CONTINUOUS ROLL-TO-ROLL SERPENTINE DEPOSITION FOR HIGH THROUGHPUT a-Si PV MANUFACTURING

M. Izu, H. C. Ovshinsky, X. Deng, A. J. Krisko, K. L. Narasimhan,
R. Crucet, T. Laarman, A. Myatt and S. R. Ovshinsky
Energy Conversion Devices, Inc., 1675 West Maple Road, Troy, Michigan 48084

ABSTRACT

In order to further improve the economies of scale which are inherent in ECD's continuous roll-to-roll amorphous silicon alloy solar cell manufacturing process, we have developed a concept for a serpentine web plasma CVD deposition process to maximize throughput while keeping the size of the deposition chambers small. When this technique is incorporated into a continuous roll-to-roll PV manufacturing process, it will maximize the throughput for a high volume production plant, reduce the machine cost, improve gas utilization, reduce power consumption, and improve the solar cell stability. To demonstrate the serpentine web deposition concept, we have constructed a single loop serpentine deposition chamber to deposit a-Si for n-i-p structure solar cells. During the initial process of optimization, we have produced single-junction a-Si solar cells with 8.6% efficiency, and triple-junction a-Si solar cells with a 9.5% initial efficiency, where the top cell intrinsic layer was deposited in the serpentine deposition chamber.

INTRODUCTION

Continuous roll-to-roll manufacturing technology, utilizing a thin flexible stainless steel substrate, offers a number of advantages in a fully automated high throughput PV module production plant [1-18]. The stainless steel substrate is rugged and this improves production yield by eliminating substrate breakage--a significant problem in many glass substrate amorphous silicon alloy PV module manufacturing plants. ECD's transport mechanism on a thin flexible stainless steel substrate is also mechanically simple and significantly less expensive than the transport mechanism for conventional glass substrates. Heating and cooling of the substrate during solar cell deposition can also be accomplished quickly compared to glass substrate manufacturing. As a result, capital equipment costs for a large volume plant utilizing ECD's roll-to-roll technology will be significantly less than for other PV manufacturing processes.

SERPENTINE DEPOSITION DESIGN CONCEPT

In order to further improve the economies of scale of the continuous roll-to-roll amorphous silicon alloy solar cell deposition process, we have developed a concept for a serpentine web deposition process to maximize throughput while keeping the size of the deposition chambers small. Such a deposition process , when incorporated into continuous roll-to-roll PV manufacturing process, will maximize the throughput for a high volume production plant, reduce the machine cost, improve gas utilization, reduce power consumption, and improve the solar cell stability. A schematic diagram for a RF plasma processor that deposits amorphous silicon alloy solar cells utilizing a serpentine web roll-to-roll process in shown in Figure 1. As can be seen in the diagram, deposition takes place on the substrate as it travels vertically through the deposition chamber in contrast to the current process in which the substrate travels horizontally. Also, in the serpentine process, the thin stainless steel substrate travels up and down through the use of rollers in the deposition chamber to create, in effect, a large deposition area. In the deposition chamber, a single RF cathode will generate a plasma which will produce film deposition on regions of substrate facing both sides of the cathode. Substantial equipment cost savings will be achieved from the compactness of this design which has half the volume of a non-serpentine design. The surface area of this machine is 3 to 4 times lower than that of a non-serpentine design and thus will reduce heat loss and consequently electric power consumption. Furthermore, the use of a mostly open perforated cathode configuration will improve the gas utilization efficiency since deposition of a-Si alloy material on the cathode is reduced. The hardware design for the internal components of the chamber is simpler for the serpentine design because the cathode heating and dark-space shields can be eliminated. In addition, for constant throughout, the number of rf power supplies, pumps, feedthroughs and cathodes is reduced by about a factor of two.

We will minimize the Staebler-Wronski efficiency degradation by depositing amorphous silicon alloy intrinsic materials with a minimum density of microvoids at a low deposition rate [19] in the serpentine roll-to-roll process. We anticipate the current 15-18% degradation in the current commercial product can be reduced to less than 8%.

