PRODUCTION START-UP OF 2 MW a-Si PV MANUFACTURING LINE AT SOVLUX PLANT

M. Izu, X. Deng, H. C. Ovshinsky, R. Crucet and S. R. Ovshinsky
Energy Conversion Devices, Inc., 1675 West Maple Road, Troy, Michigan 48084

A. Polisan
Sovlux, 129626, 3 Mytishchinskaya Str, 16 Moscow, Russia

ABSTRACT

We report the results of production start-up efforts at the 2MW Sovlux photovoltaic production line. Triple-junction solar cells with higher than 10% initial efficiency were produced in this production line with subcell yield up to 96%. The production process demonstrated high reproducibility and consistency from run to run. 2 ft^2 and 4 ft^2 modules assembled in Sovlux plant using these solar cell material have demonstrated an initial efficiency of 9.4%. The solar cell material produced in Sovlux was also shipped to ECD to assemble large area 1.3 ft. by 20 ft. rooftop modules. Lightweight, flexible rooftop modules with initial efficiency up to 9.3% were produced at a high yield.

INTRODUCTION

Energy Conversion Devices, Inc. (ECD) designed and constructed a 2 MW continuous roll-to-roll a-Si alloy PV production line for its joint venture Sovlux, in Moscow, Russia. [1-14] After the demonstration of high yield production runs and achievement of 8% stable 4ft^2 module fabrication at ECD, the machine was disassembled, shipped to Russia, and reassembled at Sovlux. The start-up production is currently going on at Sovlux. In this paper, we report the progress and current status of this production line and the commercialization efforts at Sovlux.

THE MANUFACTURING LINE

In this 2 MW PV Manufacturing line, a-Si alloy solar cells are deposited in a continuous, roll-to-roll process on a 0.005 in. thick, 14 in. wide, 2500 ft. long web of stainless steel at a speed of 1 ft/min. Figure 1 illustrates the structure of the solar cells produced by this process.

The deposition facility of the manufacturing line consists of four continuous roll-to-roll machines: i) a continuous roll-to-roll substrate washing machine; ii) a continuous roll-to-roll back-reflector machine that deposits a textured Ag/ZnO layer using DC magnetron sputtering; iii) a continuous roll-to-roll a-Si alloy rf PECVD deposition machine that produces, in a single pass, sequentially deposited thin films of doped and undoped amorphous silicon alloy semiconductors; and iv) a continuous roll-to-roll transparent conductor deposition machine that deposits a TCO layer on top of the solar cell using reactive evaporation.

The module assembly process consists of the following procedures: i) cutting of TCO coated a-Si solar cell rolls into 16 in. long, 14 in. wide slabs; ii) quality assurance and quality control (QA/QC) for performance qualification of the production roll; iii) TCO scribing with screen printed etching paste; iv) short and shunt passivation; v) screen printing of silver paste of grid pattern; and vi) final assembly which includes: cell cutting, interconnecting, module laminating, finishing, testing and packaging.

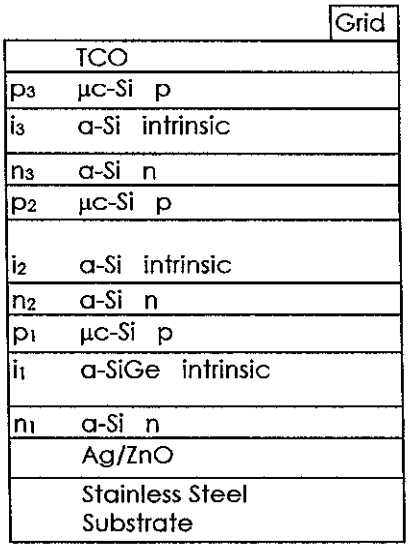

Figure 1 Device structure of triple-junction solar cells produced in Sovlux 2 MW continuous roll-to-roll manufacturing line.

0-7803-3166-4/96/$5.00 © 1996 IEEE

In the QA/QC process, samples of 4 in. long and 14 in. wide, were uniformly selected from every run for quality control. 28 test solar cells of 7.35cm^2 are processed on each sample by the following procedures: 1) TCO scribing by screen printing of etching paste, heat curing, and rinsing; 2) short and shunt passivation; and 3) screen printing of silver paste grid. These samples are then used to analyze the solar cell performance, yield, uniformity and consistency of the production runs.

