RAFTS: HANDLING AND ENCAPSULATING BILLIONS OF SLIVER SOLAR CELLS AT LOW COST

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ABSTRACT: SLIVER® solar cells are thin, mono-crystalline silicon solar cells fabricated using standard semi-conductor processing and solar cell fabrication technology. SLIVER solar power modules, comprising several thousand individual SLIVER cells, can be efficient, low cost, bifacial, transparent, flexible, shadow-tolerant, and lightweight. Compared with current conventional PV technology, mature SLIVER Technology will need less than 10% of the pure silicon, and fewer than 5% of the wafer starts per MW of factory output. Once wafer processing is complete, the individual SLIVER cells must be extracted from the host wafer, assembled and electrically interconnected into solar power modules. We have devised methods to immobilise each SLIVER cell while the peripheral portions of the host wafer are removed. The block of SLIVER cells, once removed from the host wafer, is conflated and stored in a cassette for later use. These two processes can be performed rapidly at low cost. A 100 MW SLIVER factory will produce several billion individual SLIVER cells annually. We have developed a sub-module assembly approach for rapid, reliable, low-cost production of arrays of SLIVER cells to form two main types of conventional solar cell analogues that, because of their appearance, we call "Rafts" and "Sheets". Using our invention, Rafts and Sheets can be reliably produced at high speed using low-cost equipment and entirely conventional materials. Once formed, Rafts and Sheets can be mechanically handled, and assembled into solar power modules, using simple adaptations of conventional solar cell handling and stringing equipment.

Keywords: SLIVER, Fabrication, Concentrator Cells, Manufacturing and Processing, Shading.

1 INTRODUCTION

A primary goal of the PV industry is to reduce the cost of electricity generated by solar power modules to be competitive with fossil fuel and nuclear power generation. Until recently, significant cost reduction has been achieved through economies of scale and incremental efficiency improvements. However, energy policy and public attitude, fueled largely by climate change considerations, has seen sustained rapid growth in the PV market, causing silicon supply and manufacturing capacity shortfalls that have placed upward pressure on prices.

Global responses to this situation include significant manufacturing capacity increase, planning for new silicon foundries, a drive to produce thinner silicon wafers, research into PV fabricated from lower-grade silicon, and renewed interest in ribbon and non-silicon thin-film technologies. However, all these approaches are incremental, and, while very important, will yield only incremental gains.

SLIVER Technology is a breakthrough technology that has the potential to cut silicon consumption by a factor of 10, and wafer starts by a factor of 20.

These impressive potential advantages are partially offset by increases in the cost and complexity of SLIVER cell fabrication, as well as additional cost in handling the significant increase in the number of cells required to populate a SLIVER solar power module.

1.1 SLIVER Technology

Recently the authors became aware of a paper by Iles & Soclof [1], which describes a general concept for area multiplication of a silicon wafer, and describes a number of processes for achieving an increase in wafer surface area. However, the processes described in Iles & Soclof, whilst possessing benefits for silicon utilisation, also have a number of significant problems including highly non-uniform etching of grooves in their wafers, the difficulty they experienced in holding the thin strips of silicon in place during wafer processing, and their inability to texture the hidden (sunward) faces in the grooves, along with their difficulty in fabricating solar cells on the thin strips.

Blakers and Weber at the Australian National University (ANU), with financial support from the Australian company Origin Energy and the Australian Research Council, independently re-invented [2] the concepts described by Iles & Soclof. Along with others, they have substantially improved upon this earlier work, including solving the above-listed problems [3 – 5].

Recent work at The Centre for Sustainable Energy Systems at ANU has resulted in the development of a 2nd generation of SLIVER technology, that comprises the high-performance and low-cost SLIVER solar cell fabrication technology summarized in a companion paper at this conference [6], and the handling, separation, assembly, and electrical interconnection processes [7, 8] summarized in this paper.