RESULTS

To demonstrate serpentine web deposition concept described above, we have constructed a single loop serpentine deposition chamber to deposit a-Si for the

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n-i-p solar cells. This serpentine chamber has been incorporated into ECD's continuous roll-to-roll multipurpose deposition machine, as shown in Figure 2. The tall vertically standing box in the picture is the serpentine chamber.

One critical area which requires engineering attention in the serpentine web continuous roll-to-roll PV manufacturing process, is the top roller. When the web passes over this roller, the deposition side of the web faces the roller. We used a dumb-bell shape design for the top serpentine roller, so that the deposition side of the web, except for the edges which are outside the active area, does not touch any hard surface. No deformation of the web is observed after the high tension test. Furthermore, no film peeling or other mechanical damage is observed when stainless steel web, coated with back-reflector, triple solar cell and top conductor, passes through the machine.

We have carried out an initial solar cell deposition using the serpentine chamber. During the initial process optimization, we achieved 8.6% initial efficiency for a single-junction serpentine solar cell. Figure 3 is the J-V curve of a single-junction n-i-p solar cell with the intrinsic layer deposited in the serpentine chamber. The J-V curves under the weak blue and red illumination are shown in Figure 4

We then incorporated this single-junction n-i-p solar cell into a-SiGe/a-SiGe/a-Si triple-junction solar cells. The top cell intrinsic layer of the triple cell was deposited in the serpentine chamber. We optimized the cell current matching between each of the component cells and achieved initial efficiency of 9.5%, as shown in Figure 5.

SUMMARY

A serpentine web deposition concept has been described. Such a deposition configuration, when incorporated into a continuous roll-to-roll PV manufacturing process, will maximize throughput for a high volume production plant, reduce the machine cost, improve the gas utilization, reduce power consumption, and improve the material stability. A single loop serpentine deposition chamber has been constructed and incorporated into ECD's roll-to-roll deposition machine. During the initial optimization, we have demonstrated a single-junction serpentine solar cell with 8.6% initial efficiency and a triple-junction solar cell with 9.5% initial efficiency.

In summary, the serpentine technology will provice the following benefits:

- For a given throughput, serpentine web technology will decrease the machine footprint significantly and reduce the number of rf cathodes and the required pumping speed by a factor of two. We expect that serpentine web technology will provide at least a factor of two reduction in capital and maintenance costs for the deposition machines in high volume plants.
- Serpentine web technology should increase the gas utilization efficiency by 85%, and correspondingly reduce the gas cost.

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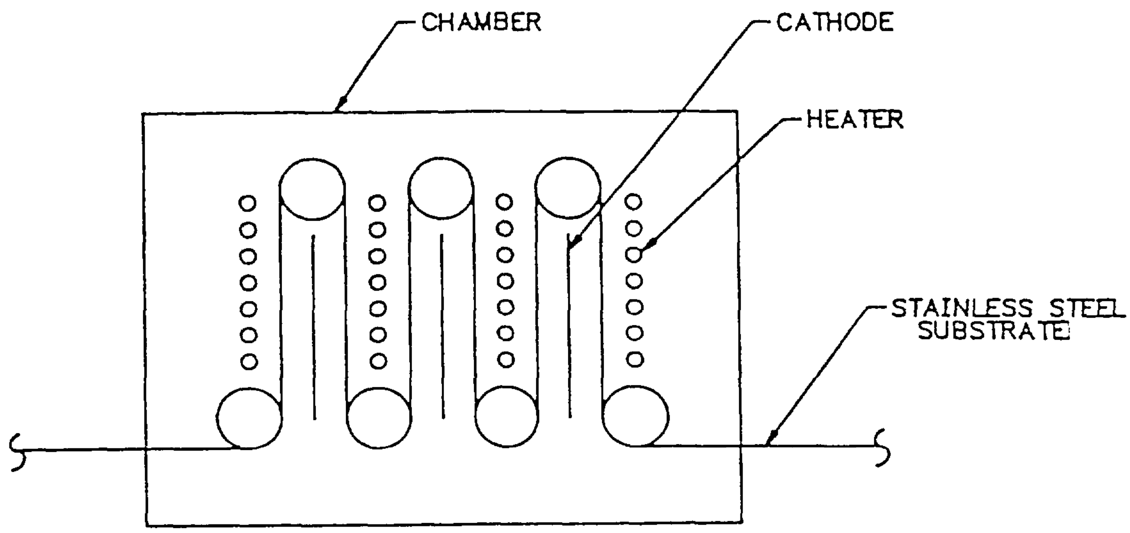

