

# Solar Energy Research at the Australian National University

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## *Abstract*

*This paper provides an overview of the Centre for Sustainable Energy Systems at the Australian National University. The Centre is a large, externally funded, commercially focussed research group working in the areas of photovoltaics and solar thermal energy.*

## **1. INTRODUCTION**

The Centre for Sustainable Energy Systems (CSES) is part of the Faculty of Engineering and Information Technology at the Australian National University (ANU). The Centre was established in 1997, and amalgamated pre-existing activities in photovoltaics and solar thermal energy. The Centre currently has 33 staff and 8 PhD students and an annual turnover of about \$2.5 million. About 80% of its income is for commercial projects, the balance being support from ANU and ARC grants.

CSES is one of the largest research groups in the area of sustainable energy technology in Australia. There is considerable synergy between the various projects, which gives CSES the capacity to undertake the development of complete solar energy systems. This paper describes work underway at CSES. Current research nodes within CSES include the following:

- Epilift project
- Multicrystalline and SiN
- Concentrator systems and components
- Thermochemistry
- Phase change materials

More information, including publications and pictures, is available at our website: <http://solar.anu.edu.au>

## **2. EPILIFT PROJECT**

About half the cost of a conventional photovoltaic module is the silicon wafers. Processing the wafers into solar cells, electrical interconnection & encapsulation constitutes the other half of the cost. Some groups and companies are developing non-silicon solar cells based on materials such as cadmium telluride, copper indium gallium selenide, amorphous silicon and titanium dioxide. However, crystal silicon has many advantages, including non-toxicity, abundance, high and stable solar cell performance, market dominance (90%) and the ability to share research and infrastructure costs with the integrated circuit industry (which is also based on crystal silicon).

CSES invented a thin crystalline silicon solar cell technique called Epilift. In this process a thin layer of silicon (50 microns thick) is grown on a conventional silicon wafer. The grown layer is peeled off and converted into a solar cell, while the silicon wafer substrate undergoes many further growth and peel cycles. The cost of silicon ingot sawing is eliminated and the mass of silicon per solar module is reduced by a factor of 5 to 10.

Origin Energy made a major investment (~\$4 million) into Epilift technology. The research phase of this project is scheduled for completion in the middle of 2002. Over the next year Origin Energy will make a decision about commercialisation of the technology. Recently Origin Energy was awarded \$1 million by the Australian Greenhouse Office (RECP6) towards the cost of building a pilot plant.

### 3. MULTICRYSTALLINE SILICON MATERIALS & SOLAR CELLS DEVICES

#### 3.1. Improved multicrystalline silicon material and solar cells

Even though it is already used to make more than half the commercial solar cells in the world due to its lower cost, multi-crystalline silicon was believed to be of an inferior quality. However, this is not necessarily the case. Thanks to special quality improvement treatments, the material has reached a superior electronic quality to single crystal silicon conventionally used to make solar cells. Advanced device designs and fabrication technologies have been applied to this improved material and resulted in laboratory solar cells with a conversion efficiency of approximately 18%, much higher than the 13% efficiency of present commercial cells. These material and device improvements will have immediate benefits to reduce the cost of solar cells and accelerate their mass production and usage.

#### 3.2. Application of Plasma Silicon Nitride to Multicrystalline Silicon Solar Cells

Remarkable progress has occurred in the last three years in the area of surface passivation of silicon surfaces by PECVD (plasma enhanced, chemical vapour deposited) silicon nitride. Highlights of our work include: very low surface recombination velocities on the p-type base region of silicon solar cells; excellent passivation of the n<sup>+</sup>-emitter regions of solar cells; and advanced device structures with an all-SiN passivation showing record open-circuit voltages of 665 mV for single crystal and 655 mV for multicrystalline silicon.

We are closely cooperating with BP Solar in Sydney to transfer these developments to the commercial production of multicrystalline solar cells. The two projects, funded by the Energy Corporation of NSW and the Australian Greenhouse Office, will be completed in 2001.

#### 3.3. Advanced Physics and Characterisation of Silicon Materials and Devices

A new class of characterisation techniques based on *quasi-steady state* conditions, in particular the determination of the lifetime of minority carriers from measurements of the photoconductance (QssPC), first proposed in 1995 by Sinton and Cuevas, is making a significant impact in the field of semiconductor physics and technology. Intense activity at the ANU has demonstrated the enormous potential of the new technique for fundamental and applied research. The combination of the QssPC technique and the associated theoretical analysis constitutes what we call *Injection level Dependent Lifetime Spectroscopy (IDLS)*, which is ideally suited to study the fundamental properties of recombination centres frequently found in the volume of silicon wafers, such as boron-oxygen pairs in CZ silicon and iron-boron centres in mc-Si.