1.2 The SLIVER process: An over-view

SLIVER solar cells are long, narrow, thin mono-crystalline silicon solar cells, fabricated in a dramatically different way to conventional wafer-based solar cells. Rather than fabricating one large solar cell on the surface of a wafer, many hundreds to thousands of long, narrow, and thin individual SLIVER cells are fabricated within a wafer. SLIVER cells are symmetrical, perfectly bi-facial, and quite fragile.

SLIVER Technology produces a significantly larger solar cell area than can be obtained from the same amount of silicon using conventional solar cell processing technology. This means far fewer wafers need to be processed in order to obtain the same solar cell area as that produced by conventional processing, resulting in a significant reduction in processing cost per unit area of cell produced. SLIVER cells are also highly efficient, requiring fewer cells to produce the same electrical power compared with conventional solar cells.

Compared with current PV technology, mature

SLIVER Technology will require less than 10% of the pure silicon and fewer than 5% of the wafer starts per MW of factory output [9]. A single 15cm diameter SLIVER wafer can contain sufficient cells to produce a module with a rating of up to 100W.

For the cost reduction potential of SLIVER Technology to be fully realised, two broad goals, embodied in the results of the 2nd generation technology developed at ANU, must be reached. Firstly, the cell manufacturing process must be able to achieve high cell efficiencies with high process yields; preferably using standard semiconductor processes and equipment in order to capitalise on existing knowledge and experience [6]. Secondly, an efficient and robust SLIVER cell handling and module fabrication method is required.

In a 100 MW_p manufacturing facility, around 13 million SLIVER cells need to be processed daily. This paper describes methods for separating, handling, and assembling [7], the 5 to 6 billion SLIVER cells produced annually by a 100MW SLIVER cell factory. Details of methods for electrically interconnecting SLIVER cell sub-modules are also presented [8].

2 EARLIER HANDLING AND ASSEMBLY

Earlier SLIVER cell handling and assembly is based on a modified pick-and-place technique [10]. In this approach, individual SLIVER cells are sequentially removed from the wafer, individually electrically tested, and binned using a binary pass/fail classification. The surviving cells are then individually assembled in a temporary array, where cell location is referenced relative to adjacent cells. The assembled array is then transferred via a vacuum transfer head on an x-y-z-θ gantry, placed, and bonded, to a substrate. The substrate defines the size of the finished module array, the size of which is in turn limited by the bounds of the placement gantry.

The earlier approach is essentially a linear process with limited scope for modularity and opportunity for process-line intermediate-stage buffering.

The electrical interconnections in the earlier method are established by printing or dispensing pads of electrically conductive material on the substrate. Depending on the material application process and the conductive material chosen, the conductive material may be placed on the substrate before or after the SLIVER cell array is bonded in place. The establishment of module electrical interconnections spans inter-cell connections on a large scale. “Large-scale” here has a dual interpretation; in number - tens of thousands of electrical connections per square metre of module area, and in scope; a large number of very small interconnections spanning the entire, quite large, module area. As well as the inter-cell connections, bus-bar interconnections between groups of cells are also required. The magnitude of the task of inter-cell electrical connections in a SLIVER module should not be under-estimated. Depending on module design there are typically 40,000 to 60,000 electrical connections per square metre of module area. Not all these connections are critical: a significant fraction provide reliability and robustness through redundant interconnections.

However, establishing electrical interconnections using this procedure may involve a batch process requiring a large accumulation-storage area and, if thermally-cured conductive material were to be used, a large-volume curing oven.

From a manufacturing perspective, any single linear assembly approach introduces yield compromise due to tolerance accumulation; limits the choice of substrate material; places limitations on the substrate size due to placement range capability; limits the product design and layout flexibility; restricts the ability to introduce input/output buffers to any of the process stages in the entire process, which is a factor that severely compromises throughput expectations; and generally requires frequent manual intervention, significantly increasing cost, reducing yield, and reducing over-all throughput.