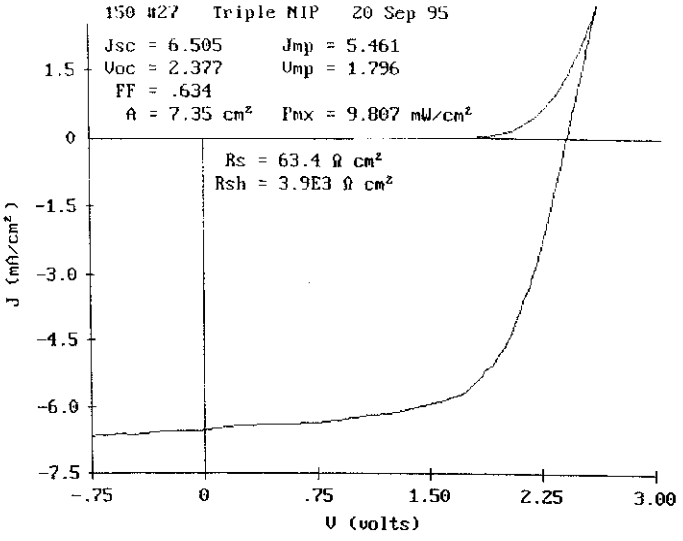

Figure 2 I-V curve of a triple-junction solar cell produced during the start-up optimization.

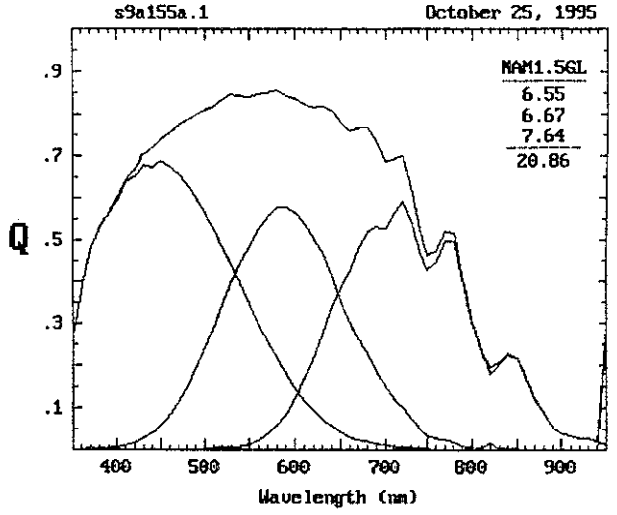

Figure 3 Quantum efficiency of a triple-junction solar cell produced during the start-up optimization.

RESULTS FROM START-UP OPTIMIZATION

Optimization test runs have been made in the Web Washing Machine, Back-Reflector Deposition Machine, a-Si PECVD Machine, and TCO Deposition Machine. Up to date, 20 test runs have been completed. During the initial startup runs, triple-junction solar cells with 10% initial efficiency were produced. These solar cells exhibits V_{oc}=2.38 V, J_{sc}=6.5 mA/cm^2 and FF=63%, as shown in Figure 2 for a 7.35 cm^2 cell produced in the start-up runs. Figure 3 shows the quantum efficiency of this triple cell, showing the short circuit current of 6.55, 6.67, and 7.64 mA/cm^2 for the top, middle and bottom component cells.

In table 1, we list the J-V performance of all 28 cells in a typical QA/QC sample. The cell performance in this sample is uniform. The subcell yield for this sample is 100%.

Table 1. I-V performance of 28 triple-junction solar cells in a QA/QC sample

Cell	Voc (V)	Jsc (mA/cm^2)	FF	η (%)
1	2.34	6.56	0.674	10.33
2	2.32	6.13	0.684	9.72
3	2.33	6.29	0.712	10.43
4	2.33	6.29	0.647	9.51
5	2.33	6.57	0.690	10.55
6	2.35	6.80	0.660	10.54
7	2.36	6.90	0.668	10.86
8	2.34	6.46	0.667	10.08
9	2.33	6.47	0.671	10.11
10	2.34	6.54	0.669	10.23
11	2.31	6.90	0.631	10.05
12	2.34	7.11	0.638	10.59
13	2.34	6.60	0.682	10.53
14	2.37	6.34	0.688	10.33
15	2.35	6.62	0.675	10.50
16	2.33	6.81	0.637	10.11
17	2.32	6.55	0.671	10.19
18	2.32	6.92	0.647	10.37
19	2.34	6.50	0.721	10.97
20	2.34	6.92	0.661	10.69
21	2.37	6.59	0.697	10.87
22	2.35	6.95	0.675	11.02
23	2.31	6.36	0.668	9.80
24	2.33	6.90	0.671	10.78
25	2.32	6.98	0.649	10.49
26	2.34	6.65	0.698	10.86
27	2.35	6.75	0.692	10.97
28	2.36	6.47	0.718	10.96
Average	2.33	6.64	0.673	10.44

