Education and Research at the centre for Photovoltaic Engineering, University of New South Wales

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Abstract

The first students from the world's first Bachelor program in Photovoltaics and Solar Energy Engineering, at the Centre for Photovoltaic Engineering (CPVE), have graduated in 2003 and 2004. They have entered into a booming global market, particularly strong in Japan, Europe and California and ramping up in China, Thailand and elsewhere. At the end of 2006 the first UNSW Renewable Energy Engineers will graduate and join them in the industry. In addition to those two pioneering undergraduate programs, the CPVE teaches a postgraduate coursework program and delivers research training at Masters and PhD level. These teaching and research activities in first, second and third generation photovoltaics are reviewed.

1. Introduction

The Centre for Photovoltaic Engineering, that operated since 1999 as one of the ten schools within the Faculty of Engineering within the University of New South Wales (UNSW), Sydney. The Centre was established with the support of the Australian Research Council to continue the proud history of photovoltaics research at UNSW and establish the world's first degree program in Photovoltaics and Solar Energy Engineering. The Centre hosts the Centre of Excellence in Advanced Silicon Photovoltaics and Photonics, which continues to carry out exciting research in three generations of silicon-based photovoltaics and in infrared emission from silicon.

2. Undergraduate Education

The educational programs described here attract a highly motivated and competent group of students. The spread of University Admission Index (UAI) scores, used to control the entry of school-leavers to university programs, for students in many programs is concentrated near the "cutoff" value below which entry is prevented, around 80 for our programs in recent years. This tendency is due to the social pressures for students to gain entry to the most exclusive program possible.
However, our programs have an unusual histogram of UAI results (Fig. 1) in which it can be seen that the concentration is, instead, at the upper end of the range. The student group is also unusual for Australian engineering programs in the relatively high fraction of female students.

2.1 Photovoltaic and Solar Energy Engineering

This program (UNSW, 2004a) commenced in 2000 and is the first of its kind anywhere. The program includes training in technology development, manufacturing, quality control, reliability and lifecycle analysis, cell interconnection and encapsulation, the full range of solar cell applications, system design, maintenance and fault diagnosis, marketing, policy development and the use of a range of renewable energy technologies. Considerable emphasis is placed on gaining hands-on experience of working with photovoltaic devices, modules and systems through undergraduate projects in a student's second and fourth years. Several renewable energy technologies, including wind, biomass, solar thermal, are included within the program although the primary focus is on photovoltaic devices, systems and policy.