In order to avoid the above difficulties, a simplified modular approach to SLIVER cell separation, handling, assembly, and electrical interconnection has been developed.

3 THE SLIVER SUB-MODULE CONCEPT

The majority of challenging problems, whether they are theoretical or practical, become more tractable upon division into a sequence of logically related modules or tasks. In the case of devising a solution to a manufacturing problem, it is advantageous for these tasks to be physically separated and, preferably, for the tasks to be procedurally independent.

In devising a 2nd generation cell handling, assembly, and electrical connection process, low-cost easily-automated, reliable and robust, procedurally-independent solutions were developed for performing each of the handling and assembly process stages, commencing with the separation of the SLIVER cells from the wafer, and proceeding right through to the finished SLIVER module.

The downstream component of the 2nd generation technology, following cell fabrication, relates to methods for separating, handling, assembling, and electrically interconnecting large numbers of SLIVER cells in a low-cost, efficient, robust, and reliable manner.

Rather than separating individual SLIVER cells from the wafer using an expensive, high-speed, automated process, the 2nd generation technology constructs modular sub-assemblies, which can be thought of as conventional solar cell analogues, in a simple, low-speed, low-precision, low cost, but high-throughput process.

The sub-module approach provides a means for the low-cost separation, handling, assembly, and electrical interconnection of groups of SLIVER cells to form a conventional solar cell analogue that, because of its appearance, is called a “Raft” [7]. Origin Energy subsequently published a sub-module approach [11].

The Raft modular sub-assemblies comprise planar arrays, comparable in size to a conventional solar cell, of SLIVER cells fixed to a supporting medium. A high-efficiency form of the modular sub-assembly structure, referred to as a “Sheet”, which may or may not require a supporting medium, constitutes SLIVER cells abutting adjacent cells in the array, providing 100% area cover sub-modules for use in high efficiency SLIVER solar power modules [7].

3.1 SLIVER cell separation

Since SLIVER cells are perfectly bifacial and perfectly symmetrical, it is only possible to determine their orientation by electrical test.

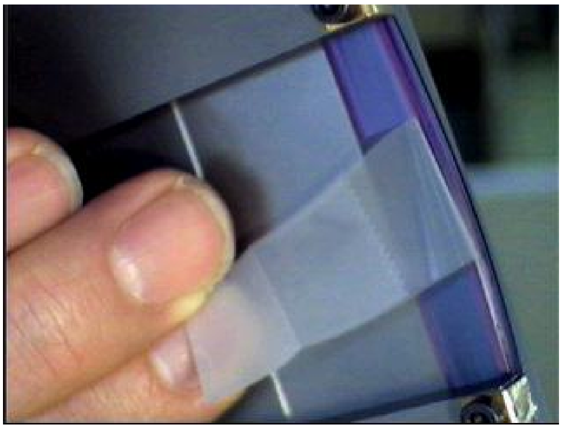

Figure 1. Transfer of SLIVER cells to a single-stack cassette.

The 2nd generation process retains the entire array of SLIVER cells contained within a wafer, or sections of an array, using simple and cheap methods. In one method, a block of cells is secured on one or both sides of the SLIVER array. The cells are released from the wafer frame by dicing saw or laser scribing. The released array is then stored in a cassette or other buffer storage device until required, as shown in Figure 1.

3.2 SLIVER cell storage

The bundle of secured SLIVER cells is placed in a cassette where the the cells are released as shown in Figure 2. The cassette, now containing sufficient SLIVER cells for a module with a rating of up to 100W, is stored until required.