The average performance of this sample is shown at the bottom of the table. Table 2 shows the average performance of all 4 in. by 12 in. samples from the entire test run. The average subcell yield for the entire test run is 96%.

Modules with $2ft^2$ and $4ft^2$ aperture sizes were assembled at Sovlux using these triple-junction solar cell materials. The initial aperture-area efficiency of these modules are around 9.4%. Figure 4 shows the I-V curve of a 2 ft^2 module measured using a Spire 240A simulator, showing 9.4% initial module efficiency.

The triple-junction solar cell material (Run 18) produced at Sovlux is also shipped back to ECD for the performance testing. We found that the yield for these Sovlux production solar cells was high. We used these materials to assemble six large area 1.3 ft by 20 ft. rooftop modules [15,16]. Table 3 list the performance of all of the six rooftop modules. The initial efficiencies of these modules are up to 9.3%. The high performance of these rooftop modules confirms that high quality a-Si triple-junction solar cell material has been produced in the 2 MW Sovlux production line.

Table 2. Average I-V performance data for 28 cells in each sample over an entire run

Sample	Yield (%)	Voc (V)	Jsc (mA/cm^2)	FF	Eff (%)
15	85.7	2.47	6.65	0.63	10.41
30	100	2.38	6.50	0.66	10.21
45	100	2.42	6.51	0.64	10.14
60	85.7	2.46	6.54	0.65	10.36
75	85.7	2.54	6.40	0.62	10.09
90	100	2.37	6.47	0.67	10.24
105	100	2.44	6.45	0.65	10.23
135	89.3	2.45	6.50	0.64	10.23
140	85.7	2.37	6.28	0.67	9.96
150	96.2	2.38	6.27	0.66	9.86
165	96.4	2.39	6.37	0.68	10.30
180	96.4	2.45	6.46	0.65	10.35
205	100	2.39	6.33	0.67	10.13
220	100	2.46	6.50	0.65	10.38
235	96.4	2.39	6.50	0.67	10.35
250	100	2.39	6.52	0.66	10.31
265	100	2.39	6.34	0.67	10.18
280	96.4	2.41	6.42	0.66	10.26
310	96.4	2.42	6.43	0.66	10.19
325	96.4	2.53	6.46	0.62	10.17
340	100	2.43	6.44	0.65	10.10
Average	95.6	2.43	6.44	0.65	10.21

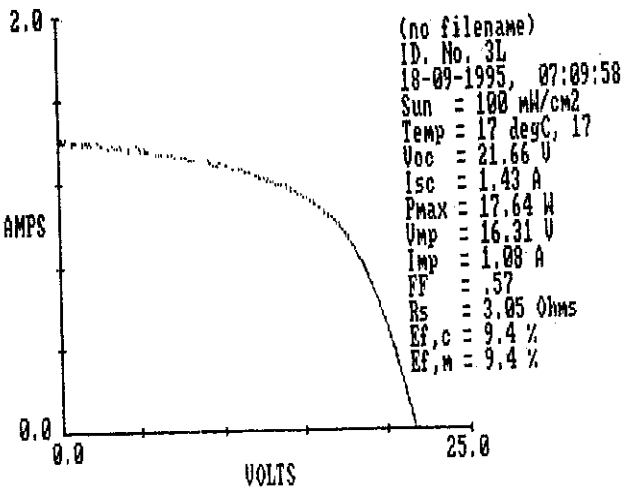

Figure 4. I-V curve of a 4 ft^2 module produced in Sovlux using the newly deposited solar cells.

