ARC Centre of Excellence for Solar Energy Systems

Report for the year 2006
CEO348198
5th March 2007

Establishment

The Centre was established late in 2003, and had initial funding until the end of 2007. Indicative funding from the ARC is $300,192 per year. Funding was first received from the ARC in November 2003. Following a review, funding has been extended until the end of 2008 and possibly until the end of 2010, depending upon a review in the 4th quarter of 2007.

The Centre is located in the Department of Engineering within the College of Engineering and Computer Science at the Australian National University. The ARC Centre works in collaboration with the Centre for Sustainable Energy Systems.

The Centre website is at http://solararc.anu.edu.au/

Personnel

Principal Researchers

Prof AW Blakers (RD)	Director
Dr VA Everett (CI)	Deputy Director
Dr E Franklin (CI)	Principal Researcher
Dr KJ Weber (CI)	Principal Researcher
Dr Sanju Deenapanray (CI)	Principal Researcher (resigned Q2 2006)

Chief Operating Officer and Centre Manager

Mr Ray Prowse

PhD Candidates

Dr E. Franklin: completed Q3 2006; PhD awarded Q1 2007

Mr David Barton: completion expected Q3 2007; social issues of sustainable technologies
Mr Jin Hao: completion expected Q3 2007; semiconductor processes
Ms Wendy Jellett: semiconductor processes
Ms Fiona Beck: commenced Q1 2007; semiconductor processes
Ngwe Soe Zin: will commence in Q2 2007
Zhang Chun: will commence in Q2 2007

Other people working in areas relevant to the Centre

Mr Bruce Condon – Electrical Engineer
Mr James Cotsell – Research Associate. Concentrator receivers
Ms Nina De Caritat – Research Assistant. Cell fabrication.
Mr Chris Holly – Laboratory Process Manager. Concentrator solar cells
Mr Neil Kaines – Laboratory Manager
Ms Josephine McKeon – Research Assistant. Cell fabrication.
Mr Sam McKeon – Laboratory Assistant
Ms Sonita Singh – Research Assistant. Cell fabrication
Mr John Smeltink – Engineer
Mr Kidane Belay – Research Assistant. Cell fabrication. Left Q4 2006.

Funding

Core funding for the Centre amounts to $430,000 per annum. Centre funding from the ARC is approximately $320,000 per annum, while the Australian National University provides a minimum of $80,000 per annum in co-funding.

Substantial additional funding to support centre activities is likely to become available in 2007. After a long period of low government support for renewable energy research in Australia, there is hope that substantial additional government support will be forthcoming.

ARC funding of the Centre has been crucial to preserving a substantial photovoltaic research capacity at the Australian National University through 4 difficult years. Members of the Centre are extremely grateful to the Australian Research Council for its support, and for the extension of support into 2008. We hope to demonstrate to the ARC in the Review due in Q4 2007 that we have a viable Centre, with bright prospects for the period out to 2010.

Substantial reorganisation and extension of Centre activities will occur if the funding listed below eventuates.

In November 2006 the Prime Minister announced funding from the AP6 (Asia-Pacific 6) program, including $1.6 million over three years to support the development of advanced concentrator receivers at ANU. Concentrator solar cells developed by the Centre will be used in these receivers. Our formal application is currently under review, and we hope that formal approval will be forthcoming in Q2 2007.

An application was made to the Defence CTD program for $2.7 million over three years to develop a range of micro photovoltaic modules for defence applications. Our application has progressed well, and we hope to be notified of a favourable decision in Q2 2007.

The University of Delaware (USA) is leading a consortium that aims to reach 55% concentrator solar cell efficiency by 2010. The technical goal is to create a highly efficient 6-cell tandem structure. One of the cells will be silicon, with 5 other semiconductors also being used. Funding of A$70 million has been provided, mostly by the US Defence Advanced Research Projects Agency (DARPA). We have been asked joined this consortium as a supplier of highly efficient and specialised silicon solar cells. There is a very good match between core activities of the Centre and the University of Delaware program. Funding of approximately A$460,000 over three years has been offered, and negotiations are currently underway.

The Government of Singapore, together with a Government owned company, is interested in the application of Sliver cells to unmanned aerial vehicles for purposes. Under discussion is an $80,000 feasibility study.

Relationship with

Centre Research

The focus of Centre research is the development of improved silicon concentrator solar cells for 10-50 sun linear concentrators.

Background

The worldwide solar energy industry is booming, driven primarily by growth in the international photovoltaic market. The size of the photovoltaic (PV) industry is doubling every 18 months, and is projected to reach $100 billion per year by 2011. The growth is driven largely by concern about the enhanced greenhouse effect.

Sliver technology has such promise for making a major impact upon the worldwide photovoltaic industry that it has become the focus of Centre research activities. The application of Sliver technology to linear concentrator systems has large economic potential. The most significant outcome of Centre research to date is the development of high performance and low cost concentrator Sliver solar cells using a substantially simplified and more manufacturable process sequence. Conversion efficiencies above 20% have been achieved. Large improvements have been made in our understanding of the opportunities and limitations of Sliver technology.

Sliver Solar cells

Sliver technology is a disruptive technology within a well-established conventional photovoltaic (PV) industry. The Sliver solar cell concept was invented by Andrew Blakers and Klaus Weber of the Australian National University in 2000. The Sliver solar cell process uses standard materials and techniques in novel ways to create highly efficient, thin, single crystalline solar cells with sharply reduced cost.

Sliver cells optimised for 10-50 sun concentrator systems differ significantly from those for non-concentrator applications. Important differences include the need to handle output currents that are 10-50 times larger, the greater difficulty of handling reverse voltages and currents, a reduction in the relative importance of shunt and non-ideal recombination, the need to include provision for removing 10-50 times more heat from each cell and the need to design specialised cell mounting systems.