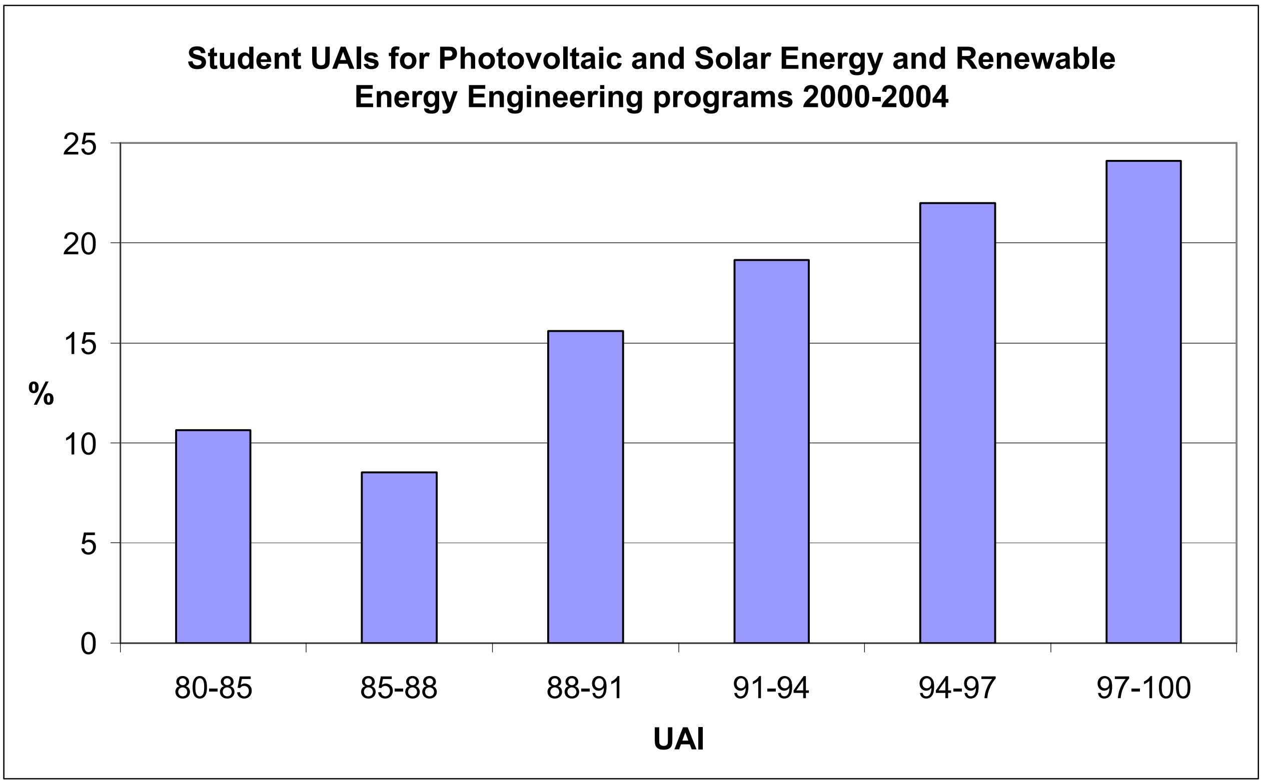

Fig. 1. Incoming undergraduate students' University Admissions Index scores, 2000 – 2004

Two features particularly attract students to this program: the "strand" and the undergraduate projects. In their second and third year students choose a second area of specialisation which complements their study of photovoltaics and solar energy. This strand is comprised of 18 units of credit (out of a nominal 192 for the four-year degree) of courses taken from the Faculties of Engineering, Science or Built Environment. The aim is to provide students with broader engineering backgrounds important for the cross-disciplinary nature of the photovoltaics and renewable energy industries. The most popular strands have been Architecture, Electronics, Physics, Mechanical (including solar thermal) Engineering and Computing.

In addition to a final year thesis project, students undertake a project in the photovoltaics or other renewable energy areas in the second year of this program (UNSW, 2004b). Most are enthusiastic about being involved with these projects.

The following projects are being undertaken in 2004:

? **Biodiesel:** This project aims to develop the capability to convert waste vegetable oil from UNSW food outlets to Biodiesel in a mobile trailer. The process heat for the reaction is to be provided from a solar hot water system and the electricity for the monitors and pumps is to be from photovoltaic modules.

? **Developing Countries:** The Centre has enabled opportunities for student projects associated with, learning from and benefiting developing countries (Corkish et al., 2004). This is the most popular project among the students, who get involved in a variety of renewable energy work. Fundraising and project management are an important part. The social context of these activities is paramount (Gregory and McNelis, 1994) and projects are carried out in close cooperation with local non-governmental organisations (NGOs) and/or universities and government departments to ensure appropriateness and sustainability. In January/Februay 2004 a group of staff and students visited urban and rural Nicaragua as a result of fundraising and project work undertaken in 2003. A previous visit to Nicaragua had been made in 2003.

A group of 2004 students is working towards a visit to install, maintain and monitor systems in Vanuatu in mid-2005. In preparation, they are undertaking projects concerned with vaccine refrigeration, improved lighting, water purification and the feasibility of electrical or mechanical power generation by micro-hydro systems. This group had originally intended to focus their work on the same Nepalese village that had been visited in February 2004 by another group of students and staff who installed photovoltaic-powered lighting in a health clinic that serves tens of thousands of people in central Nepal. Unfortunately, the focus of the current group needed to be diverted from Nepal due to security concerns.

? **Micro-hydro demonstration:** This project aims to install a small demonstration micro-hydro generator for use as an educational tool and as a display for UNSW Courses and Careers Day when prospective students visit the campus. Water from roof-top tanks atop the five-storey Electrical Engineering Building will turn the turbine by gravity and be pumped back. A major aspect will be project management within a large, diverse organisation with multiple stakeholders.

? **Thin-film cell processing:** This project provides students with the opportunity to work in one of the Centre's research laboratories, on thin-film silicon-on-glass solar cell processing.

As of October 2004 there are 103 students enrolled in the four years of this program, thirteen of whom are combining it with a second degree in Science (five years full-time) and nine of whom are combining it with an Arts degree (also five years full time). (A combined degree with Commerce will become available from 2005). One student graduated in October 2003, sixteen graduated in April 2004 and seven in October 2004.

Some graduates are continuing education, particularly PhD research in photovoltaic devices and further studies towards Masters degrees in Commerce. Most of the others have employment in the renewable energy field in Australia or Germany. Their jobs are spread across the industry sectors of systems, manufacturing, consulting and policy, including in indigenous communities in remote regions of Australia (Bushlight, 2004).