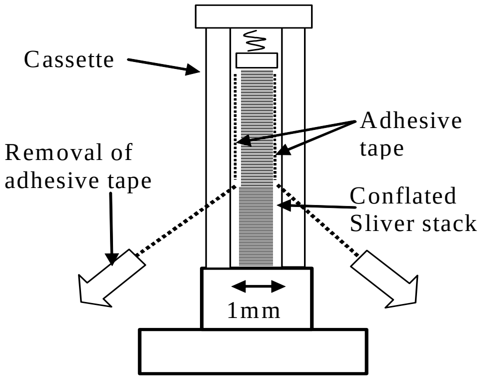

Figure 2. Transfer of SLIVER cells.

Alternatively, the array of retained SLIVER cells can be loaded into a multi-stack cassette. The spacing of individual cassette stacks, or stacks within a multi-stack cassette, can be arranged to suit the SLIVER cell spacing in sub-module arrays formed from these devices.

3.3 SLIVER sub-module assembly

Raft modular sub-assemblies comprise planar arrays, comparable in size to a conventional solar cell, of SLIVER cells fixed to a supporting medium. The supporting medium can be a collection of long, thin material in the form of a ribbon or a track, or it may be quite wide, up to slightly larger than the size and shape of the SLIVER cell array.

It can be transparent or opaque and, depending on the sub-assembly application, it may be flexible or rigid. A simple method has been developed to extract the SLIVER cells from their host wafer and to subsequently lay them out in a planar array format, either on supporting beams, planar substrates, or even in free-standing contiguous arrays in a bulk handling approach [7].

The SLIVER cell arrays so formed can be fixed to the supporting medium to form Rafts, or to adjacent SLIVER cells to form Sheets, using adhesive, electrically conductive adhesive or solder.

Similarly to Rafts, Sheet modular sub-assemblies comprise planar arrays of SLIVER cells, comparable in size to a conventional solar cell, but with the additional feature that a separate structural supporting medium is not essential for these contiguous arrays. The Sheet SLIVER cell arrays can be formed such that the electrically conductive medium also forms the structural support for the Sheet array.

The 2nd generation technology Rafts can be readily formed using an array of single-stack cassettes as shown in Figure 3, or, alternatively, a multi-stack cassette [7]. For example, 50 single-stack cassettes full of 100mm long SLIVER cells are placed side by side so that the top (or bottom) SLIVER cells in each cassette form a planar array of SLIVER cells with the required spacing, say on a 2mm pitch, so that 100 x 100mm Rafts are formed.

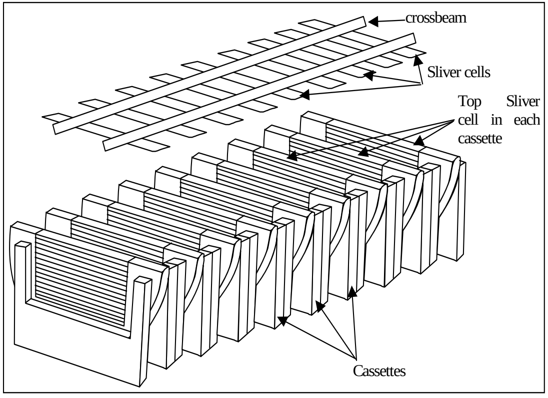

Figure 3. SLIVER Raft formation using an array of clamped, spaced, SLIVER cell cassettes.

A pair of pre-metallised crossbeams, 104mm long, is adhered to the top (or bottom) SLIVER cell of each cassette and the secured planar array is then withdrawn, with the 50 SLIVER cells arranged and secured in a Raft format. Alternatively, a vacuum device and clamp arrangement can be substituted for the adhesive-based separation process, with solder subsequently forming the electrical interconnections as well as establishing the physical structure of the Raft.

A low-cost solder process has been devised to electrically interconnect each of the 50 SLIVER cells to the intermittent metal tracks on each crossbeam, and via the intermittent tracks to adjacent cell electrodes, thus forming a functional, series-connected string of 50 SLIVER cells in a 100 x 100mm Raft. The process is repeated several thousand times until the SLIVER cells in the cassettes are exhausted, creating Rafts with a rating of several kW.

