

Improving Czochralski Silicon PV Manufacturing Technology

Siemens Solar Industries participated in both Phase 1 and 2A of PVMaT.

PVMaT is a 5-year, cost-shared partnership between the U.S. Department of Energy and the U.S. PV industry to improve the worldwide competitiveness of U.S. commercial PV manufacturing.



Siemens Solar Industries

Goals

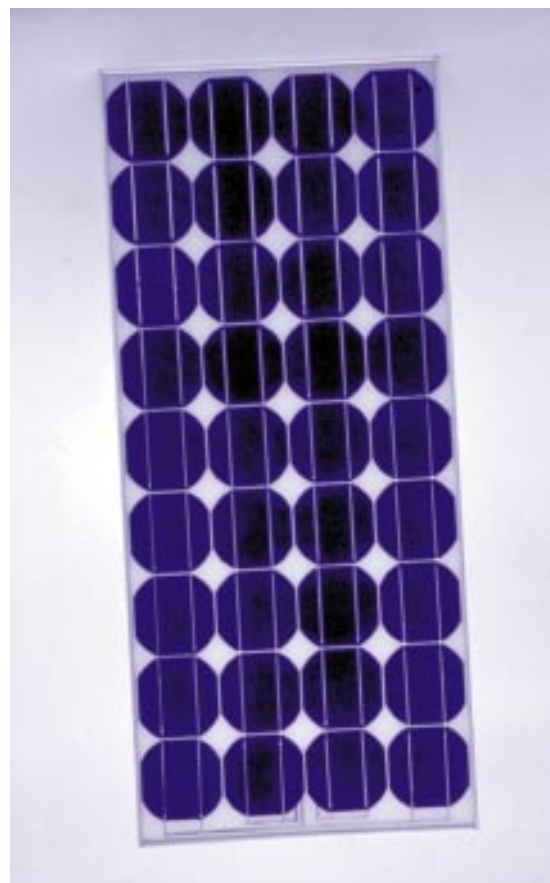
The goal of Siemens Solar Industries (SSI) under the PVMaT Project has been to decrease single-crystal silicon (Si) module cost by more than 50%, while doubling U.S. manufacturing capability. In meeting this goal, SSI (1) improved Czochralski (Cz) Si-ingot quality, (2) increased material-use efficiency for Cz Si sawing, (3) investigated improvements in device processing, (4) investigated introducing automation to a significant portion of its Cz Si module manufacturing lines, and (5) reduced the amount of hazardous waste generated.

Results

Reducing Cz PV manufacturing costs is driven by several parameters: low wafer cost, high electrical and mechanical yields in fabricating cells, low labor in cell and module fabrication, and materials used for making modules. SSI reduced costs by more than 25% in the last 2 years by addressing each of these items.

Several factors contributed to increased production in the SSI crystal-growing operation. These factors included improved polysilicon quality and cleaning, upgrades to the growing equipment—specifically, diameter controls—and upgrades to the hot-zone parts, which increased reliability and reduced cycle time. A wide range of polysilicon starting materials was also evaluated, and analyses were conducted on crystal-growing yields, cell performance, and impurity. As a result of these studies, overall crystal-growing yields improved by 8%. In addition, incorporating graphite design changes into the SSI crystal growers led to significant savings.

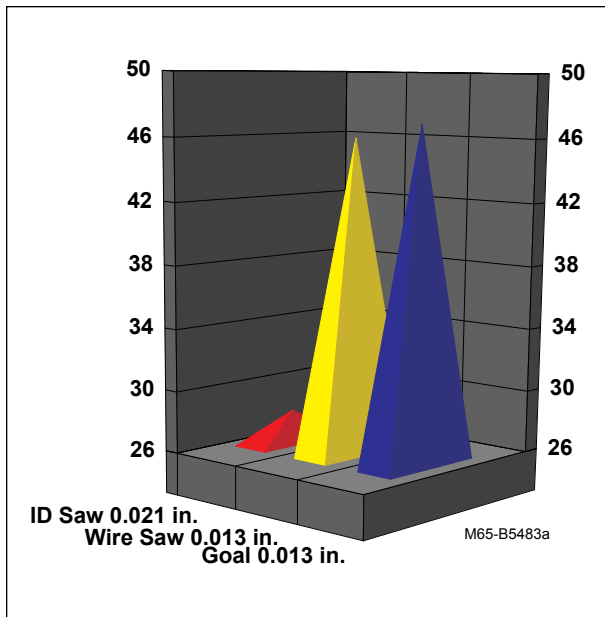
Wire-saw processing for slicing wafers was implemented under the PVMaT Program. Wire sawing reduced kerf loss and yielded thinner wafers. The average number of wafers obtained per inch is now more than



Siemens Solar ProCharger 4JF module fabricated with "sqround" cells, which are made by using new larger SSI ingots.

45—a 55% improvement in yield over the results obtained for wafers sliced with internal-diameter saws. Mechanical yields for this process also improved from less than 70% to more than 90% in less than a year.

Improvements to the solar cell focused on reducing labor costs by automating various material-transfer steps. Electrical output increased by decreasing the contact resistance and improving the diffusion processes. Siemens gained a significant shift in the electrical distribution by experimenting with process changes.



Yielded wafers per inch: ID saw vs. wire saw

Module design costs were also reduced significantly. Changes in the module manufacturing process reduced the final cost per watt of modules manufactured. These changes included Siemens' newly commercialized large-cell, 75-watt module. A general module improvement—redesigning the junction box—contributed significantly to reduced costs.