Additional techniques also developed at the ANU are: a) the quasi-steady state open-circuit voltage ( $QssV_{oc}$ ), proposed in 1999 by Sinton and Cuevas to measure the current-voltage characteristic curves of solar cells; b) the spectral photoconductance ( $QssPC-\lambda$ ), which gives the spectral response in a contactless manner; c) the qss junction capacitance ( $QssC_j$ ) to determine the background dopant density.

### 4. PHOTOVOLTAIC CONCENTRATOR SYSTEMS

Over the last five years CSES has developed a range of parabolic trough solar concentrator designs fitted with photovoltaic collectors. CSES has identified suitable components that are available off-the-shelf. In addition, CSES has systematically developed a range of component technologies where existing components are not ideal, including solar cells, receivers, mirrors and controllers.

#### 4.1. PV/Trough System

A photovoltaic/trough concentrator system for the production of electricity in remote areas has been developed in conjunction with Solahart. The system is based on sun-tracking glass mirrors that reflect light onto a receiver lined with solar cells. The solar cells are illuminated with approximately 25 times normal solar concentration, and convert about 20% of the sunlight into electricity. The balance of the solar energy is converted into heat,

which is removed via a finned aluminium heat exchanger. A 160 m<sup>2</sup> demonstration system was constructed at the Rockingham campus of Murdoch University in Perth in 2000. Suitable markets exist in remote areas in Australia, in competition with diesel electric systems.

## 4.2. Combined Heat and Power Solar Concentrator System (CHAPS)

A solar concentrator system suitable for the generation of both electricity and hot water in urban regions is being developed. It has many features in common with the PV/trough system described above. The system is called the Combined Heat and Power Solar (CHAPS) concentrator system. The system is based on sun-tracking glass mirrors that reflect light onto a receiver lined with solar cells. The solar cells are illuminated with approximately 25 times normal solar concentration, and convert about 20% of the sunlight into electricity. The balance of the solar energy is converted into heat, which is removed by water flowing in a channel behind the solar cells. The resulting hot water is collected for use in the building on which the system is mounted. Suitable markets include light industrial enterprises such as hospitals, shopping centres and food processing plants, as well as houses. The electrical and thermal efficiency of the system approaches 70%, which is far higher than conventional PV or solar hot water systems.

Recently ANU and Solahart were awarded \$1 million by the Australian Greenhouse Office (RECP6) to assist with the construction of a CHAPS system on the roof of Burton and Garran Colleges of residence at ANU. This will allow demonstration of technology developed by CSES, and will complement the Rockingham PV/Trough plant. The system will be constructed during 2002.

Construction of the demonstration system will require mechanical, electrical and solar cell skills available within the concentrator group in CSES, including solar cells, solar receivers, solar controllers and advanced mirrors (described below). Solahart contributes hot water storage systems, plumbing systems and market experience.

## 4.3. High performance solar cells and solar receivers

High-performance silicon solar cells for concentrator systems in the range 10-60 suns are being manufactured. An elegant process sequence allows high efficiencies (20-24%) to be obtained at moderate cost. Several thousand cells were fabricated for the 20 kW demonstration photovoltaic/trough concentrator system at Rockingham in Perth. Facilities have been developed that allow the manufacture of significant quantities of concentrator solar cells.

Concentrator receivers for use with parabolic trough concentrator systems have been developed. One version has a lightweight, high-performance, patented, aluminium-fin heatsink. Another version has water-cooling. The receivers feature thermal cycling stress relief, bypass diodes, high-quality encapsulation and high-performance silicon concentrator solar cells.

## 4.4. Solar Controller

A microprocessor-based controller is being developed with sponsorship from the Australian CRC for Renewable Energy to allow advanced strategic control of solar energy systems. This usually means maximising the solar energy collection while minimising running costs.

Initially developed for the CHAPS platform, the controller has general application to domestic and commercial hot water systems. Indeed, it can be retro-fitted to existing systems. The controller takes care of solar tracking for sunlight concentrating systems, operation of the hot water tank heater, the thermostat and the heat collection device. Importantly, the device has the ability to learn and adapt to its environment. The controller algorithms are supported by extensive modelling.

## 4.5. Glass Mirrors

Mirrors using Glass-On-Metal-Laminate (GOML) technology have been developed that form the optical elements of several reflective solar concentrators designs being produced in the CSES. These mirror elements use large sheets of 1mm, back-silvered 'white' glass, having 94% reflectivity and 96% shape accuracy. Two fundamental reflector types have been pursued:

- Two-dimensionally curved, cylindrical trough concentrators that reflect solar radiation to a line focus for use with linear photovoltaic concentrator receivers. The troughs use a straight forward GOML structure, flexed into the required parabolic shape.
- Three-dimensionally curved, spherical panels for use with point focus, large-area dish solar concentrators. These panels utilise a sandwich structure, having GOML mirrors as the front skin, a simple metal sheet as a rear skin, and both skins bonded either side of a core-material. This structure shows high flexural rigidity, such that it is shape-preserving and self-supporting. It also shows high optical accuracy, low weight per unit area and offers low cost of production.