The important outcomes of Centre research in this area to date are encapsulated by the achievement of 20% Sliver cell efficiency while at the same time removing about 40% of the process steps. We are confident we will achieve Sliver cell efficiencies above 21%. These efficiencies are far above those of competing thin film PV technologies.

Modelling has been conducted to determine the limitations of concentrator sliver cells. A preferred, simplified sliver cell processing sequence has been designed and discussed in detail, along with some other suitable processing sequences. Detailed investigations into various details of sliver cell fabrication have been undertaken and explored. Drawing from the results of these investigations, numerous batches of sliver cells have been produced to demonstrate the value of the preferred sliver cell processing sequence, to highlight the high efficiency and low cost potential of sliver solar cells, to test the validity of cell modelling and to place practical bounds on concentrator sliver cell design and operation.

Sliver cells were modelled for a range of device parameters. Modelling outcomes suggest that Sliver cell thickness is mostly constrained by the light-trapping regime employed and by bulk lifetime. While it is preferable from a material utilisation point of view to produce cells that are as thin as possible, the amount of light absorbed by thin cells is dependent upon the quality of light-trapping. Because they are so thin and have collecting p-n junctions at both front and rear surfaces, sliver cells have very high internal quantum efficiencies.

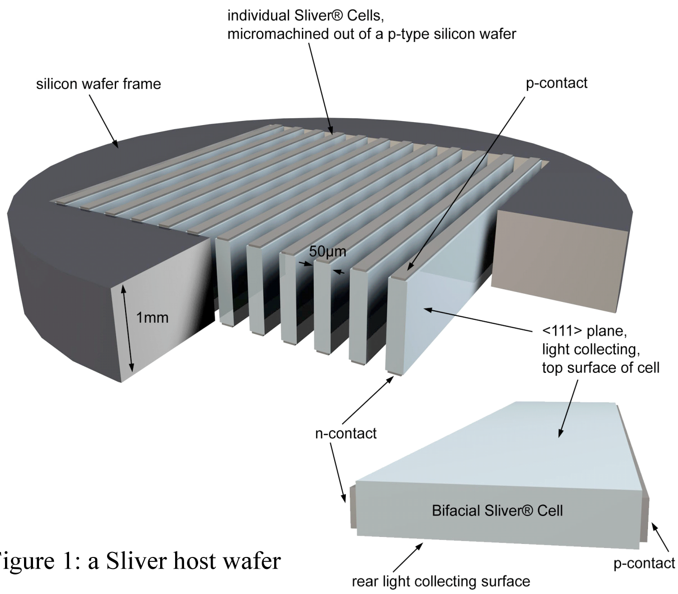

Figure 1: a Sliver host wafer

Excellent V_{OC} and IQE are maintained if minority carrier diffusion lengths in the bulk are similar to or greater than sliver thickness. Due to the large lateral current flow in the base region of sliver cells, bulk resistivity needs to be low to minimise resistance losses, but the bulk must be lightly enough doped to maintain acceptable bulk diffusion length. A substrate resistivity around 0.1 ohm.cm is a good compromise. Cell width, sidewall emitter sheet resistance and operating concentration ratio are all linked through series resistance losses.

Provided that bulk resistivity is chosen so that bulk resistance is minimised then the resistance loss in diffused emitters becomes the most significant extrinsic loss mechanism for sliver cells, particularly for operation at concentration. Resistance loss increases most significantly with the square of cell width. Sliver cells designed for operation at 10 – 50 suns benefit from relatively heavy emitter diffusions (around 50Ω/□) and should be narrow, typically between 500µm and 800µm wide. As sliver cells are bifacial, gains can be made by illuminating evenly on both sides of the cell, thereby reducing the series resistance loss from a single emitter illuminated from one side only.

Numerous methods for fabricating sliver cells have been explored. A simplified sliver processing sequence has been developed that uses 40% fewer steps than the original sliver processing sequence. Testing of cells produced using the simplified processing sequence frequently revealed the presence of non-ideal recombination with high ideality factor. The non-ideal recombination can be ascribed to a region of compensated silicon at the confluence of boron and sidewall phosphorus diffusions at sliver cell corners. The severity of the non-ideal recombination has been shown to be dependent upon relative doping levels of the two diffusions – being worse for heavier sidewall phosphorus diffusions and for lighter boron diffusions. Non-ideal recombination reduces fill-factor significantly, and can also lower open-circuit voltage.

Heavy and deep sidewall diffusions are desirable in terms of lowering series resistance loss in sliver cells. For deep emitters on conventional planar cells, sheet resistances as low as 50Ω/□ have been shown to have only minimal loss in emitter transparency. However, achieving heavy doping on sliver sidewalls necessitates the use of much heavier diffusions than normally called for on unpatterned, planar wafers. Sheet resistances measured on sliver sidewalls are typically 2 to 2.5 times higher than those measured on planar wafers from the same diffusion. While the measured dose profile across sliver sidewalls has been shown to be relatively uniform, it is probable that doping at sliver corners, corresponding to the boron diffused wafer surface, is at its highest. Therefore, heavy sidewall emitter diffusions result in heavy phosphorus cross-doping at boron doped sliver corners, thus enhancing non-ideal recombination.

A careful compromise is required to achieve sufficient doping without excessive non-ideal recombination. Formation of contacts on sliver cells is more difficult than for conventional cells, primarily owing to the fact that it is more difficult to open up contact areas on groove patterned wafers: photolithography, for example, cannot easily be used. Generally it is desirable to minimise the total contact area for solar cells, thereby reducing recombination losses under metal/silicon interfaces. A method has been devised to achieve this, which is undergoing patent protection.

