a non-contacting device that measures the electrical characteristics of the PV device in the take-up chamber of the a-Si machine before deposition of the ITO layer. This device has also been previously described[1,3]. The 3rd generation PVCD has been installed in the 5 MW a-Si production machine

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since November 2000. The measured noise is about 0.2% rms, similar to the noise in offline QA/QC data [see Fig. 2]. Measurements are taken about once/minute, and this noise can be reduced with averaging.

The PVCD has demonstrated the ability to detect non-conforming material, and is able to measure most PV cell characteristics. It is in routine use as an online QA/QC instrument, though we have not yet used it for real-time optimization.

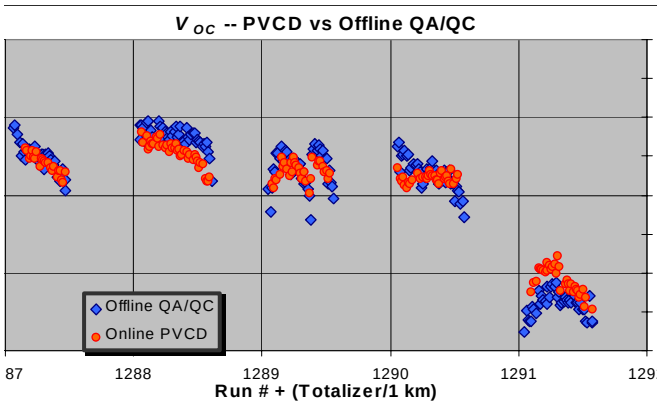

Fig. 2. A comparison of online data from the PVCD with offline QA/QC data over a period of 5 production runs in 2001. [2.4% per division].

Thickness Monitoring Reflection Spectrometers are being developed to measure the thickness of the ZnO, a-Si, and ITO layers. In the a-Si machine, without extensive operation, we observe a precision of about 0.1% [see Fig. 3].

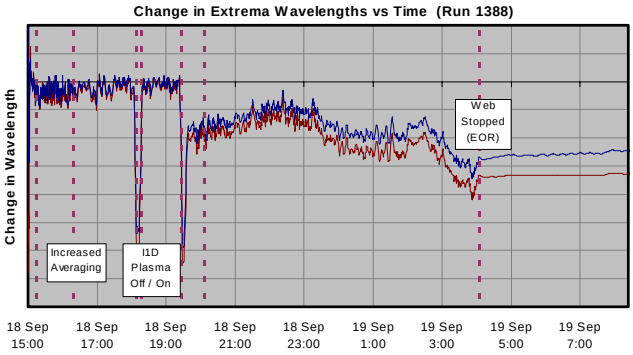

Fig. 3. Thickness measurement in the a-Si machine [0.5%/vertical div.; 2 hr/horizontal div.]. Experiments during this run resulted in thickness changes.

NEW PINCH VALVE TECHNOLOGY

The new pinch valve technology, which allows rolls of substrate to be changed without venting the deposition area of the machine to air, was put into routine operation in the summer of 2001. The use of this device reduces the "turn-around" time, as shown in Fig. 4, and also has other benefits. The machine throughput may have increased by as much as 10%.

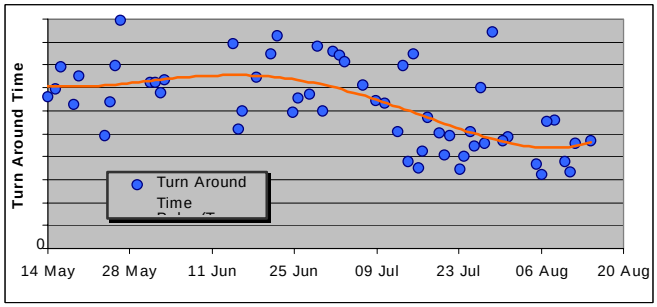

Fig. 4. Plot showing the reduction in "turn-around" time due to the pinch valves.

IMPROVED CATHODE GEOMETRY

We have also continued our work in optimizing the geometry of the a-Si deposition cathodes. A single new style cathode has been operating in the 5 MW production machine since the beginning of 2001, and will be the standard cathode in the new 25 MW production machine. With this cathode we have demonstrated substantially increased deposition uniformity [see Fig. 5], and have also developed recipes that reduce the cost of gases.

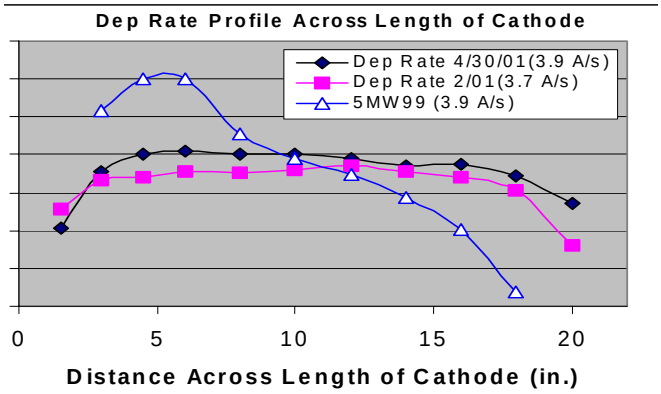

Fig. 5. Deposition profiles of the new cathode taken 3 months apart, compared with previous cathode design [blue curve] (Note: offset vertical scale).

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