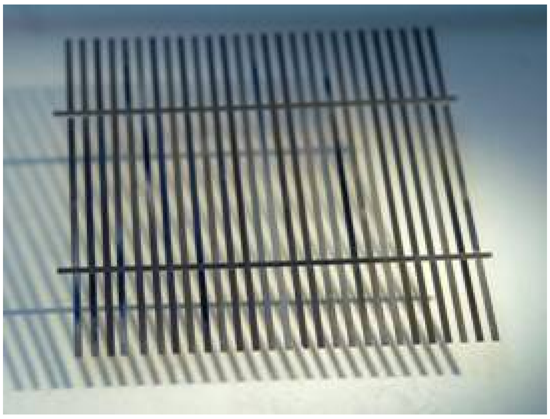

Figure 4. A Raft sub-module, consisting of an array of SLIVER cells interconnected by two thin, narrow supports; it can be handled and encapsulated in the same manner as a conventional solar cell.

SLIVER "Sheets", a high-efficiency modular sub-assembly structure, constitutes SLIVER solar cells abutting adjacent cells, providing a sub-assembly with 100% cell area cover. A Sheet sub-module can be thought of as a high-efficiency SLIVER cell analogue of a conventional solar cell.

In both the Rafts and Sheets implementations, the modular sub-assembly produces a high voltage – up to 60V or more, and a correspondingly low current, typically of the order of a few tens of milli-amps.

3.4 SLIVER sub-module electrical interconnections

Having successfully devised a high-throughput low-cost, reliable assembly method the remaining task is to rapidly and reliably form a large number of electrical interconnections within the Raft or Sheet sub-assembly.

For large-scale manufacturing applications, it is preferable to reduce the number of steps in the process of forming an electrical connection, as well as reducing the number of required iterations applied for that process. Having decided to use only conventional PV module materials in 2nd generation modules, the second of these two considerations makes dispensing unattractive, whilst the first makes stenciling or dispensing and subsequent solder reflow unattractive.

A selective wave solder process has been developed to rapidly and reliably form low-cost sub-module electrical interconnections. The selective wave solder process is a single-step, in-line modular approach that requires no materials measuring, no accurate registration of components, and no dispensing, cleaning, or waste disposal. Eliminating any handling and materials requirements assists with reducing costs.

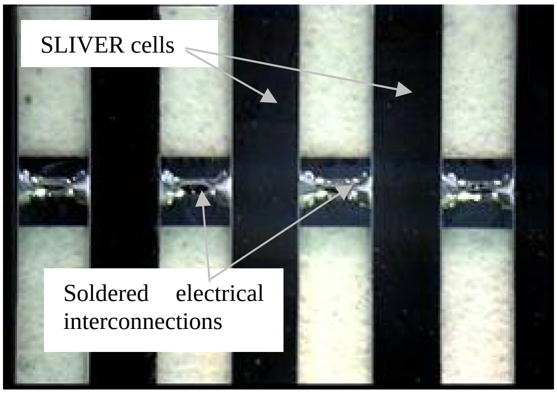

Figure 5. Detailed view of a selective wave-soldered SLIVER Raft, formed using a multi-stack cassette.

The selective wave solder process uses low-cost equipment and there is no material wastage. Further, throughput can be increased, up to a factor of four, with a very low-cost modification involving the simple incorporation of additional solder fountains. Because the solder quantity and location applied with this method is "automatically" controlled by the process, there is no additional complexity such as registration and control, or machine vision requirements as may be the case where additional dispense heads are attached to a dispense gantry to increase throughput for alternative methods of establishing electrical interconnections.

A detailed plan view of a section of a selective wave soldered Raft is shown in Figure 5. The location of the solder joint is determined by the metallisation on the Raft cross beam. The quantity and distribution of the solder can be controlled by the shape of the metallisation and the solder process parameters such as speed, temperature, and fountain-workpiece separation. Because the thermal mass of the Raft assembly is very small, the selective wave solder process can be very rapid.