Many batches of sliver cells were fabricated using the simplified fabrication process. Cells produced covered a range of cell dimensions and emitter sheet resistances, and were tested over a range of illumination intensities. Generally speaking, wafers that produced sliver cells with good performance also displayed excellent consistency and very high yield. Measured one-sun open-circuit voltages, for 1mm wide cells produced using the simplified processing sequence, were typically between 660mV and 670mV. Fill-factors of around 0.81 or 0.82 were normally realised, provided that emitter doping was not so heavy as to cause non-ideal recombination and not so light as to result in series resistance losses.

Median values for 10 cells	**V_{oc} (mV)**	**J_{sc} (mA/cm^2)**	**FF**	**Eff**
0.5 suns polished	651	17.0	0.79	17.5%
1 sun polished	**669**	**33.9**	**0.76**	**17.4%**
2 suns polished	687	67.7	0.70	16.5%
StdDev -1sun polished	1.5	0.28	0.006	0.2%
1 sun textured	**672**	**38.0**	**0.79**	**20.2%**

Measured IV curves (ten randomly selected cells from one wafer) and summary data for a simplified process.

Efficiencies of greater than 18% were recorded for polished cells with oxide only ARC, with well over 19% measured for polished cells with SiN ARC. Improved light-trapping, via the addition of a simple white reflective coating to the rear surface of cells, resulted in measured efficiencies exceeding 20%. There is a clear path to laboratory cell efficiencies approaching 22%. Production cell efficiencies of 21% are clearly possible, given the care that can be afforded even in a production environment because of the large effective surface area contained in each wafer.

Conventional concentrator solar cells

About 3000 20cm^2 monocrystalline silicon concentrator cells (figure, right) have been fabricated to populate the receivers in the Bruce Hall CHAPS system. The cells were specifically designed for the system in 2002-2004. The design is a compromise between cost, performance and yield. Typical cell performance is around 20% at 25C and 30 suns illumination. This exercise yielded valuable experience and information with respect to statistical analysis of performance and yield. It was found that both performance and yield increased as the design was bedded down.

The cell metallisation technique was refined, and a patent application was lodged. These contacts are capable of being formed simply and reliably. They exhibit high adhesion, tolerance of temperatures up to 800 ºC, low contact resistance required for concentrator applications and low surface recombination rates required for high conversion efficiency. The cell metallisation technique has been adapted for both laboratory and commercial production of Sliver solar cells. Many of the high efficiency cell process techniques developed for these concentrator cells were also carried over into Sliver cell technology, and are being used by Origin Energy.

Upgraded commercial one-sun solar cells for concentrator applications

We have devised a method to upgrade solar cells designed for non-concentrator applications so that they produce conversion efficiencies above 17% in the concentration range 10-30 suns. The importance of this work is that these cells come from production lines that process tens of millions of wafers each year, and have low cost per cm^2 compared with specialist concentrator solar cells. The technique appears to be eminently manufacturable and probably patentable. Importantly, high-voltage low current modules are a natural outcome of the work. This confers substantial shadow tolerance because the submodules can be connected in parallel rather than in series. It may be possible to retrofit thermal linear concentrator systems (in which little attention has been paid to minimising shadows cast by structural elements). We have won an ARC Linkage grant with Solar Heat and Power to develop PV receivers based on these cells for application in concentrator systems developed by ANU, SHP and other companies.

Photovoltaic Trough Concentrating Systems

The solar cells under development within the Centre are designed for linear concentrators that produce a solar intensity at their focal line of 10-40 times normal solar intensity.

Combining solar PV and thermal elements to form a hybrid system improves the cost effectiveness of solar conversion. Combined electrical and thermal efficiencies of up to 70% have been achieved in Combined Heat and Power Solar (CHAPS) systems designed and built at ANU. The cells are mounted on an extruded aluminium receiver “looking down” at the mirrors. About 20% of the radiation incident on the solar cells is converted into electricity, with the balance becoming heat. Water is circulated behind the solar cells in order to extract the heat.

A 160m^2 air-cooled two-axis tracking system was constructed in Perth. Water-cooled single-axis tracking 30m^2 and 300m^2 demonstration CHAPS systems have been constructed at ANU on the roofs of the Fenner Building and Bruce Hall (a college of residence) respectively. A low-profile linear microconcentrator is under development for deployment on house roofs. This system is a scaled down version of the CHAPS system, and will take advantage of the unusual shape and characteristics of Sliver solar cells.

Energy & environment

Two long-term projects are being undertaken. The first is a PhD study by David Barton, looking for the social and technical reasons for the poor uptake of renewable energy technology on Australian islands such as Norfolk and Lord Howe. Extensive surveys of technical options and resident's views have been carried on both islands and are currently being analysed.

The second is to devise ways to improve the uptake of retrofitting of insulation, solar water heaters and other energy-saving measures to reduce greenhouse gas emissions from domestic dwellings. A proposal called "solarisation" has been devised and widely promulgated in Canberra (and elsewhere by others).

Luminescent concentrator systems

Work is being conducted on incorporating Sliver cells into luminescent solar concentrators. Luminescent solar concentrators are thin sheets of plastic (1-2mm thick with an area of ~1000cm^2) impregnated with dyes that absorb sunlight and re-emit in narrow wavelength bands. Total internal reflection conducts the emitted light to the edges of the plastic sheets. Sliver cells are ideal for the conversion of this light to electricity because they have high quantum efficiency at these wavelengths, they are long and thin and they are bifacial. They can be attached to the edges of the plastic sheets with relative ease.

Strategic Plan Including Future Goals and Objectives

Future goals and objectives

We are interested in both fundamental R&D and commercial R&D. The activities of the Centre are predominantly in areas that could be realistically commercialised in the 3-10 year time frame.

Centre researchers aim to achieve the following outcomes over 2007 and 2008.

