PVMaT Improvements in BP Solar Large-Scale PV Module Manufacturing Using Ultra-thin Multicrystalline Silicon Solar Cells

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ABSTRACT

This paper reports on the work performed by BP Solar under NREL Subcontract #ZDO-2-30628-03. The major objectives of this program are to continue the advancement of BP Solar multicrystalline silicon manufacturing technology in order to:

Increase ingot size; improve ingot material quality and improve material handling; develop wire saws to slice 100 µm thick silicon wafers on 200 µm centers; develop equipment for demounting and subsequent handling of very thin silicon wafers; develop cell processes using 100 µm thick silicon wafers that produce encapsulated cells with efficiencies of at least 15.4% at an overall yield exceeding 95%; expand existing in-line manufacturing data reporting systems to provide active process control; establish a 50 MW (annual nominal capacity) green-field factory model template based on this new thin multicrystalline silicon technology; and facilitate an increase in the silicon feedstock industry's production capacity for lower-cost solar grade silicon feedstock.

1. Introduction

Achieving the overall objectives of the program is based on the following components:

- Complete the development of a solar-grade silicon feedstock and compatible casting process.
- Cast ingot size increase of at least 25% with reduced variation in material quality.
- Wire saw process for 100-micron large wafers on 200-micron centers.
- Demounting and handling processes for very thin, large wafers.
- High-efficiency cell process for very thin, large wafers.
- Module assembly process for very thin large cells.
- Active, in-line process control systems.
- Establish a 50 MW (annual nominal capacity) green-field plant factory model template based on a new thin multicrystalline silicon product line

2. Solar Grade Silicon Feedstock

In this task, BP Solar has worked with several silicon feedstock vendors to establish an understanding of their and our strategic needs with respect to silicon specification, price and future availability.

Sample material from several vendors has been processed. Results have generally been acceptable, and feedback has been provided to the vendors. Sample material from additional vendors will be included in the survey as it becomes available from their internal development work. The goal of the work is to establish one or more strategic partners for the long-term, cost-effective supply of solar feedstock.

3. Casting

In this task, BP Solar is investigating improvements in the casting process in order to increase ingot size by 25%, improve material quality and improve material handling.

In 2002, we completed a two-year, Phase 1 expansion of our casting facility in Frederick, MD, roughly tripling the casting and wafering capacity of the site.

We have developed modified crucible coatings that are less variable in performance than commercially available coatings, reducing stress in the completed ingot and thereby reducing process variation. We have established a mix of feedstock piece sizes appropriate for increasing the charge size in the newer stations from 240 kg to 300 kg or more. Crucible modifications for larger charge size have been prototyped.

4. Wire Sawing

BP Solar has demonstrated 12.5 cm x 12.5 cm wafer cutting to an average thickness of 140 microns using a conventional wire sawing process and equipment. Manual demounting of these wafers produced reasonable yields. Further reduction in silicon use by reducing the center-to-center wire spacing depends on the development of a lower-kerf cutting medium and wire combination.

Work was initiated to look at using slurry based on a much more durable abrasive in the conventional saws. The new approach may allow for smaller grain size for the cutting medium and increased tolerance of silicon loading in the slurry, thereby prolonging its useable life.

Work begun under the previous contract to develop a diamond-coated wire process was dropped after a prototype diamond-coated wire saw for ingot sizing did not meet its design objectives. Full-scale recycling of wire saw slurry is being implemented.

5. Wafer Demounting and Handling

We have worked with an equipment vendor who has demonstrated automatic wafer demounting for wafers of standard thickness, (250 microns). This equipment has potential application to existing manufacturing lines. Work is also planned to demonstrate a similar process with thinner wafers.

BP Solar is also supported in this task by ARRI, the Automation and Robotics Research Institute of the University of Texas at Arlington. ARRI has developed a wet wafer-demounting prototype. This has been successfully demonstrated on standard thickness wafers. The concept also appears applicable to thinner wafers.

6. Cell Processing

In this task, BP Solar is developing, demonstrating and implementing a cost-effective, robust cell process that produces a minimum average cell efficiency of 15.4% on large, very thin silicon wafers.

In 2002, silicon nitride (SiN) deposition equipment was installed in the BP Solar factory in Sydney, Australia, and is now in full production. SiN was installed in the Tata BP Solar factory in Bangalore, India in 2000, and implementation in Frederick is planned in 2003. SiN provides higher cell efficiency through bulk and surface passivation. It is an enabling step for further gains.

A technology road map to production implementation of various efficiency improvements was established in 2001, with the SiN implementation as the first step. The next incremental efficiency improvement is being implemented in the Bangalore in early 2003, with the other factories to follow. We have demonstrated advanced process variations producing up to 15.7% average efficiency on large multicrystalline screen-printed cells.

New, rotary screen print equipment, along with no-cure paste technology developed under the previous contract was installed in Frederick and then in Sydney. This technology reduces cell handling, is more forgiving for thin wafers, and reduces the cell line footprint and cost significantly. These lines are capable of producing cell sizes larger than the current 12.5 cm x 12.5 cm standard.

7. Module Assembly

In this task, BP Solar will develop and demonstrate a module assembly process and equipment suitable for very thin solar cells. This task should result in an assembly process that produces framed, terminated PV modules using very thin cells at an overall yield exceeding 98%.

We have continued development of a module design including laminated-in bypass diodes. We have revisited a BP Solar array that has been in the field for over five years with laminated diodes. Visual and IR inspection revealed no diode failures, no overheating of diodes, and that all modules remained fully protected against shading.

The new design uses a circuit board on which the diodes and module busing are pre-assembled in order to improve reliability and make it easier to automate the termination assembly. External certification of the new design is underway.

A design effort has begun to incorporate the best features of the heritage Solarex and BP Solar junction boxes into one box while reducing the box cost and the installation labor.

8. In-line Process Control

In this effort, BP Solar will incorporate active feedback from the manufacturing processes into the in-line MES system.

BP Solar completed an assessment of crack detection methods for application to conventional and to very thin wafers and completed prototype testing with the most promising detection system.

During the development of the wafer crack detection system, BP Solar had placed orders for automated handling equipment for several cell lines. The initial concept for the wafer crack detection system was that it would be integrated with these and similar automated handling systems in order to provide real-time feedback on wafer breakage. Two issues emerged during the wafer crack system development. First, it was not clear that the system, as finally conceived, could be small and light enough to integrate into the handling tools of our automated handling systems. Second, the vendors of these automated handling systems were willing to guarantee such low rates of breakage that the value of in-line wafer crack detection would be much diminished.

Development work was therefore halted after demonstration of the new prototype at the vendor. It appears unlikely that the method will prove useful for in-line use in high-volume manufacturing.

9. The 50 MW Green Field Factory Template

In this effort, scheduled to begin in the second contract year, BP Solar will establish a 50 MW (annual nominal capacity) green-field factory model template based on a new, thin, cast multicrystalline silicon product line. This model will include the very thin wafer and the compatible high efficiency cell and module assembly processes. Using the model, we will establish cost baselines and perform a cost study of the integrated processes, then validate these projected manufacturing costs using the existing BP Solar multicrystalline silicon factory. This effort is expected to demonstrate that the integrated processes will reduce overall costs by 25% and overall Coefficient of Variation (COV) by 50%, compared to the baseline manufacturing process. Based on these results and market data, BP Solar will determine the optimal sizes for wafers and modules for full scale manufacturing of this new product line.

To date, optimal wafer size and initial cost models have been established.