2.2 Renewable Energy Engineering

This degree program (UNSW, 2004c) was introduced to address the projected shortage of trained engineers for the renewable energy industries. All students take specialised material in each of the renewable energy areas. They study energy generation from solar thermal systems, photovoltaics, wind generators, biomass, tidal energy, micro-hydro systems, fuel cells and geothermal systems and also the important areas of solar architecture and energy efficiency. Consultations on course content and design have been held with Australian manufacturers, major end-users, the NSW Sustainable Energy Development Authority, the Australian Cooperative Research Centre for Renewable Energy and the industry representative association, the Australian Business Council for Sustainable Energy. This new program appeals to students who wish to learn about the broader application of renewable energy technologies. This program excludes the second year project but does include a final year thesis. Ten students commenced this program in 2003 and, as of September 2004, there are 25 enrolled. The first graduates are expected at the end of 2006.

3. Postgraduate Education

The one-year Master of Engineering Science in Photovoltaics and Solar Energy program is designed to build on the previous engineering education of engineers from other engineering disciplines who are attracted to the photovoltaics and renewable energy industries. Students study courses selected from the areas of photovoltaic devices, photovoltaic systems and applications, and renewable energy technologies. The program commenced in 2002 and the first students graduated in May, 2003. Seven are currently enrolled.

4. Research

The above mentioned educational activities have been built on the foundation of over two decades of leading research into photovoltaics at UNSW. The Centre incorporates the Australian Research Council's Centre of Excellence in Advanced Silicon Photovoltaics and Photonics and carries out research training through PhD and Masters degrees. There are currently 22 enrolled research students.

4.1 Wafer Based Cells

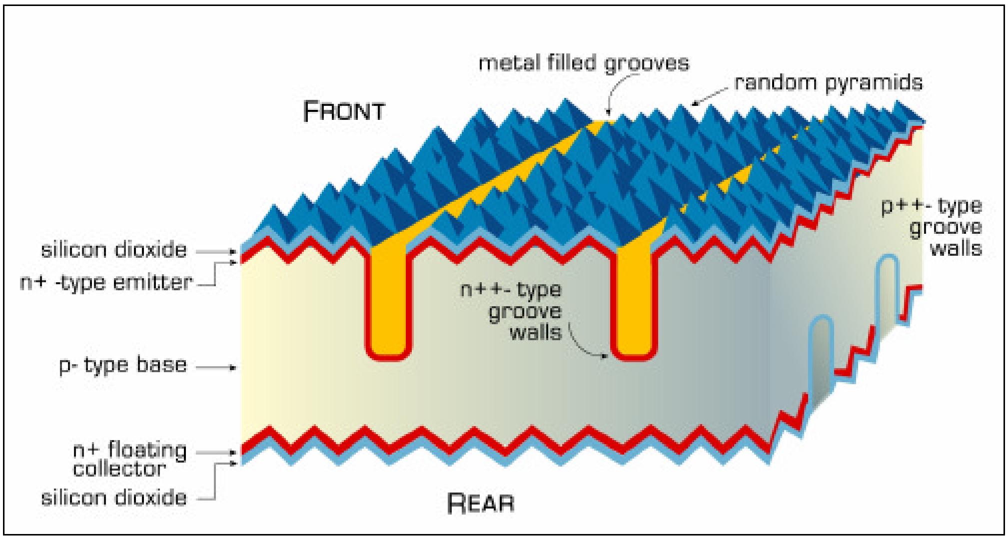

Figure 1: Conceptual structure of the double-sided buried contact cell

Silicon wafer (p-type) based cells currently dominate the global cell market and despite many predictions for their demise, their production growth rate is currently over 30%/year. The

Centre has several research projects on refining designs for cells formed from p-type wafers and on developing n-type designs. Work on p-type designs includes the double-sided buried contact (laser-grooved) cell (Fig. 1), which adds a high-efficiency grooved rear contact structure to the commercially successful design that is presently in mass production by BP Solar (2002) in Spain; investigation and minimization of recombination mechanisms in double-sided buried contact cells; and numerical modeling and experiments to understand and reduce growth induced and thermal mismatch stresses during silicon.
The double-sided buried contact technology is also being modified to use n-type wafers, such as in an interdigitated back buried contact approach, in which all the metallization is on the rear. N-type wafers are less prone to light-induced degradation. The latter structure is somewhat prone to shunting at the diffusion overlap region between the p-type and n-type grooves and numerical modeling is being used to better understand how it occurs and thermally sensitive liquid crystal sheets are being employed to locate shunts in experimental devices. The effect on stability with light-soaking of the use of thin Ga- and P-doped wafers is being investigated with the double-sided structure, as are alternative, laser-based, methods for surface texturing.
Additionally, the group is pioneering the application of laser-cut steel stencils for production of thin metallization lines for "screen"-printed cell manufacture.