Prototype soldering, with reliable electrical interconnections, has been demonstrated at speeds up to 400 mm/sec, establishing electrical connections at this transport speed. This compares quite favourably with perhaps 5 to 10 electrical connections per second

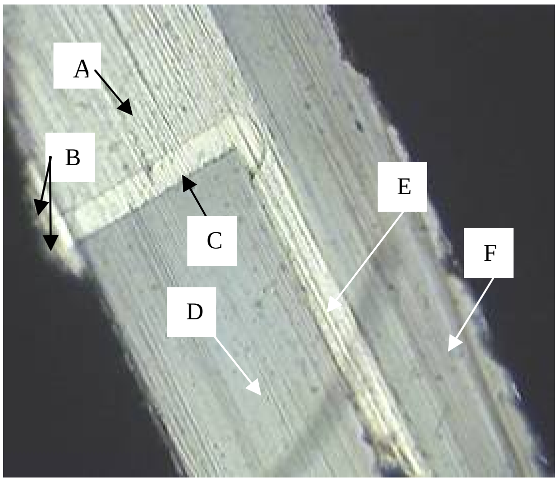

Figure 6. Detail of a cross-section through a cross beam support of an SLIVER Raft sub-module.

achieved with expensive, high-speed dispensing. The use of solder to establish electrical connections as well as to maintain the physical sub-assembly structure is an important feature of this process.

Figure 6 shows a detailed view of a cross section through a selective wave-soldered Raft cross-beam support. Label ‘A’ shows the solder joint, with the solder wetting the silver SLIVER electrode, ‘C’, and beading in the region ‘B’ to provide extra strength to the joint. The SLIVER electrode ‘C’ shows no structural damage from the solder process; either by dissolving in the solder, electrode delamination from stress in the solder joint, or warping of the structure. The solder, ‘E’, shows very good wetting of the metallisation, wicking under the SLIVER cell along the metallisation that extends slightly under the cell along the cross-beam ‘F’. The electrode material on this batch of SLIVER cells was silver.

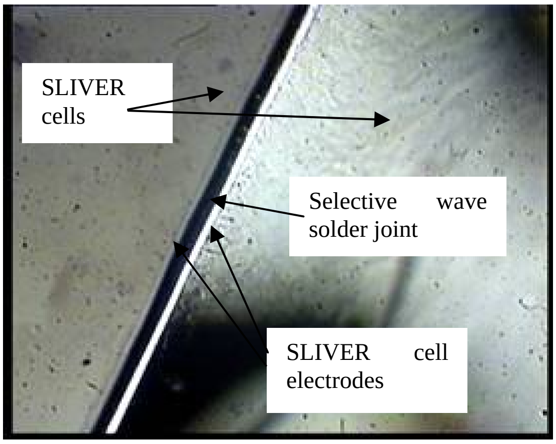

Figure 7. Detail of a selective wave-soldered joint of a SLIVER Sheet sub-module.

A selective wave solder process is also ideal for establishing electrical interconnections in high-efficiency Sheet sub-modules. A detailed image of such a selective wave soldered joint is shown in Figure 7. The width of the solder joint is such that it imposes no appreciable shading, or reduction in SLIVER cell coverage to the Sheet surface ratio, thereby substantially maintaining one of the valuable attributes of SLIVER cells, namely, no electrode shading of the cell surface..

The Raft and Sheet SLIVER sub-modules described above can be flexible or rigid, semi-transparent or full-cover high-efficiency, and bifacial or mono-facial. They form the versatile building blocks for a very broad range of PV modules ranging from large-scale solar power modules suitable for solar farms to micro-modules for powering portable electronic devices; building-integrated PV to remote power supply, bifacial PV noise barriers to flexible and rollable portable PV power supplies. The list also extends to concentrator PV applications.