1. Continue to be one of the top two solar research groups in Australia, and in the top 10 worldwide.
2. Continue the development of Sliver and other silicon solar cells for linear concentrators, and commercialise the technology, in conjunction with partners.
3. Extend the Sliver concept to non-silicon semiconductors, and extend the use of the silicon Sliver cells to concentration ranges above 100 suns, in order to make a major impact upon high concentration photovoltaic technologies.

A closely related goal is for Sliver technology to make a major impact upon world markets for non-concentrator solar cells relying upon the multiple advantages of Sliver technology over alternative PV technologies.

Financial stability

An important goal of the Centre is to be in a position to carry on our work following cessation of Centre funding.

One strategy for achieving this goal is to have a prominent national and international research profile through excellent research that will allow us to establish diversified income sources. Another is to obtain large royalty income streams from commercialisation of Centre research.

Activity plan for the next twelve months

Activities planned for 2007 include the following:

- Development of a streamlined cell process capable of reaching 21% efficiency but with reduced process complexity and cost.
- Further characterisation of Sliver solar cells, particularly for concentration where series rather than shunt resistance is the main parasitic loss.

Education and Training

Researchers associated with the Centre delivered lectures and tutorials in undergraduate courses ENGN 2224, ENGN 4519, ENGN 6519, ENGN 3213 and Phys 3053. Several final year Engineering students undertook Projects during 2005.

Industrial Interactions

Centre activities have close links with three commercial projects underway at ANU:

- Origin Energy is commercialising Sliver solar cell technology, which was developed by Blakers and Weber at ANU. Origin has constructed a pilot plant in Adelaide. Origin is likely to partner in 2007 and proceed to the construction of a full scale factory. An ARC Linkage grant (LP0347095) between ANU and Origin focusing on micromachining techniques for the formation of Sliver solar cells concluded in 2006.
- Success in the development of high-performance concentrator solar cells will assist the commercialisation of tracking parabolic trough solar concentrator systems developed at ANU. A 300m^2 demonstration system has been constructed on the roof of Bruce Hall College of Residence at ANU in conjunction with Rheem/Solahart.
- ANU and ActewAGL are developing a microconcentrator system that will supply electricity and hot water to domestic dwellings. This system will take advantage of solar cell technology developed in the Centre. The work is supported by an ARC Linkage grant (LP0454195).
- A new activity with Solar Heat & Power to develop efficient photovoltaic concentrator receivers utilising commercial non-concentrator solar cells is supported by Linkage grant LP0669751.

Other commercial interactions within related areas include BASF, Sunpower, Sierratherm, T3 and Wizard Power.

Awards, Prizes and Honours

The following honours and achievement were accorded to researchers in the Centre during 2006:

- Blakers & Weber, Australian Institute of Physics Alan Walsh Medal for services to industry (2006)
- Blakers, Weber & Everett, ACT Sustainable Cities 2006 Environmental Innovation Award
- Blakers, Weber & Everett, ACT Sustainable Cities 2006 Overall Award.
- Franklin, award of a PhD, with strong commendation from the reviewers

Advisory Board of the Centre

The Advisory Board met in April and November 2006, and has also had meetings in January and March 2007. Substantial interactions between Centre researchers and members of the Advisory Board continued throughout the year

The role of the Advisory Board is to provide strategic advice on the research focus of the Centre, to provide an independent perspective on Centre structure and operating principles, to provide advice on intellectual property and commercialisation management and to assist with external contacts, linkages and relationships as the opportunity arises.

The Board is playing a major role in resolution of issues relating to the relationship between the University, the Centre and Origin Energy.

Mr Ian Farrar – Chair of the Board

Ian Farrar has a distinguished career in senior management in CSIRO and the coal industry. He has a Bachelor of Commerce from ANU.

From 2002 until his retirement in 2005 he was Managing Director/CEO of Coal Services Pty Limited (CSPL), Coal Mines Insurance Pty Limited (CMI) and Mines Rescue Pty Limited, as well as Chairman of Coal Services Health and Safety Trust and Injury Prevention and Control Australia Limited.

From 1992-2002 he was Chairman/CEO of the Joint Coal Board, Coal Mines Insurance Pty Limited and the Joint Coal Board Health and Safety Trust

From 1964 to 1992 he held a range of senior management position within CSIRO, including General Manager (Corporate Resources) and Senior Principal Advisor (Special Projects).

Mr Drew Clarke

Drew Clarke commenced as Head of the Energy and Environment Division in the Australian Government Department of Industry, Tourism and Resources in April 2003. His previous position was Executive General Manager of AusIndustry, the Department's business assistance agency. Drew has worked in Australian Government science and business agencies for 25 years, including national and international representative roles. His professional background is in the spatial sciences.

The Energy and Environment Division comprises four Branches:

- Energy Futures: focussing on economic and policy research, energy data and forecasts, technology RD&D, fuel mix, and energy efficiency.
- National Energy Market: focussing on the policy, development and regulation of the wholesale, network and retail elements of the national electricity and gas market.
- International: focussing on Australia's interest in the International Energy Agency, APEC Energy Working Group, bilateral energy cooperation arrangements, energy security policy and energy security risk assessments.
- Environment: focussing on greenhouse policy, sustainable development, and development of the environment and renewable energy industries.

The Division provides the Secretariat for the Australian Ministerial Council on Energy, comprising Energy Ministers from the Commonwealth, State and Territory governments.

Professor Lawrence Cram

Professor Lawrence Cram is Deputy Vice-Chancellor (Research) at the Australian National University. His career spans more than 30 years of research in engineering, mathematics, astronomy, physics and computing. He has a track record of involvement in successful commercialization of research, through experience at CSIRO and the University of Sydney as well as the ANU. Professor Cram also has extensive experience in research management and public sector research funding, having worked for three years as Executive Director in the Australian Research Council. He is currently a non-executive Director on four companies involved in the commercialization of research.

