



Next Generation SLIVER solar cells

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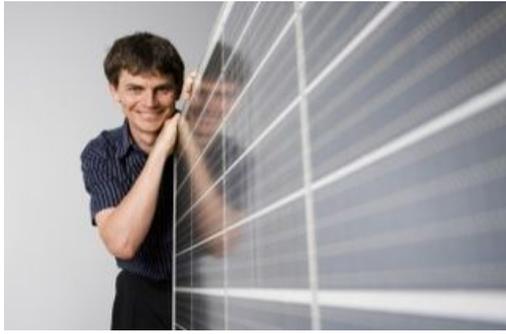
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Project summary



SLIVER technology is a technology for the fabrication of silicon based solar photovoltaic panels with unique attributes that make the panels very attractive for a range of applications. The goal of this project was to demonstrate the streamlined production of more efficient SLIVER cells on a low volume, commercial production line.

Several key areas with substantial scope for improvement were identified at the start of the project, including laser processing, surface treatments and improvements to material quality. Advances in these areas were adapted and rigorously proved for SLIVER cells, and then incorporated in a carefully staged manner into the SLIVER manufacturing process.

Successful completion of the project resulted in a substantial boost in the conversion efficiency of SLIVER modules, and a substantial reduction in their manufacturing cost. The project played a significant role in lowering the cost and increasing the competitiveness of SLIVER technology.

Project scope

SLIVER Technology

SLIVER technology is a technology for the fabrication of silicon based solar photovoltaic panels with unique attributes that make the panels very attractive for a range of applications. SLIVER technology enables the fabrication of modules that can deliver high voltages, are flexible and conformable, have high power-to-weight ratios and have substantially better tolerance to partial shading than conventional modules. SLIVER cells are completely bifacial – that is, they are able to capture and convert sunlight to electricity equally effectively from both cell surfaces, unlike almost every other solar cell technology. This allows the production of completely bifacial modules. In addition, the production of SLIVER modules requires less silicon than conventional silicon-based modules.

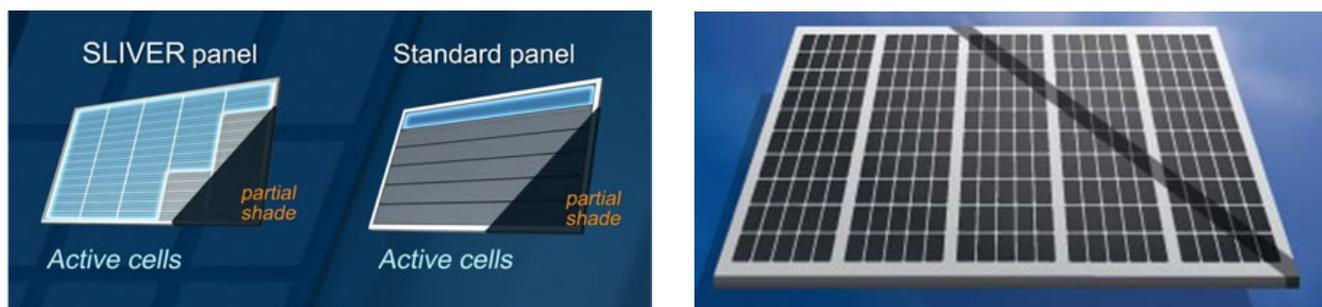


Figure 1: Left: Demonstration of the effect of shading. Right: A Module with a long crossing shadow (such as a power line or vent crosses 3 modules of an array). In this situation SLIVER modules deliver 17% more output than conventional modules. Source: Transform Solar



Figure 2: SLIVER modules undergoing outdoor testing to measure the effect of shading on power output. SLIVER modules display substantially better shade tolerance than most other commercial modules. Source: Transform Solar

SLIVER modules are well suited for use in most applications where other Photovoltaic modules are used, such as on the rooftops of residential dwellings. In addition, the unique attributes of the technology mean that SLIVER modules can be used in applications where conventional modules are not a good option. For example, the roofs of many commercial or industrial buildings cannot support the weight of conventional modules, which are heavy as they use a thick sheet of glass. In these situations, lightweight, conformable SLIVER modules may be used. These modules take advantage of the flexibility of the solar cells in the module and replace the thick front glass with a thin and much lighter film of inter plastic.



