Tandem PV Micro Concentrator

Project results and lessons learnt

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Executive Summary

The project aims to produce a commercially competitive micro concentrator tandem solar module with over 30% efficiency.

The best commercial and laboratory silicon-only solar cells have efficiencies in the range 23-26%. In order to reach efficiencies of 30% and beyond, tandem solar cells comprising of two or more different materials must be used. Silicon (Si) is often used as the rear cell in tandem devices along with a higher bandgap top cell.

III-IV materials such as gallium arsenide (GaAs) are promising candidates as high bandgap top cell due to the excellent efficiency and stability of the material. However, these materials are expensive. In order to develop a commercially competitive GaAs/Si tandem solar cell system, the cost of the GaAs component must be reduced. This project aims to achieve this by using the ANU developed Sliver technique for creating GaAs solar cells, in conjunction with a micro concentrator system.

Individual measurements of the GaAs solar cells under concentrated light, combined with simulated performance measurements of the underlying silicon cell, indicate a tandem efficiency ≥ 30% can be achieved using this system.

Initial measurements of a complete, integrated concentrator/GaAs/Si device have been completed, demonstrating that the components can all function together effectively. Further improvements in the devices in areas such as anti-reflection coatings and bonding materials are ongoing.

The creation of narrow grooves into the GaAs wafer (an integral part of the Sliver process) has been achieved using dicing. Other methods have been tested and ICP/RIE etching identified as a likely candidate for further improving the pitch and quality of the groove etching. The production of narrow GaAs grooves and the demonstration of a fully functioning tandem micro concentrator device are important steps towards achieving the final goal of a producing an efficient, commercially viable tandem PV micro concentrator.

Project Overview

Project summary

The project aims to produce a commercially viable tandem photovoltaic (PV) micro concentrator. The micro concentrator component was designed and developed as part of the ARENA-funded MUSIC project (ended 2017). The current project is aimed at development of the GaAs solar cell component as well as producing an integrated tandem cell/concentrator package. We have demonstrated the operation of the concentrator and tandem cells as an integrated package and the creation of narrow grooves through the GaAs wafer.

Project scope

The project was designed to develop a solar cell module with high efficiency (>30%) and reliability while keeping material cost to a minimum. Currently, the world's highest efficiency solar cells are made of expensive III-IV materials in tandem or multi-junction arrangements.

In order to reduce the materials cost, the project aims to utilise the Sliver technique (developed at ANU for silicon solar cells) and apply it to GaAs. The Sliver technique will allow for GaAs wafers to be processed in a way that increases the surface area per wafer which is available for light collection. This, in conjunction with the concentration of sunlight, will reduce the total amount of GaAs material required for the tandem device.

The other novel feature of the device is having a large-area silicon cell on the rear. This will allow the Si to receive direct light which passes through the micro concentrator and GaAs cell, as well as collecting diffuse sunlight. The device is designed to be mounted on standard 1-axis PV trackers that are used in most ground-mounted PV power stations.

Outcomes

Significant outcomes of the project to date are:

1. Production of narrow (<50 µm-wide) grooves through a GaAs wafer using dicing
2. Production of 23 µm-wide grooves in GaAs to a depth of 100 µm using Inductively Coupled Plasma/Reactive Ion Etching (ICP/RIE)
3. Demonstration of operation of the integrated Tandem PV micro concentrator package
4. Measured GaAs cell efficiencies of over 25%

Outcomes 1 and 2 indicate the feasibility of a GaAs Sliver system, with the formation of narrow, deep grooves being the starting point for this process.

Outcome 3 is significant as this is the first time the whole system has been measured as a functioning, integrated package rather than as separate parts.

Outcome 4 demonstrates the high efficiency of the GaAs material and performance under concentration. Cell improvements will continue to be made in future work to further improve this efficiency.

Transferability

The tandem PV micro concentrator was carefully designed to be compatible with existing PV tracking systems. The majority of new installed ground-based PV employs 1-axis tracking and the tandem PV micro concentrator can be directly used in these systems.

Tandem solar cells are currently widely studied as they are the pathway to higher efficiencies. Many projects are investigating the potential of perovskite/Si tandems as well as III-IV/Si systems both at ANU and worldwide. There is potential for some technology transfer between these projects, particularly in areas unrelated specifically to the concentrator or Sliver components i.e. bonding, mounting, and connectors.