4 SLIVER MODULES

The Raft and Sheet sub-module approach avoids the placing of SLIVER cells one by one into a solar power module. Sub-modules can be formed in sizes similar to conventional solar cells, typically 10x10 to 12x12 cm^2. Each sub-module can be incorporated as a conventional solar cell analogue in a SLIVER module, allowing techniques similar to those used for conventional solar cells and modules to be adapted for testing, binning, handling, assembling, electrically connecting and encapsulating SLIVER solar cells. The appropriate number of sub-modules can be deployed to form a SLIVER module with any desired shape, area, current and voltage characteristics, and associated output power. An example of a SLIVER module constructed using Raft sub-modules in shown in Figure 8.

A very important advantage of the Raft sub-module approach is that solar power modules constructed using SLIVER sub-modules can be manufactured using entirely conventional PV module materials - the SLIVER cells, solder and conventional bus-bars, EVA and glass.

Figure 8. A SLIVER module constructed using Raft sub-modules.

Measurement of the efficiency of a large number of individual small SLIVER solar cells is both inconvenient and expensive. However, the characteristics of sub-modules can be directly measured, thus effectively allowing dozens to hundreds of small solar cells to be efficiently measured in a single operation and binned according to performance.

Sub-modules will have a large voltage and a correspondingly small current, if the constituent SLIVER cells are connected in series. For example, a 12x12 cm^2 sub-module composed of sixty 1mm wide, series-connected SLIVER cells with a gap between each cell of 1mm will have a V_{oc} and J_{sc} of about 40 volts and 70mA respectively after encapsulation, and including a Lambertian rear reflector for the module. This compares very favourably with typical figures of 0.63V and 5A respectively for a conventional solar cell of similar area.

SLIVER Raft and Sheet modules can be constructed to provide high voltage outputs. For example, the module shown in Figure 8 has an output voltage of $45V_{mpp}$, with twelve 45V-strings connected in parallel. Alternatively, each string could be connected in series to provide a module output of 540V. Many other intermediate arrangements are readily implemented.

The SLIVER Raft and Sheet sub-modules can be connected primarily in series to further build voltage, allowing the voltage up-conversion stage of an inverter associated with the photovoltaic system to be eliminated. Alternatively, the sub-modules can be primarily connected in parallel. This parallel connection ability can greatly reduce the effect on module output of non-uniformities in illumination, arising for example from shadows cast by dirt on the module surface or from neighbouring buildings. This is in addition to the inherent shadow tolerance of the individual SLIVER cells arising from reverse conduction allowed by the adjacent placement of boron and phosphorus diffusions.

Advantage can be taken of the flexibility of Raft sub-modules fabricated using thin and flexible SLIVER solar cells and substrate supports to mount the sub-modules conformally onto a curved supporting structure. The sub-modules can optionally be made semi-transparent, to any selected degree, by selecting suitable spacing for the SLIVER cells. It is difficult to achieve such outcomes using conventional solar cells. The sub-module approach lends itself readily to the fabrication of flexible modules, such as the example in Figure 9.

Figure 9. A flexible SLIVER module constructed from flexible Raft sub-modules.

5. CONCLUSION

In this paper, and a companion paper [6] at this conference, we have demonstrated the broad framework for a complete 2nd Generation Technology. High-efficiency SLIVER cells can be reliably produced using a simplified cell fabrication process. These high quality SLIVER cells, using the 2nd Generation Rafts and Sheets process can:

- Cut the cost of SLIVER Technology handling and assembly equipment by an order of magnitude with respect to prior art processes;
- Increase SLIVER cell throughput by an order of magnitude with respect to prior art methods;
- Provide a dramatically simplified, robust, and reliable 2nd Generation Technology assembly and handling process, with commensurate increases in yield;
- Modularise the process-line operational flow for SLIVER cell separation, handling, and assembly processes – thus providing opportunities for easy line balancing, establishing buffered line input and output stages, eliminating critical line-blockage sites, and eliminating requirements for manual intervention;
- Form electrical connections at a rate at least two orders of magnitude faster than prior art methods, using a dramatically simplified process, with dramatically reduced cost per connection compared with prior art processes.