Figure 1. A Schematic Diagram of Serpentine Web, Roll-to-Roll RF PECVD Deposition Chamber.

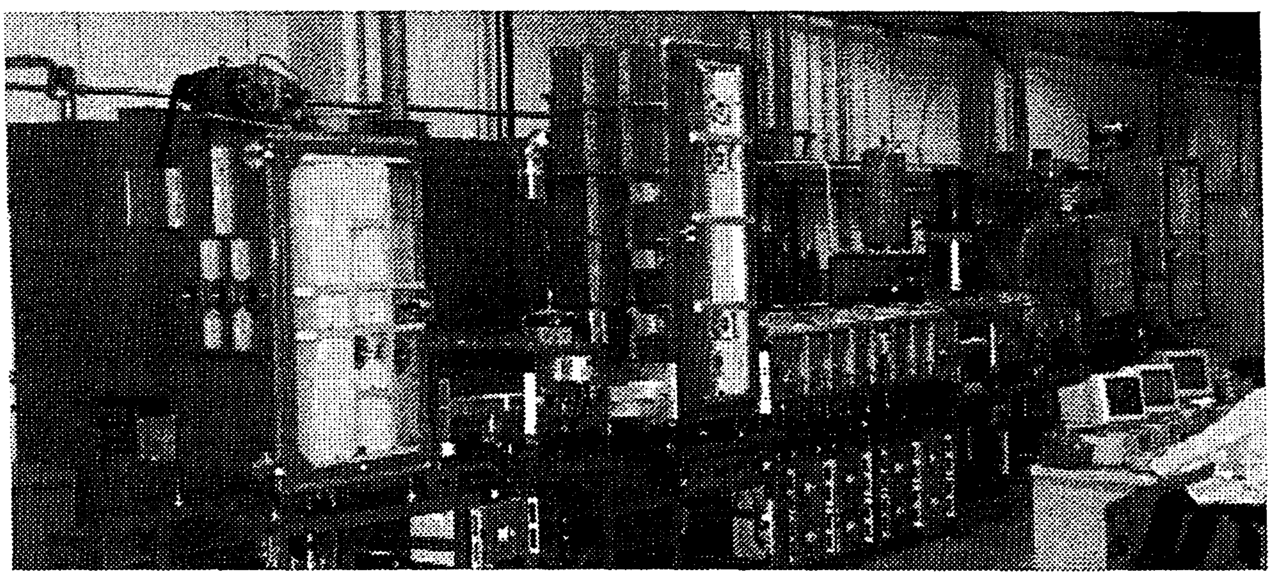

Figure 2. ECD's Multipurpose Continuous Roll-To-Roll A-Si Solar Cell Deposition Machine. The Tallest Chamber Is The Serpentine Deposition Chamber.