Figure 3: Left: A flexible prototype SLIVER PV sheet; right: SLIVER LightForm monocrystalline module prototype. Weighing 2.8kg, it delivers more kWh per roof area with its combination of extremely high efficiency, increased packing density, and partial shade response.

Project motivation

SLIVER solar cells are made from crystalline silicon, the same material that is used in over 80% of commercial Photovoltaic modules sold today. The process for turning the starting material – a silicon wafer – into solar cells uses much the same equipment and processes as are used for the fabrication of conventional silicon cells. However, there are several key differences in the fabrication, arising from a fundamentally different approach to solar cell fabrication. In conventional cells, each silicon wafer is turned into one solar cell by treating the surfaces of the wafer. In SLIVER technology on the other hand, each silicon wafer is processed to allow hundreds, or thousands, of solar cells to be made from one wafer. This approach brings many benefits but also introduces significant challenges, as the details of solar cell fabrication process must be radically re-thought. Fig. 4 shows the basic idea behind SLIVER technology. A micromachining technique is used to create grooves which extend through the silicon wafer, in the process defining silicon strips which are then processed to produce individual solar cells. At the end of the process, the strips are removed from the wafer frame to complete the fabrication of SLIVER cells. This is done using high speed robotic tools specifically developed for this purpose.

At the commencement of the project, the best known processes for producing SLIVER solar cells were complex and involved many more processing steps than conventional cells, while the cell conversion efficiency was relatively low. The high process complexity meant that overall module costs were likely to be competitive but not significantly better than conventional module costs, while module efficiencies would be lower.

The purpose of this project was to trial, refine and implement radical process improvements. Several promising technologies had been identified at the beginning of the project with the clear potential to substantially streamline the cell production process and, at the same time, raise the cell efficiency.