In addition to the potential for providing a source of cheap, high-efficiency, low-concentration concentrator solar cells, 2nd Generation Technology also provides a means of significantly reducing a range of serious performance-compromising difficulties associated with non-uniform illumination in concentrator systems when using conventional concentrator cells.

By using a smart configuration of SLIVER cells the requirement for by-pass diodes can be avoided. Similarly, reductions in receiver performance arising from partial shading of series-connected strings can also be avoided. A typical SLIVER concentrator sub-module, formed by a series-connected string of 50-100 SLIVER cells, occupies an area comparable to that of a conventional concentrator cell yet has a much lower current and much higher voltage output; up to as high as a conventional concentrator receiver, or even as high as system voltage, depending on design.

With each short, sub-module string of series-connected concentrator SLIVER cells connected in parallel, rather than in series as is generally the requirement for conventional cells in a linear concentrator receiver, the receiver output is no longer limited by the cell receiving the lowest illumination. A sub-module approach incorporating SLIVER cells in concentrator receivers introduces many significant advantages.

6. ACKNOWLEDGEMENTS

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SLIVER is a registered trademark of Origin Energy.

7. REFERENCES

[1] P. A. Iles and S. I. Soclof, Applied Solar Energy Corporation, City of Industry, Ca.91746, 'Silicon Solar Cells Formed by Orientation Dependent Slicing', Proceedings 15th IEEE Photovoltaic Specialist Conference, p.115-119, 1981.

[2] K.J. Weber and A.W. Blakers, "Semiconductor Processing", PCT/AU01/01546, 2001.

[3] A.W. Blakers, M.J. Stocks, K.J. Weber, V. Everett, J. Babaei, P. Verlinden, M. Kerr, M. Stuckings and P. Mackey, "SLIVER Solar Cells", *13th NREL workshop on Crystalline Si Materials and Processing*, Vail, Colorado, 2003.

[4] K.J. Weber, A.W. Blakers, M.J. Stocks, J. H. Babaei, V.A. Everett, A.J Neuendorf, and P.J. Verlinden, "A Novel Low Cost, High Efficiency Micromachined Silicon Solar Cell", Electron Device Letters 25, 37, 2004.

[5] K.J. Weber, A.W. Blakers, M.J. Stocks, J. H. Babaei, V.A. Everett, A.J Neuendorf, and P.J. Verlinden, "A Novel Low Cost, High Efficiency Micromachined Silicon Solar Cell", *Electron Device Letters* 25, 37, 2004.

[6] E. Franklin, A. Blakers, V. Everett, and K. Weber, "A 20% Efficient SLIVER Solar Cell", , 22nd European Photovoltaic Solar Energy Conference, Milano, 2007.

[7] V. Everett and A.W. Blakers, "Solar cell (SLIVER) sub-module formation", Australian Provisional Patent 2004904478, PCT/AU2005/001193, WO 2006/015430 (2004)

[8] V. Everett and A.W. Blakers, 2005, "Solar Cell

Interconnection Process", Australian Provisional Patent 2005903172, PCT/AU2006/000840, WO2006133507.

[9] K.J. Weber, A.W. Blakers, V. Everett and E. Franklin, "Results of a Cost Model for SLIVER Cells", 21st EC Photovoltaic Solar Energy Conference, Dresden, September 2006.

[10] P. Wong, R. Abnoos, V. Everett, and M. Kerr, "Separating and Assembling Semiconductor Strips." Australian Provisional Application No. 2003902270, PCT/AU2004/000594, WO2004100252.

[11] M. Kerr and P. Verlinden, "Modular sub-assembly of semiconductor strips", WO 2006/079174 A1 (2005).