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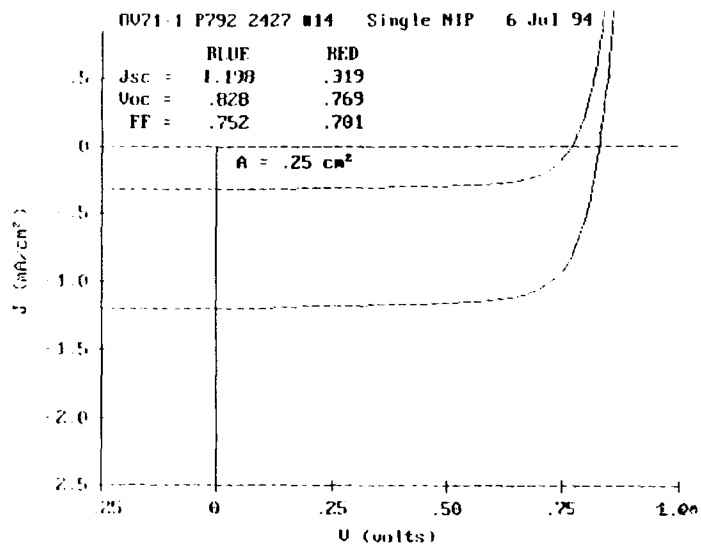

Figure 4. J-V Curve of the Single-junction Serpentine Solar Cell Under Weak Blue and Red Light.

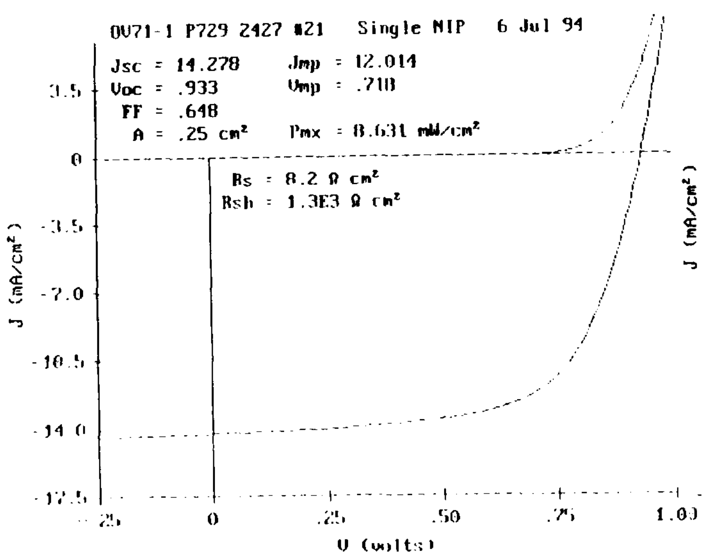

Figure 3. J-V Curve of a Single-junction Serpentine a-Si Solar Cell.

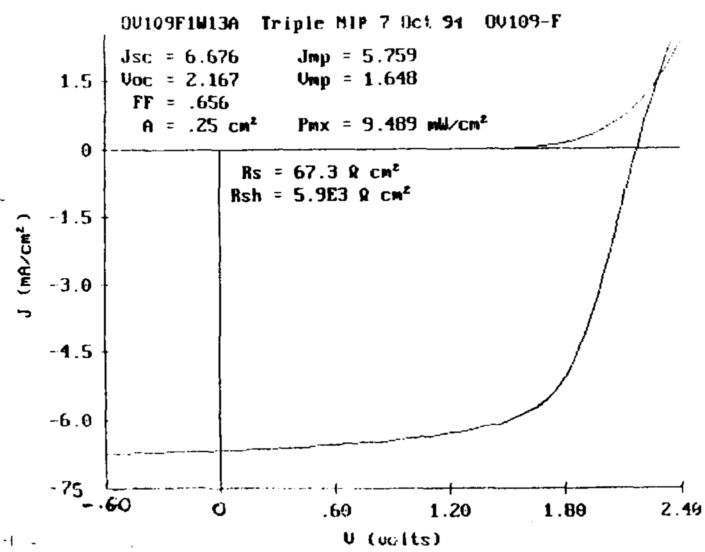

Figure 5. J-V Curve of a Triple-junction a-Si Alloy Solar Cell with the Top Intrinsic Layer Deposited in the Serpentine Chamber.