Final Technical Report (FTR)

Project Title: Innovative manufacturing technologies for low-cost, high efficiency PERC-based PV modules

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Executive Summary: The goal this project was to accelerate the deployment of innovative solar cell and module technologies that reduce the cost of PERC-based modules to best-in-class. New module integration technology was to be used to reduce the cost and reliance on conventional silver bus bar pastes and enhance cell efficiency. On the cell manufacturing front, the cost of PERC solar cells was to be reduced by introducing advanced metallization approaches to increase cell efficiency. These advancements will be combined with process optimization to target cell efficiencies in the range of 21 to 21.5%. This project will also explore the viability of a bifacial PERC solar cell design to enable cost savings through the use of thin silicon wafers. This

project was terminated on 4/30/17 after four months of activity due financial challenges facing the recipient.

Table of Contents

Background: Suniva is the leading U.S. manufacturer of high-efficiency, high-quality PV solar cells and high-power modules. Our corporate offices, cell manufacturing plant and R&D labs are headquartered in Norcross, Georgia, with a newly established module manufacturing plant in Saginaw, MI. Suniva's American innovation evolved from Georgia Tech's University Center of Excellence for Photovoltaic Research and Education (UCEP), one of the most advanced crystalline Si PV labs in world. The close relationship that Suniva has with Georgia Tech is an excellent example of how a successful public/private partnership can create and commercialize world-class technology. This relationship combines world class research from the Georgia Tech UCEP group with pragmatic insights and discipline from Suniva's development organization, and leverages Suniva's manufacturing capabilities and solar supply chain relationships to transform innovative ideas into reality. Since its inception, Suniva has rapidly introduced three new generations of cell technology, each more efficient and lower in cost than the preceding one. The company's patented cell designs, unique manufacturing processes, and continual innovations of our R&D division have led to world records in cell efficiency using rugged, sustainable, low-cost processes. This in turn allows us to produce high-quality, high-power PV modules that exceed global and U.S. certifications and provide outstanding reliability. Suniva's most recent manufacturing success was born from a Suniva-Georgia Tech collaboration and has been achieved using our industry-first application of ion implantation to re-engineer the emitter with surface passivation, leading to an increase of 1% (absolute) in cell efficiency. Today, Suniva has an annual capacity of 170 MW for its best in class solar cells that have an average efficiency of 19.6%. Suniva is moving forward with expansion of its solar cell manufacturing capacity at its Norcross headquarters in order to respond to the tremendous demand for our products. The expansion will take place during 2016 and will result in a cell manufacturing capacity of 400 MW. This expanded manufacturing capacity will enable Suniva to take advantage of the economies of scale and participate in larger PV projects. Along with the capacity expansion, the cell product will be upgraded from Al-BSF to PERC on a mono-Si wafer with an expected cell efficiency increase to 20.8%. This project aims to further enhance cell efficiency from the 20.8% baseline to 21-21.5%, while reducing the cell and module manufacturing cost. The work plan has been organized into three tasks to optimize, evaluate, de-risk, and deploy advanced technologies into high volume manufacturing (HVM) in Norcross, GA.

A distinct advantage of a bifacial cell design that enables cost reductions not feasible with conventional device architectures is related to the wafer thickness that is compatible with module fabrication. Due to the difference in coefficients of thermal expansion between the metal contacts and the silicon substrate, thin wafers show significant bow when processed with full Al prints on one side. This renders the usable wafer thickness to $\geq$ 160 μm for both Al-BSF and PERC devices. A bifacial cell design has two factors in its favor that eliminate the bowing issue. First, the amount of Al paste applied on the rear side is significantly lower than in monofacial cells and secondly, similar metal layouts and dielectric films on the front and back largely negate thermal stresses on the two faces of the cell as they act in opposite directions . This eliminates the bowing issue for very thin and will enable a wafer thickness reduction to down to 100µm (cell processing line limits). Such thinner wafers have the potential to significantly lower the overall cost of the wafer by $0.20/piece from current prices as projected by the wire-sawing division at AMAT.

Reduced wafer strength makes thin wafers more susceptible to breakage when exposed to the forces encountered during automated handling. In addition, less force is required to flex a thin wafer, which can cause wafers in a carrier to bow and stick together (during wet processing) and/or strike parts of a tool in unintended ways, resulting in breakage. Suniva has largely overcome these challenges and developed high yield processes on production scale equipment compatible with thin (≤120µm) wafers as part of its development efforts supported by another DOE award. We have demonstrated good mechanical yield for 90-120um thick, p-type Cz wafers at each step of our manufacturing process for Al-BSF cells. All steps and tools used standard production recipes, with the exception of the rear print in which a grid-line pattern rather than a full-area Al print to avoid bowing during contact firing. Furthermore, we have had considerable success with integrating thin bifacial cells into modules with >99% yields through stringing and lamination. Bifacial PERC cells also require much less Al paste (10% of the mass used for monofacial cells) which reduces the cost of the panel by $0.007/W. Bifacial PERC cells may provide some benefits due to a deeper Al-BSF with fewer voids that increases Voc, and reduced SiN capping layer thickness since Al firing through the rear dielectric is avoided. The bifacial design is expected to increase series resistance of the cell due to the conductivity of fired Al paste, but this can be minimized with a five bus bar design. We also expect a loss in Jsc when the wafer thickness is reduced, and plan to mitigate this problem at the module level by introducing a reflective back sheet that will be evaluated and selected as a part of this project.

Project Objectives: The objective of this project is to reduce the cost of photovoltaic (PV) modules based on mono-PERC cells through the development of advanced screen printed metallization to increase cell efficiency, and a bifacial cell structure that enables the use of thin wafers to reduce cost. The objectives of Budget Period 1 are to establish baseline efficiency for passivated emitter rear locally contacted (PERC) cells using our manufacturing line, improve the metallization to increase cell efficiency, refine the device design to improve the yield of thin silicon cells. The objectives of Budget Period 2 are to further improve metallization to increase cell efficiency, demonstrate the robustness of the thin cell design and process, and develop a module integration solution.

Project Results and Discussion: This project will improve the capabilities of our solar cell and module manufacturing lines to enable manufacturing of solar cells on thin wafers and their integration into modules. We will begin Budget Period 1 by establishing a software device model calibrated with baseline data from the manufacturing line to assess the impact of planned improvements. We will also develop advanced screen print metallization that will increase cell efficiency, and modify our cell design and manufacturing equipment to improve the yield of thin wafers through our manufacturing process. In Budget Period 2, we will further improve metallization and demonstrate pilot production of bifacial PERC cells on thin wafers. We will also develop tool upgrades in collaboration with our equipment vendor that enable high-throughput automated-stringing of bifacial PERC cells.

Significant Accomplishments and Conclusions: N/A

Inventions, Patents, Publications, and Other Results: N/A

Path Forward: N/A

References: N/A