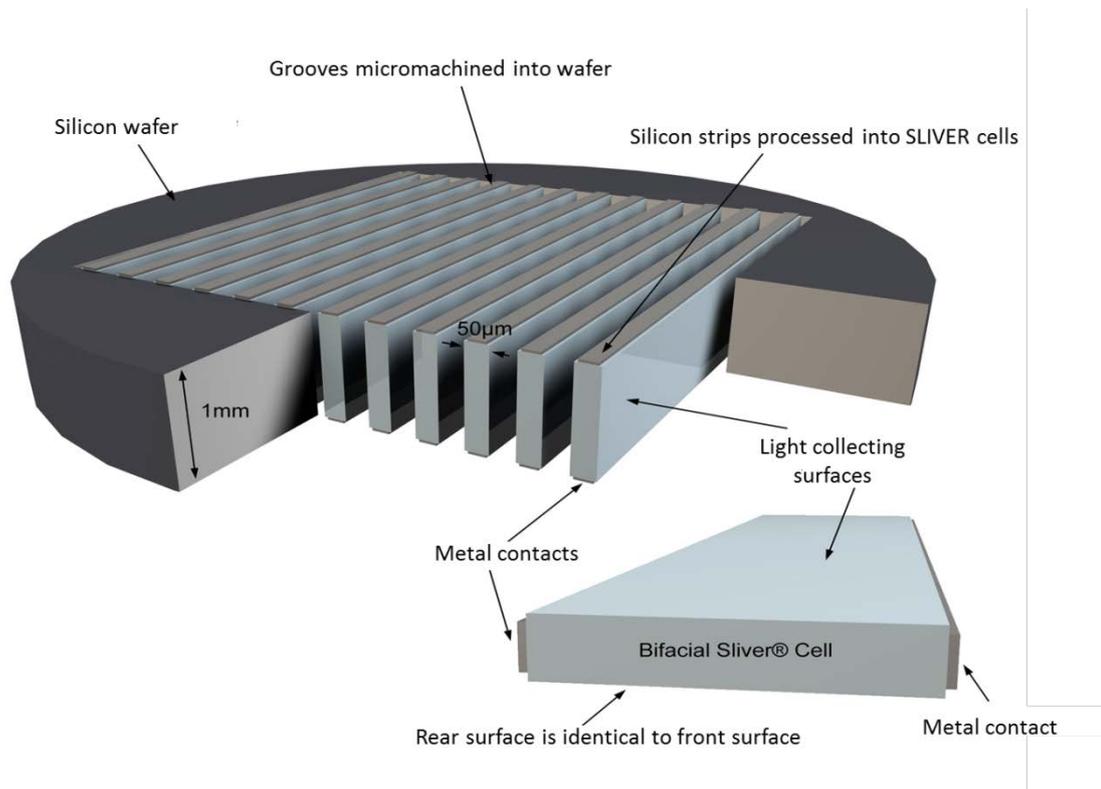


Figure 4: Schematic diagram illustrating the SLIVER cell concept

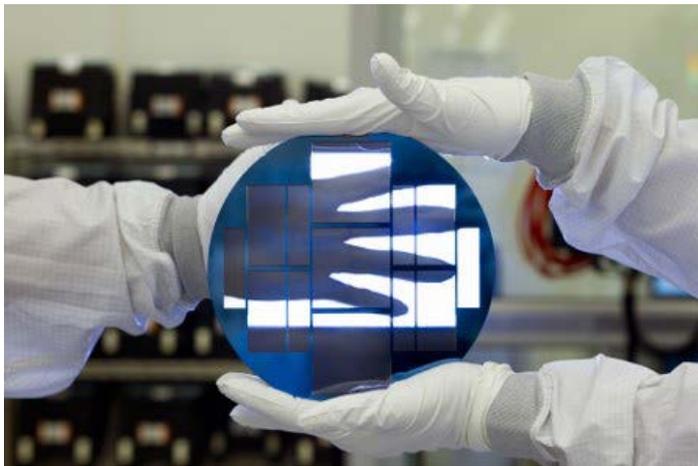


Figure 5: A SLIVER wafer following groove etching. At this stage the wafer contains thousands of individual SLIVER cells. Source: Transform Solar

Outcomes

The SLIVER fabrication process that existed at the beginning of the project was relatively mature but complex, and as a consequence had low yield. Further the cell efficiency was significantly lower than what was considered achievable. Specifically, the fabrication sequence required so-called aligned steps, where patterning steps were required that had to be aligned with previous patterning steps. Such aligned process steps are usually slow, complex and prone to error. Hence, an early focus of the project was to simplify the process and eliminate the need for aligned process steps.

This part of the project was achieved by introducing new, self-aligned technologies into the cell fabrication process. This allowed a substantial simplification in process complexity, with the total number of process steps reduced from 75 to 53. In addition, the conversion efficiency was boosted, with small modules measured at 16.1%, up from just over 13% at the start of the project. The improved cells and modules were also tested for reliability and comfortably passed the reliability tests required for certification.

To achieve further enhancements in efficiency, the silicon material was identified as a key limitation of the current cell design. Initially, p doped silicon was used for SLIVER cells. This material is used in the majority of currently produced solar cells. However, the electronic quality of n type silicon – silicon containing different impurity elements from p type silicon – is known to be higher. The use of n type rather than p type silicon necessitates significant changes in solar cell fabrication processes. Hence the second part of the project was focused on the development of the next generation of SLIVER cells based on n type silicon. To do this, new surface coatings had to be developed. The new coating is based on films of aluminium oxide and titanium dioxide, deposited by atomic layer deposition. A large amount of work was devoted to developing and investigating these new coatings, particularly when they are used for coating SLIVER cells and have to be incorporated into the overall cell manufacturing sequence.

A second innovation for the fabrication of n-type SLIVER cells was the incorporation of laser-based processes, which allow the creation of local features without the need for expensive photolithography – the conventional technique for defining such local features. By carefully studying the laser process and its interaction with surface coatings we were able to determine suitable values for laser power and other laser parameters to allow the selective removal of surface coatings with virtually no damage to the underlying silicon.

This work resulted in the demonstration of n type SLIVER cells with high conversion efficiencies of 19%, as well as open circuit voltages (V_{OC}) of more than 700mV. V_{OC} is a measure of the overall quality of the device, and a value of 700mV indicates that excellent quality has been achieved and maintained for every surface and every region of the cell. Only a few silicon solar cells have achieved such high values of V_{OC} .