He is a Fellow of the Australian Institute of Physics, and the Royal Astronomical Society, as well as a member of the American Astronomical Society, the International Astronomical Union and the Astronomical Society of Australia.

Mr Merv Johnston

Merv Johnston (B.Eng (Syd), FIEAust) has more than thirty years experience in industry, including, multinational private sector organisations; management consulting; as founder and principal shareholder of a small computer sales and service company; and in the public sector. He is currently Managing Director of CVC REEF Limited, which specialises in providing Venture Capital to businesses which are commercialising innovative Renewable Energy technologies, Managing Director of Magma Pty Limited, a management consultancy, specialising in the innovation and commercialisation processes, and early stage businesses, and a Director of Windcorp Australia Limited.

Ms Susan Neill

Susan Neill has a tertiary background in mathematics and modern languages.

Susan commenced working in the renewable energy industry at a wholesale level in 1986, obtained PV System Design Accreditation and completed postgraduate Applied PV certificate from UNSW. She became involved in the development of the Solar Energy Industry Association of Australia (SEIAA) in 1990 through to its present status as part of the Business Council for Sustainable Energy, fulfilling the role as national president of SEIAA through the mid 1990s. Susan is currently a member of the PV Directorate for BCSE.

Susan was formerly Managing Director of Quirk's Victory Light Co. Pty. Ltd. - Energy Today. This company specialised in stand-alone and grid-connected wind and solar systems. In 2005 Quirks was acquired by Conergy. Sue is now Conergy Australia's Business Development Manager for off-grid and on-grid products and services

Susan has broad experience in industry development issues and a wide network of contacts at industry level.

Mr Peter Ottesen

Peter Ottesen is Executive Director of the Office of Sustainability within the Chief Minister's Department of the Australian Capital Territory government. The Office is responsible for driving implementation of the Government's sustainability agenda and has whole-of-government policy responsibility for water, energy and greenhouse.

He has more than 20 years senior level policy and management experience in the public and private sectors within the environment, protected areas, commercial fisheries, tourism, agricultural, transport, waste management, sport and event management industries, within Australia and Canada.

A personal career highlight was his five years with the Sydney Organising Committee for the Olympic Games (SOCOG) where he established and led its Environment Program. In 2001 the United Nations Environment Program elected SOCOG to its Global 500 Roll of Honour. He was subsequently an adviser to the successful Beijing 2008 Olympic Games Bid team on environmental matters and the London 2012 Bid.

He has been an adviser to a senior cabinet minister in the Australian Government and held positions in the Australian Government's Department of Primary Industry and the Great Barrier Reef Marine Park Authority, and Environment Canada.

Peter is Chair of the Banksia Environmental Foundation, a leading Australian NGO that identifies and rewards environmental excellence, an Executive Member of the ACT Division of the Environment Institute of Australia and New Zealand and an "Honorary Ambassador" to the ACT for his contribution to the Canberra-Beijing sister-city relationship.

Peter has a BSc, with Honours (Marine Ecology) from the James Cook University and a MSc (Natural Resource Management) from the University of Western Australia.

Professor John Richards

Professor John Richards is the director of the ANU Institute for Information Sciences and Engineering.

He is also Master of University House, and Graduate House

Professor Richards was formerly Deputy Vice-Chancellor and Vice-President of the Australian National University from October 1998 to October 2003.

From 1987 to 1998 he was at the University College, Australian Defence Force Academy, where he served as Head of School of Electrical Engineering, Deputy Rector and Rector.

He graduated from the University of New South Wales with the degrees of Bachelor of Engineering (Hons1) and Doctor of Philosophy, both in Electrical Engineering, in 1968 and 1972 respectively. He is a Fellow of the Australian Academy of Technological Sciences and Engineering, and a Fellow of the Institute of Electrical and Electronics Engineers, NY.

Mr Denis Smedley

Denis Smedley, MIE Aust

Manager Renewable Energy Technologies

Department of Environment and Heritage

Australian Greenhouse Office

Denis Smedley joined the Australian Greenhouse Office in 2001 and is responsible for the Australian Government's renewable energy commercialisation, deployment and industry development programs that are administered through the Office. Prior to this, Denis worked for the Western Australian Government's Office of Energy, looking after energy efficiency and renewable energy programs for the State. This followed a 24 year engineering career in the Royal Australian Air Force. Denis is an electrical engineer.

Publications

The commercial value of Sliver solar cell intellectual property is large. The Centre has generated an extensive Sliver patent portfolio. Legal/commercial constraints continue to heavily restrict publications in this area. This situation is anticipated to change gradually over the coming year.

Journal papers

1. Prakash N. K. Deenapanray, C. S. Athukorala, Daniel Macdonald, W. E. Jellett, E. Franklin, V.E. Everett, K. J. Weber and A. W. Blakers, Reactive Ion Etching of Dielectrics and Silicon for Photovoltaic Applications, Progress in PV Vol 14 (7), pp603-614, 2006
2. Hao Jin and K.J. Weber, "The effect of low pressure chemical vapor deposited silicon nitride on the Si-SiO2 interface of oxidised silicon wafers" Journal of The Electrochemical Society, 154 (1) H5-H8 (2007)
3. J. Coventry and A.W. Blakers, Direct measurement and simulation techniques for analysis of radiation flux on a linear PV concentrator, Progress in Photovoltaics, Vol 14, pp341-352, 2006