SUMMARY

The start-up optimization of 2 MW continuous roll-to-roll a-Si alloy PV production line at Sovlux in Moscow, Russia, has demonstrated promising results. After the entire production line was disrupted by the disassembly, shipping, and reassembly, it quickly came back to high performance operation after reassembly. Triple-junction solar cells with higher than 10% initial efficiency were produced with a subcell yield of 96%. PV modules with 9.4% initial efficiency have been produced at Sovlux. Large area rooftop modules, 1.3 ft. wide by 20 ft. long, produced using these solar cells show initial efficiency up to 9.3%.

ACKNOWLEDGMENTS

The authors thank all colleagues in the photovoltaic team at ECD and Sovlux who contributed to the start-up effort of the Sovlux production line. The authors also would like to thank Drs. S. Guha and J. Yang for their helpful advice. This work was partially supported by the NIS-IPP (No. HAX-5-15200-01) program and CRADA (No. 3-95-035) program.

Table 3. I-V performance data for rooftop modules assembled at ECD using solar cells produced at Sovlux.

Module No	V_{mp} (V)	I_{mp} (A)	P_{max} (Watt)	Efficiency (%)
N19	31.7	4.7	149.0	9.0
N20	23.5	4.5	105.8	6.4
N21	29.2	4.6	134.3	8.1
N22	33.1	4.3	142.3	8.6
N23	33.5	4.3	144.1	8.7
N24	33.4	4.6	153.6	9.3

REFERENCES

[1] M. Izu and S. R. Ovshinsky, SPIE Proc. 407, 42 (1983).

[2] M. Izu and S. R. Ovshinsky, Thin Solid Films 119 55 (1984).

[3] H. Morimoto and M. Izu, JARECT 16 (1984); Amorphous Semiconductor Technology & Devices, North Holland Publishing Company, Edited by Y.Hamakawa, 212 (1984).

[4] S. R. Ovshinsky, Proc. International PVSEC-1, 577 (1988).

[5] J. Yang, R. Ross, T. Glatfelter, R. Mohr, G. Hammond, C. Bernotaitis, E. Chen, J. Burdick, M. Hopson and S. Guha, Proc. 20th IEEE PV. Spec. Conf. 241 (1988).

[6] J. Yang, R. Ross, R. Mohr and J. P. Fournier, Proc. MRS Symp. Vol. 95, 517 (1987).

[7] P. Nath and M. Izu, Proc. 18th IEEE PV Spec. Conf, 939 (1985).

[8] P. Nath, K. Hoffman, J. Call, C. Vogeli, M. Izu and S. R. Ovshinsky, Proc. of the 3rd International Photovoltaic Science and Engineering Conf., Tokyo, Japan, 395 (1987).

[9] P. Nath, K. Hoffman, C. Vogeli and S. R. Ovshinsky, Appl. Phys. Lett. 53 (11), 986 (1988).

[10] J. Yang, R. Ross, T. Glatfelter, R. Mohr and S. Guha, MRS Proc. 149, 435 (1989).

[11] M. Izu, X. Deng, A. Krisko, K. Whelan, R. Young, H.C. Ovshinsky, K.L. Narasimhan and S.R. Ovshinsky, proc. 23rd IEEE PV Spec. Conf., 919 (1993).

[12] M. Izu, S.R. Ovshinsky, X. Deng, A. Krisko, H.C. Ovshinsky, K.L. Narasimhan, and R. Young, AIP Proc. 306, 198 (1994).

[13] X. Deng. M. Izu, K. L. Narasimhan, and S. R. Ovshinsky, MRS Proc. 336, 699 (1994).

[14] S. Guha, J. Yang, A. Banerjee, T. Glatfelter, K. Hoffman, S. R. Ovshinsky, M. Izu, H.C. Ovshinsky, and X. Deng, MRS Proc. 336, 645 (1994).

[15] M. Izu, H. C. Ovshinsky, K. Whelan, L. Fatalski, S. R. Ovshinsky, T. Glatfelter, K. Younan, K. Hoffman, A. Banerjee, J. Yang, and S. Guha, Proc. of 1st WCPEC, (1994).

[16] T. Ellison, L. Fatalski, R. Kopf, H. C. Ovshinsky, M. Izu, R. Souleyrette, K. Whelan, and J. Wiehagen, Proc. 25th IEEE PVSC, this volume, (1996).