Both technologies have undergone several thousand hours of accelerated environmental testing at ANU and at BHP research laboratories at Port Kembla, and have shown high resistance to environmental degradation.

## 5. HIGH TEMPERATURE SOLAR THERMAL RESEARCH

The Australian National University has long experience with high temperature point-focus concentrator systems, dating back to the White Cliffs solar thermal power plant constructed in 1978.

### 5.1. Ammonia Based Thermochemical Storage of Solar Energy

Thermochemical energy storage systems allow solar energy to be stored with reduced thermal loss for recovery as needed. The Solar Thermal Group is working on a system based on the reversible dissociation of ammonia. Work includes experiments with a prototype system driven with a 20m<sup>2</sup> dish concentrator, catalyst development, exergy analysis and system studies. 1998/99 saw world-first operation of a solar driven closed loop using this reaction. This project was supported by the Australian CRC for Renewable Energy, the Australian Research Council and the Swiss Ministry of Energy. A grant has recently been received from the ACT government R&D fund to continue work with this experimental system and to work on scaling up to operate on the Big Dish, a 400 m<sup>2</sup> parabolic dish located at ANU.

### 5.2. Mirror Panels for Large Concentrators

One of the major items contributing to the capital cost of large solar concentrators is the mirror panels. The SG3 400m<sup>2</sup> dish prototype has hand-made panels that would be impractical and uneconomic for large production runs. This project is attempting to find an optimised design for the first generation of dish-based power plants which will consist of production runs of around 200 dishes. A project supported by the NSW Office of Energy has led to the design and production of prototypes. Plans to extend this to a small-scale pilot production that can be used to replace the SG3 mirror panels are underway. ACRE has given in principle support for a project in this area but funding has not yet been finalised

### 5.3. High Temperature Solar Thermal System Modelling

A key prerequisite for the performance optimisation of high temperature solar thermal systems is experimentally verified models. Work in this area follows two parallel lines of investigation; detailed steady state modeling of receivers and transient modeling of overall system performance. Transient modeling is being pursued using the TRNSYS package, while steady state receiver modeling is being undertaken with a program developed at ANU. This work has been supported by an ARC small grant and is the subject of work by PhD students.

## 6. PHASE CHANGE MATERIAL THERMAL STORAGE SYSTEMS

The ANU has been working on Phase Change Material (PCMs) for the past 12 years. PCMs are substances that absorb and release large amounts of heat by changing from solid to liquid (heat absorption) and liquid to solid (heat release) at a constant temperature.

There are a number of applications for this technology. An obvious one is the storage of heat obtained from solar

air heaters - these are very efficient generators of heat but have never gained widespread commercial success because of the absence of a suitable storage medium. This is in contrast to solar water heaters in which the energy can be stored in the water from day to night. We now have a range of PCMs with melt/freeze temperatures of 29.6°C, 43°C and 58°C – temperatures that are ideal for the storage of energy from solar air heaters. The Centre for Sustainable Energy Systems at the ANU, in conjunction with Origin Energy Pty Ltd, has been successful in obtaining a grant of \$600,000 from the Australian Greenhouse Office (RECP5) to further develop and commercialise this technology. It can be used for space heating for commercial, industrial and domestic applications, as well as other applications such as drying fruits and vegetables, fibreglass, timber and leather.

Our calculations show that if just 1% of the potential market for space heating and drying were to adopt this technology, there would be a reduction in greenhouse gas emissions in Australia of 1.25 million tonnes annually.

## 7. OTHER ACTIVITIES

A spin-off company called Sustainable Energy Systems Pty Ltd has been established for the purpose of commercializing aspects of our work. The company welcomes inquiries from potential investors (see the CSES website: <http://solar.anu.edu.au>).

In addition to research work, considerable effort is being devoted to renewable energy education. The Engineering Degree at ANU is a broad degree that provides a solid foundation for students to specialize in a variety of related areas in their later years, including Mechatronics, Photonics, Telecommunications, Materials, Electronics, Sustainable Energy Systems and Environmental Systems. The latter two specializations allow the student to acquire considerable knowledge of sustainable energy issues and systems while still having skills that would allow employment in many other areas of engineering. The presence of the Institute of Advanced Studies at ANU, with its large pool of prominent research scientists and engineers, is a major asset for engineering education at ANU.

## 8. ACKNOWLEDGMENTS

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Many people over many years have contributed to the skills and technologies available within CSES.