The etching of the GaAs Slivers may also find applications in other areas of GaAs technology, for example in the formation of through-vias or diffraction gratings.

Conclusion and next steps

The project has the potential to benefit the Australian energy system through the introduction of a novel, high efficiency solar cell system. The system is designed to be easily integrated into existing 1-axis tracking system for simple large-scale deployment.

The second half of the project will involve the fabrication of GaAs solar cells using the Sliver process, as well as further refining of the Sliver etching methods. Improvements in GaAs cell design will be implemented to further improve the efficiency of the integrated tandem package.

Accelerated lifetime testing will be conducted to test the durability of the system.

If the next stage of the project is successful, a prototype cost-competitive tandem micro concentrator system will be developed and be ready for the next stage of commercialisation.

Lessons Learnt

Lessons Learnt Report: GaAs Sliver grooves

Project Name: *Tandem PV Micro Concentrator*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT

Key learning

Grooves in GaAs wafers with a width of <50 µm could be produced by dicing the GaAs wafers with a narrow (27 µm) blade (Figure 1). However, there was some chipping on both surfaces and tapering of the groove as well as roughness on the Sliver sidewall to contend with. Adjusting parameters such as spindle speed and dicing cut rate reduced the amount of taper, although the chipping was still significant. A post-dicing acid etch was demonstrated to decrease the roughness of the sidewall surface. The minimum pitch (groove + GaAs Sliver) which could be produced was 150 µm.

In order to reduce the groove width and pitch, ICP/RIE was investigated as an etching method. Using SiO_2 *as an etch mask, grooves up to 100 µm deep have been etched in a GaAs wafer with a groove width of 23 µm (Figure 2). Ultimately, grooves of 250 µm depth will be required. The initial results suggest that the mask durability of the* SiO_2 *will be suitable for this process and that grooves with the required width and depth can be obtained using the ICP/RIE method.*

Implications for future projects

The learning gained in this section will be directly applied through the second half of the project. The ICP/RIE etching method demonstrates very good potential to meet the requirements for this project and will be further investigated as the means to create GaAs Sliver grooves.

Knowledge gap

Using ICP/RIE etching to etch through an entire GaAs wafer has yet to be demonstrated. Due to the effect of RIE-lag, this will most likely require etching from both sides of the wafer, something that is yet to be tested.
The quality of the groove sidewall has not been extensively investigated. Parameters such as surface roughness should be measured and etching parameters tested to indicate what treatment is necessary to produce a surface smooth enough for the subsequent processing steps.

Background

Objectives or project requirements

The objectives of this section of the project were to develop a method to create Sliver grooves in a GaAs wafer with a groove width of <50 µm. Ideally, the method will produce a minimum amount of damage to all surfaces.

Process undertaken

Dicing: *Experiments were conducted using a dicing saw with a 27 µm-wide blade. Parameters such as spindle speed and cut speed were varied in order to obtain the narrowest possible grooves with minimal tapering and chipping. The grooves in Figure 1 were diced with spindle speeds of 3000 rpm and a cut speed of 0.1 mm/s.*

ICP/RIE: *Etching of grooves was conducted using a 10 µm-thick SiO_2 mask. An example of grooves etched using ICP/RIE is shown in Figure 2. The etch of highly vertical grooves demonstrates good selectivity for the GaAs over the masking material. This is a promising method for the creation of narrow, high quality Sliver grooves in the wafers.*

Supporting information

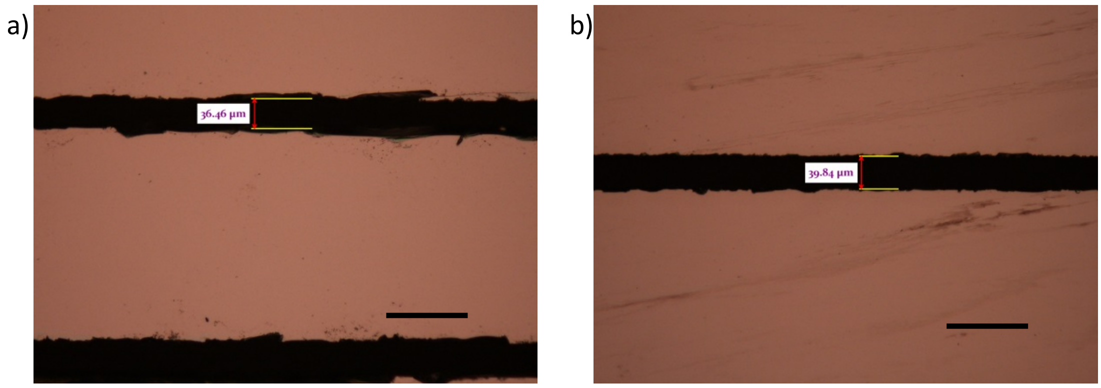

Figure 1. *Grooves diced in GaAs using a 27 µm-thick blade through a 650 µm-thick wafer mounted on dicing tape; a) top side and b) rear side of wafer. Scale bar is 100 µm. Grooves are < 40 µm wide.*