Journal papers and book chapters in press

1. A. Blakers, "Silicon concentrator solar cells", invited chapter in "Concentrator Photovoltaics", edited by Antonio Luque and Viacheslav Andreev, 310 p., ISBN: 978-3-540-68796-2
2. C. Gatzert, A. W. Blakers, P.N.K. Deenapanray, D. Macdonald and F.D. Auret, "Investigation of reactive ion etching of dielectrics and Si in CHF3/O2 or CHF3/Ar plasmas for photovoltaic applications" J. Vac. Sci. Technol. A
3. Hao Jin and K.J. Weber, "The Effect of Low Pressure Chemical Vapor Deposition of Silicon Nitride on the Electronic Interface Properties of Oxidised Silicon Wafers", Progress in Photovoltaics
4. Hao Jin, K.J. Weber and A.W. Blakers, "*Hydrogen Passivation of LPCVD $Si_3N_4/SiO_2/Si$ Stacks by Ammonia Plasma Treatment*", Journal of The Electrochemical Society

Patents

1. Klaus Weber, Andrew Blakers and Vernie Everett, "A Process", provisional filed February 2006
2. Andrew Blakers, Klaus Weber and Vernie Everett, "A method for processing elongate substrates and a substrate securing apparatus", provisional filed 15/2/06
3. Vernie Everett, Andrew Blakers and Klaus Weber, "A substrate assembly, an assembly process, and an assembly apparatus", provisional filed 15/2/06
4. Vernie Everett, Andrew Blakers, A solar cell (Sliver) submodule formation, PCT/AU2005/001193, WO 2006/015430, PCT filed 9/8/05, published 9/2/06
5. Vernie Everett and Andrew Blakers, A Solar Cell Interconnection Process WO2006133507, WO2006AU00840, published December 2006
6. Andrew Blakers, Klaus Weber, Sanju Deenapanray, Evan Franklin and Vernie Everett, A Method for localised processes, 2006903331, filed 20th June 2006

Conference papers

1. Andrew Blakers, "Renewable Energy", invited talk to the Business & Climate Group, Melbourne Dec 2006
2. A.W. Blakers, K. Weber and V. Everett, "Sustainable Energy", ABARE Outlook 2006 conference, Canberra, 2006 (invited)
3. Andrew Blakers and Klaus Weber, Walsh Medal address to the 17th National Conference of the Australian Institute of Physics, Brisbane, December 2006
4. Klaus Weber, Andrew Blakers, Vernie Everett and Evan Franklin, Australian Institute of Energy annual conference, Melbourne, September 2006
5. Andrew Blakers, Evan Franklin, Klaus Weber and Vernie Everett, " Making solar energy cheaper: where to next with photovoltaics?", Solar 2006, Canberra, September 2006
6. Evan Franklin, Andrew Blakers, Klaus Weber and Vernie Everett, "20% efficient sliver cells fabricated with a simplified processing sequence", Solar 2006, Canberra, September 2006
7. Klaus Weber, Andrew Blakers, Vernie Everett and Evan Franklin, "Results of a cost model for SLIVER cells", 21st EC Photovoltaic Solar Energy Conference, Dresden, September 2006
8. Klaus Weber, Andrew Blakers and Phil Mackey, Sliver solar cells, Annual conference of the Business Council for Sustainable Energy, Brisbane May 2006

9. Andrew Blakers, Klaus Weber, Vernie Everett, Evan Franklin and Sanju Deenapanray, Sliver Cells – A Complete Photovoltaic Solution, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006
10. Evan Franklin, Andrew Blakers, Klaus Weber, Vernie Everett and Prakash Deenapanray, Towards a Simplified 20% Efficient Sliver Cell, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006
11. Hao Jin, K.J.Weber, and A.W.Blakers, Depassivation of Si-Sio2 interface following rapid thermal annealing, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006
12. Hao Jin, K.J.Weber, and A.W.Blakers, The effect of a post oxidation in-situ nitrogen anneal on Si surface passivation, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006
13. Hao Jin, K.J.Weber, and A.W.Blakers, Passivation of LPCVD nitride silicon stacks by atomic H, 4th World Conference on Photovoltaic Energy Conversion, Hawaii May 2006

Visitors, Seminars and Outreach

There has been a rapid increase in interest in the solar energy activities at ANU. Prominent visitors to the Centre in 2006 included the Governor General, the Leader of the Opposition Kim Beazley, ten Senators and members of the House of Representatives and the Chief Scientist.

Visits

1. 4/12/06: Visit by Danna Vale, MP
2. 30/10/06: Visit by Greg Hunt MP, Parliamentary Secretary to the Minister for the Environment and Heritage
3. 24/10/06: Meeting with Senator Gary Humphries and the Chief of Staff of Environment Minister Campbell
4. 14/9/06: Visit by Dr Zhengrong Shi, CEO of Suntech (World #3 solar cell manufacturer)
5. 11/9/06: Visit by Senator Bill Heffernan
6. 10/8/06: Visit to Senator Gary Humphries and a senior member of staff of the Minister for Environment
7. 26/7/06: Visit by the Chief Scientist, Dr Jim Peacock
8. 2/6/06: Visit by Senator Gary Humphries (ACT) of the Liberal Party
9. 26/5/06: Visit by Don Henry, CEO of the Australian Conservation Foundation
10. 23/5/06: Visit by Mr Peter Cockbain, National President of Engineers Australia
11. 5/4/06: Visit by Lt. Col. Jack Galbraith of the ADF
12. 3/4/06: Visit by Dr Steve Morton, Group Executive, Sustainable Energy & Environment Group, CSIRO
13. 31/3/06: Visit by Senator Christine Milne of the Greens
14. 30/3/06 Visit by Mr Kim Beazley MP, Opposition Leader, and Mr Anthony Albanese MP, ALP Environment spokesperson
15. 17/3/06: Visit by Mr Anthony Albanese MP, ALP Environment spokesperson
16. 7/3/06: Visit by the Governor General
17. 3/3/06: Visit by Senator Christine Milne, Senator Bob Brown and Dr Deb Foskey of the Greens
18. 1/3/06: Visit by Senator Lyn Allison, Democrats Energy & Climate Change spokesperson
19. 27/2/06: Visit by Dr Hermann Scheer, Member of the German Parliament, President of the European Association for Renewable Energy and General Chairman of the World RE Council