For the analysis of both solar cells and test structures, we developed new measurement and modelling techniques, and refined existing ones. The simulation and modelling program Quokka was developed by one of the researchers, Dr. Andreas Fell. This freely available program allows the rapid simulation of solar cells and other structures that are inherently 3-dimensional and require sophisticated modelling to be able to accurately reproduce these 3-D characteristics. Compared to existing, commercial simulators, Quokka is much less computationally intensive because it makes several simplifications which do not affect the accuracy of the results. This program was combined with advanced photoluminescence imaging – a technique that allows the measurement of many important material properties with high resolution. A version of Quokka was specially adapted to SLIVER cells, allowing the rapid and accurate simulation and optimisation of SLIVER cells. This is extremely important since SLIVER cells are inherently 3-D in nature.

Transferability

The project involved a detailed investigation of laser processes (for application to solar cells), new surface coatings and improved measurement and modelling techniques. In all these areas, new findings were made that are applicable to other solar cells (and possible to devices other than solar cells) and these findings have been published in a scientific journals and conferences so that they are available to the scientific community.

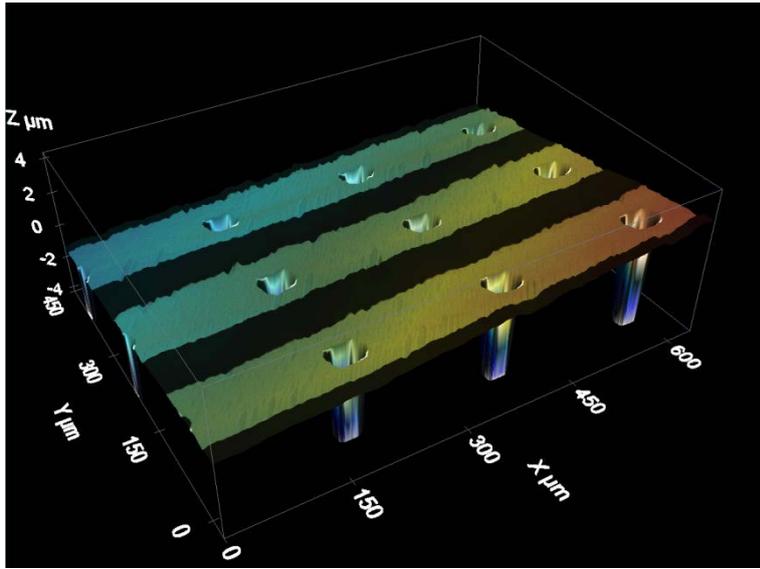


Figure 6: Confocal microscope image of an array of laser contact openings produced on several SLIVER cells (contacts were opened with the laser and then etched). Note the different scales for the depth (z) axis compare to the x and y axes, to clearly show the depth of the processed regions. Only a fraction of the entire length of the cells is shown for clarity.

These outcomes are already finding application elsewhere. For example, the laser processes for the selective removal of surface coatings have already been applied to other types of silicon solar cells, where efficiencies as high as 23.5% have been achieved, which is not far below the world record efficiency of 25.6% for a silicon cell. The modelling program Quokka is also finding widespread use for many other types of silicon solar cells, and for the investigation of other processes used in making silicon solar cells. It is freely available through the PV Lighthouse website.

Conclusion and next steps

This project achieved significant improvements in SLIVER cell fabrication, demonstrating a reduction in process complexity, improved yield and substantial increases in conversion efficiency. The original goals of the project were therefore achieved.

This project was a collaboration between the Australian National University and Transform Solar. In late 2012, Transform made the decision to exit SLIVER technology, due to unfavourable market

conditions. All the intellectual property and the know-how has reverted to ANU. In addition, ANU has acquired key physical equipment, including machines specifically developed by Transform for the separation, testing and placement of SLIVER cells and SLIVER modules, module precursors and SLIVER cells.

With the return of technology to ANU with no encumbrances, ANU is actively seeking partners for commercialisation of SLIVER technology. Through the results of the project, the potential for very high efficiency SLIVER products has been demonstrated. ANU will look to identify potential markets for SLIVER products, which include lightweight rooftop products as well as products for applications where a combination of high efficiency, low weight and flexibility, as well as possibly other attributes unique to SLIVER technology (high voltages, shade tolerance) are important. These could include defence applications or consumer products.