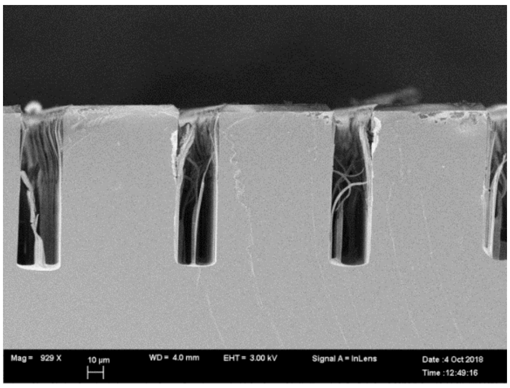

Figure 2. *Grooves etched using ICP/RIE in GaAs. Grooves are 100 µm deep and 23 µm wide. Scale bar is 10 µm.*

Lessons Learnt Report: Functioning integrated Tandem PV Micro Concentrator Module

Project Name: *Tandem PV Micro Concentrator*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT

Key learning

The tandem PV micro concentrator was demonstrated to function effectively as a fully integrated package. All components (micro concentrator, GaAs cell and Si cell) were bonded together and encapsulated in a weather proof box for measurement and testing.

Implications for future projects

Fabrication aspects of the cell and module designs were identified as sub-optimal which can be addressed in future stages of the project to improve the efficiency of the module. Specifically, the antireflection coatings can be optimised for better performance in the concentrator module, the application of silicone gel for bonding with the GaAs cell can be improved to minimise the amount used and the type of silicone gel can be changed to one with a higher refractive index for better optical coupling.

Knowledge gap

Some knowledge gaps have been identified, to be addressed in future stages of the project. The optimum antireflection coating thicknesses for samples bonded to the concentrator need to be identified, as do improved methods for application of the silicone bonding gel.

Background

Objectives or project requirements

The objective of this stage of the project was to demonstrate that all of the components of the tandem PV micro concentrator can function together effectively, as previous results have only considered the components individually.

Process undertaken

The module components (glass, concentrator lens, solar cells) were bonded together using silicone gel, encapsulant and epoxy. Electrical connections were made to the solar cells. The components were then housed in a weatherproof box for indoor and outdoor measurements.

Supporting information

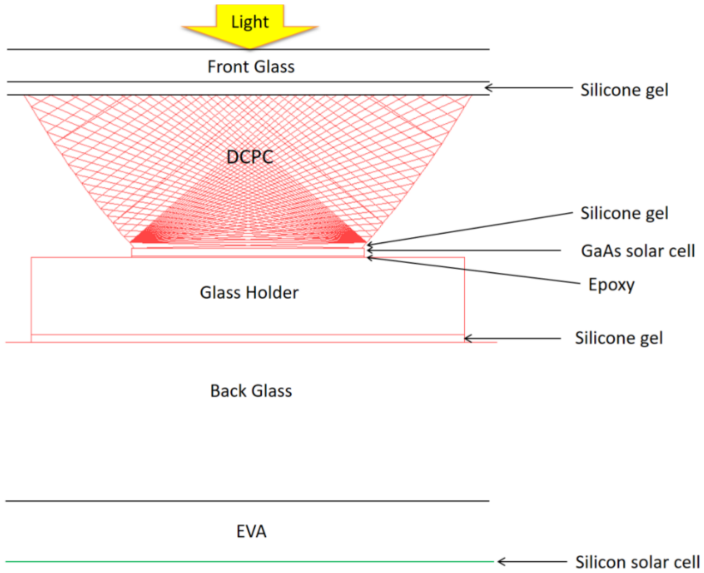

Figure 4*. Front schematic view of the tandem micro concentrator including the bonding materials (silicone gel, epoxy, EVA) (figure not to scale).*