Early in the PVMaT Project, SSI made significant environmental improvements. The company completely eliminated chlorofluorocarbon chemicals in its manufacturing facility during the first half of 1993 by using a no-clean solder flux paste. SSI also reduced waste volume by 10% and waste costs by 20% by concentrating the plant's waste streams.

Company Profile

SSI, located in Camarillo, California, employs about 370 people. Its primary business is manufacturing PV cells and modules.

References

Pauls, K.L.; Mitchell, K.W.; Chesarak, W. (1993). "The Effect of Dislocations on the Performance of Silicon Solar Cells," *Conference Record of the Twenty Third IEEE Photovoltaic Specialists Conference - 1993, 10-14 May 1993, Louisville, Kentucky*, pp. 209-213

Printed with a renewable source ink on paper containing at least 50 percent wastepaper, including 20 percent postconsumer waste

Color printing costs were paid for by several U.S. PV companies.

King, R.R., et al. (1993). "Silicon Concentrator Solar Cells Using Mass-Produced, Flat-Plate Cell Fabrication Technology," *Conference Record of the Twenty-Third IEEE Photovoltaic Specialists Conference - 1993, 10-14 May 1993, Louisville, Kentucky*, pp. 167-171.

Mitchell, K.W. (1994). "Renaissance of Czochralski Silicon Photovoltaics," *Progress in Photovoltaics: Research and Applications*, Vol. 2, pp. 115-120, 1994.

Jester, T.L. (1994). "Photovoltaic Cz Silicon Manufacturing Technology Improvements," *AIP Conference Proceedings 306; 12th NREL Photovoltaic Program Review, Denver, Colorado*; pp. 256-264.

Mitchell, K.W.; King, R.R.; Jester, T.L.; McGraw, M. (1994). "The Reformation of

Czochralski Silicon Photovoltaics," 1994 IEEE First World Conference on Photovoltaic Energy Conversion: *Conference Record of the Twenty-Fourth IEEE Photovoltaic Specialists Conference, 5-9 December 1994, Waikoloa, Hawaii*; Vol. II, pp. 1266-1269.

King, R.R.; Mitchell, K.W.; Gee, J.M. (1994). "Back-Surface Cell Structures for Reducing Recombination in Cz Silicon Solar Cells," 1994 IEEE First World Conference on Photovoltaic Energy Conversion: *Conference Record of the Twenty-Fourth IEEE Photovoltaic Specialists Conference, 5-9 December 1994,*



For More Information

Ed Witt, NREL 303-384-6402

Richard King, DOE 202-586-1693

Doug Ruby, SNL 505-844-0317

Clay Aldrich, SEIA 202-383-2628

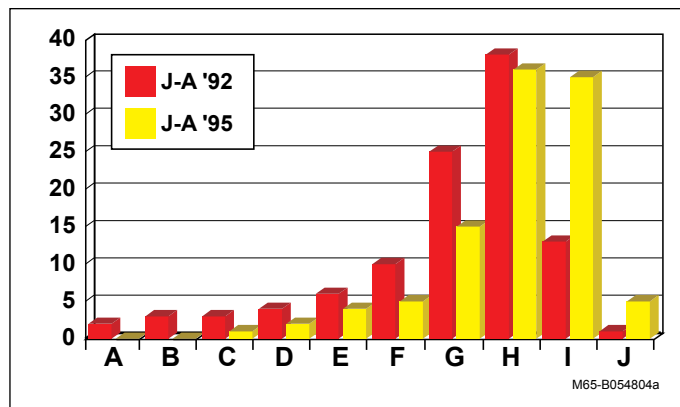
Theresa L. Jester,
Siemens 805-388-6500

Waikoloa, Hawaii; Vol. II, pp. 1291-1294.

Jester, T.L.; Mitchell, K.W.; Probst, R.; Tanner, D.; Vasquez, S. (1994). "Photovoltaic Cz Silicon Manufacturing Technology Improvements," 1994 IEEE First World Conference on Photovoltaic Energy Conversion: *Conference Record of the Twenty-Fourth IEEE Photovoltaic Specialists Conference, 5-9 December 1994, Waikoloa, Hawaii*; Vol. II, pp. 824-827.

Jester, T. (January 1994). *PV Cz Silicon Manufacturing Technology Improvements: Annual Subcontract Report, 1 April 1992-31 March 1993*. NREL/TP-411-6010. Golden, CO: National Renewable Energy Laboratory. Work performed by Siemens Solar Industries, Camarillo, California.

Jester, T. (March 1995). *Photovoltaic Czochralski Silicon Manufacturing Technology Improvements: Annual*



Electrical performance of cells has improved from 1992 to 1995. Vertical axis is relative quantity of cells. Horizontal axis is electrical performance of cells (within "bins" A to J), with performance increasing to right. A greater number of cells now have higher performance than previously.

Subcontract Report, 1 April 1993-31 March 1994. NREL/TP-7498. Golden, CO: National Renewable Energy Laboratory. Work performed by Siemens Solar Industries, Camarillo, California.

Jester, T. (October 1995). *PV Cz Silicon Manufacturing Technology Improvements: Final Subcontract Report, 1 April 1992-31 May 1995*. NREL/TP-411-20016. Golden, CO: National Renewable Energy Laboratory. Work performed by Siemens Solar Industries, Camarillo, California.

SP21590
DOE/GO-10096-301
DE96013083