Media

1. 1/12/06: 5 min interview on Radio National: carbon pricing and renewable energy
2. 28/11/06: 4 min interview about solar power on ABC radio NT
3. 26/11/06: Quarter page article in the Canberra Times on ANU's CHAPS solar technology
4. 24/20/06: 5min ABC radio interview on solar power
5. 7/10/06: Major article about Sliver cells in the Canberra Times
6. 6/10/06: ABC radio interview, 5 min
7. 3/10/06: WIN TV news segment, 1min
8. 3/10/06 ABC radio interview, 10min
9. 3/10/06 Large front page article (with photo) in the Canberra Times on Sliver technology
10. 22/9/06: 2 min on Sky news talking about solar energy
11. 13/9/06: Article about Slivers in the Australian newspaper
12. 11/8/06: 7 minute Stateline TV item on Sliver cells
13. 26/7/06: Interview for WIN TV news about Sliver technology
14. 26/7/06: Article in Canberra Times about the Alan Walsh Medal
15. 25/7/06: Quarter page item in Canberra Times about the Sustainable Cities Awards
16. 6/7/06: Interview on Ch10 TV about Sliver cells
17. 7/6/06: Interview on ABC Lateline about solar energy
18. 8/3/06: 400 word article + picture on ANU solar technology in the Canberra Times
19. 9/2/06: 800 word article on energy conservation and Sliver technology in the Canberra Times

Seminars, articles and community activities

1. 13/12/06: 2 hour seminar, "Renewable energy", Business & Climate Group (invited)
2. 17/10/06: Member of an energy discussion panel organised by the Australian Inst. of Physics
3. 10/06: A.W. Blakers, "photovoltaics", seminar at RSISE, ANU
4. 10/06: A.W. Blakers, "photovoltaics", seminar at University of Qld
5. 10/06: A.W. Blakers, "Solar Energy", after dinner talk at the Greens National Policy Conf

6. 10/06: ANU Combined Heat and Power Solar (CHAPS) System, John Smeltink and Andrew Blakers, Solar Progress
7. 13/9/06: Article about Slivers in the Australian newspaper
8. 18/8/06: "Photovoltaics", invited presentation, Energy Options for Australia's Future, Canberra
9. 26/7/06: Article in Canberra Times about the Alan Walsh Medal
10. 3/5/06: Article in Future Materials Newsletter, "Solar Cells and silicon"
11. 1/5/06: Article in ANU Reporter + several media interviews
12. 5/06: "Sliver Away", 2 page article about Sliver cells in Materials Monthly from the ANU Centre for the Science and Engineering of Materials
13. 27/3/06: Sliver solar cells, seminar at the Department of Education, Science and Training
14. 13/3/06: "Moments in the sun", 600 word article in ANU's "On Campus" monthly newsletter
15. 13/3/06: Solar Energy Solutions, delivered to the National Council of Women of the ACT
16. 10/3/06: Sliver solar cells, ANU Colloquium
17. 8/3/06: Sliver solar cells, seminar at the Department of Industry, Tourism and Resources
18. 3/06: A.W. Blakers, submission to the review of the ACT energy and greenhouse policies
19. 3/06: A.W. Blakers, K. Weber and V. Everett, "Sliver solar cell technology", Energy News (Journal of the Australian Institute of Energy), Vol 24
20. 3/06: A.W. Blakers, submission to the review of the ACT energy and greenhouse policies
21. 23/2/06: Sliver solar cells, invited seminar at the Department of Prime Minister and Cabinet
22. 23/2/06: Sliver solar cells, seminar delivered to ABARE
23. 13/2/06: Sliver solar cells, seminar delivered to the ACT Government
24. 24/1/06: Sliver solar cells, seminar at the Australian Greenhouse Office

Community Activities

- 30/07/06: presentation to Wesley Uniting Church in Forrest on sustainable energy options and energy efficient building
- 05/04/06: presentation to the Zonta club of Canberra on sustainable energy options and energy efficient building
- 21/02/06: presentation to Woden U3A on sustainable energy options and energy efficient building
- 15/02/06: Expert panel member for Queanbeyan Business Council forum on sustainability
- 22/11/05: Townsville Climate Change Forum as member of expert panel
- 09, 10, 11/09/05: Principle organiser of ANZSES Solar House Day in the ACT
- 17/08/05: CSIRO Discovery expert advice to year 12 students for mock senate enquiry as part of Science Week
- 2/04/05: Presentation to annual general meeting of Sustainable Population Australia

External Consultancy

- July 2005 and May 2006: Technical assessment of Expressions of Interest and Detailed Business Cases under the Department of Environment and Heritage's $75million Solar Cities Programme