4.2 Thin Film Cells

This research group focuses on the development of polycrystalline thin film cells on glass (Fig. 2), an extremely promising path towards lowered solar electricity costs. The main research directions include texturing glass substrates for light trapping with novel techniques, aluminium-induced texturing and optimization of seed layers (for subsequent crystalline silicon growth) that have been produced by aluminium-induced crystallization. The latter technique has been shown to produce highly crystalline layers with grains exceeding 10 µm. Ion-assisted deposition, able to produce a high growth rate of silicon at glass-compatible temperatures, is being used to epitaxially thicken such seed layers for subsequent processing into cells. Research is concentrating on reducing the incorporation of contaminants into the active layers.

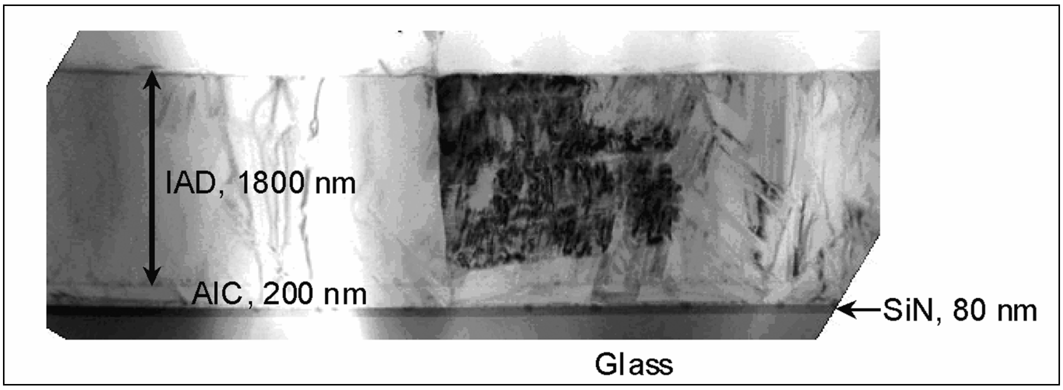

Figure 2: Bight-field TEM image of thin-film silicon-on-glass cell.

An alternative approach under investigation is to deposit the active layers on the seed layer in amorphous form then crystallize in a solid-phase epitaxy step. Cell construction has also been achieved by solid-phase crystallization of polycrystalline silicon on glass.

4.3 Third Generation Cells

These approaches each address one or more of the two main fundamental loss mechanisms: non-absorption of sub-bandgap photon energies and lattice thermalisation loss (Green, 2004). The main research directions are bandgap engineering of silicon/oxide and silicon/nitride nanostructures for silicon-based tandem cells; spectral conversion, (energy up-conversion of infrared light passing trough the cell and energy down-conversion of incident high energy photons into multiple lower-energy photons); and hot carrier cells using energy-selective charge-carrier membranes. Other areas being investigated include the use of surface plasmons to trap light energy into surface modes and novel applications of luminescent solar concentrators.

4.4 III-V Cells

The Centre also has recently undertaken investigations into novel techniques for peeling off thin, high-efficiency III-V cells from their parent substrates for subsequent substrate reuse and possible production of silicon-III-V tandem cells.

4.5 Systems and Markets

Research is underway into interaction of photovoltaic systems and energy markets. One of the most exciting aspects is the potential for distributed photovoltaic generation capacity to offset the problematic load peaks and massive inter-regional transfers on power grids related to air conditioning. This is an urgent issue in many areas, including parts of Australia (Commonwealth of Australia, 2004) and USA (Perez, 2004).

5. Conclusion

The Centre for Photovoltaic Engineering has recently expanded its well established research and research training role into undergraduate and postgraduate education. The first of its ndergraduate engineering programs has now produced its first batch of graduates and graduates are expected from the other at the end of 2006. These and the postgraduate programs are briefly described, as are the main reseach activities within the Centre.

6. Acknowledgements

The educational activities of the Centre for Photovoltaic Engineering were established with support from the Australian Research Council's Key Centres program. Many of the research activities described here are carried out within the Australian Research Council's Centre of Excellence for Advanced Silicon Photovoltaics and Photonics.

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