Key Result Areas and Performance Measures

Performance measure	Target	Outcome in 2006
	Research findings	
Publications	2/yr in general journals such as Applied Physics Letters, Journal of Applied Physics, Electron Device Letters 2/yr in solar energy journals such as Progress in Photovoltaics and Solar Energy Materials and Solar Cells 2/yr in international conferences 2/yr in local conferences	3 journal articles (4 in press) 6 international conf. papers 7 local conference papers Legal constraints limited publications.
Number of patents	Two over 5 years	6 patent applications (total of 11 to date)
Invitations to address and participate in national and international conferences	Five per 5 years	1 invitation (total of 6 to date)
Number and nature of commentaries about the Centre's achievements	1/year in quality lay publications 1/year in electronic media	Many – see the list of publications
	Research training and professional education	
Number of postgraduates recruited	Three per 5 years. Note:	Dr E. Franklin: completed Q3 2006; PhD awarded Q1 2007 Mr David Barton: completion expected Q3 2007; social issues of sustainable technologies Mr Jin Hao: completion expected Q3 2007; semiconductor processes Ms Wendy Jellett: semiconductor processes Ms Fiona Beck: commenced Q1 2007; semiconductor processes Ngwe Soe Zin: will commence in Q2 2007 Zhang Chun: will commence in Q2 2007
Number of postgraduates completions	Three per 5 years	Joe Coventry completed PhD in 2004 Evan Franklin completed PhD in 2006
Number of Honours students or Summer Scholars	Two per year	Averaging 4 per year
Number and level of undergraduate and high school courses in the priority area of solar energy	At least two relevant undergraduate courses delivered per year	4 relevant undergraduate courses delivered

Performance measure	**Target**	**Outcome in 2006**
	International, national and regional links & networks	
Number of international visitors	Two per year	13
Number of national and international workshops and conferences attended	Two per year	9
Number of visits to overseas laboratories	Two per year	Nil
Examples of relevant social science and humanities research supported by the Centre	At least one significant program supported most of the time	David Barton, PhD scholar, investigating the technical and social issues curtailing application of renewable energy on Norfolk Is. Active in promoting reductions in greenhouse gas emissions
Number and nature of commercialisation activities	Per 5 years: One substantial; 2 minor commercial interactions	Major commercialisation of Sliver cells
Number of Centre associates trained/ing in technology transfer and commercialisation	3 (either formally or by experience)	Many staff are acquiring commercial experience through active collaborations with 8 companies
Number and nature of public awareness programs	One substantial media program on a particular theme per year	Sliver cells
Number of government, industry and business briefings	3 per year	Many – see list above
Networking contributions to the solar energy industry	Substantial non-technical contributions to solar energy industry development	Many – see list above
	Organisational support	
Annual cash contribution from collaborating organisations	ANU: at least $90,000 per year cash	Received.
Annual in-kind contributions from collaborating organisations	ANU: provision of the salary of the Research Director and Deputy Research Director	Director's salary received
Level and quality of infrastructure provided to the Centre	ANU: Full access to ANU research facilities, including CSES laboratories	Achieved
Acquisition of additional support for Centre activities	Additional grants or commercial investment at ANU that make use of Centre IP directly or indirectly.	LIEF grant and Major Equipment grant to purchase a 4-stack furnace

Performance measure	Target	Outcome in 2006
	Governance	
Breadth and experience of the members of the advisory board	Membership by senior academic and commercial people	Senior academic, Government and commercial people have accepted positions on the Advisory Board. Biographies attached to the Annual Report.
Frequency and effectiveness of advisory board meetings	Two per year; effective Board briefings; effective interaction between the Board and Centre	Board meetings were held in April 2006, November 2006, January 2007 and March 2007. The Board's effectiveness was substantially improved in 2006.
Quality of the Centre strategic plan	Effectively guides Centre activities; reviewed and updated regularly	Reviewed
The adequacy of the Centre's key performance measures	Reflect Centre focus; are challenging but achievable with available resources; are updated as required.	Reviewed
National benefit		
Measures of expansion of Australia's capability in the priority area of solar energy	Good research outcomes; good research training outcomes	Too early to say
Contributions to economic, social, cultural and environmental benefits of solar energy	Good commercial outcomes; good outcomes from outreach activities	Too early to say

Facilities Available to the Centre

The Centre of Excellence for Solar Energy Systems has full access to the resources of the Centre for Sustainable Energy Systems within the Department of Engineering, as well as facilities elsewhere in the University. The resources include:

E125 Gingera Laboratory: clean room used for production of high efficiency cells. 3 fume cupboards, 6 furnaces, photolithographic facilities (resist spinner, HMDS & baking ovens, 2 mask aligners, laminar flow HEPA units).

E126 Gudgenby Laboratory: clean room for metal deposition under high vacuum conditions. Two cryo-pumped Varian deposition systems.

E127 Ginini Laboratory: used for device characterisation activities. IV curves, Suns-Voc.

E124 Bimberi Laboratory: clean room device fabrication. 3 furnaces, 2 fume cupboards, spin rinsers, silicon etching station

E123 Tidbinbilla Laboratory: general purpose lab. 2 fume cupboards, Ag plating, APCVD deposition system

E122 Piccadilly Laboratory: clean room for device processing. 2 fume cupboards, silicon etching, laser machining workstation, furnaces, LPCVD deposition system, microscopes, rapid thermal annealing furnace

E131: Franklin Laboratory – downstream processing and module/receiver assembly: 2 dicing saws, soldering jigs, IV characterisation workstation, screen printer, workbenches, glass cutting table, vacuum chambers, accelerated life testing.

E114: Mechanical Workshop: Full workshop facilities with metal fabrication facilities shared with Department of Engineering

E138: Characterisation Laboratory. Several minority carrier lifetime systems

E129: Electronics Workshop. Used for fabrication of electronic components and as a maintenance resource for all other equipment

E128: Maintenance Office.

Faculties Teaching Centre at building 42 (separate from PV Laboratories). Rooftop used for installation of prototype and demonstration systems – clear sky access from large flat roof area. 16m^2 of parabolic troughs delivering solar intensities of 30-40 kW/m^2 for testing and prototyping.

Bruce Hall: 300m^2 of parabolic troughs.

Other facilities at ANU: Access to extensive facilities in other Departments, including good microscopes, PECVD, RIE, lasers, ion implanters, MOCVD and an extensive array of characterisation facilities.