4.2 FACILITIES AND INFRASTRUCTURE

The ARC Photovoltaics Centre of Excellence is located at the Kensington campus of the University of New South Wales, about 6 km from the heart of Sydney and close to its world famous beaches including Bondi, Coogee and Maroubra (Fig. 4.2.1).

Organisationally, the Centre of Excellence is located within the School of Photovoltaic and Renewable Energy Engineering (SPREE) within the Faculty of Engineering. The Centre of Excellence has a large range of laboratory facilities (Fig. 4.2.2). These include the Bulk Silicon Research Laboratories, the Device Characterisation Laboratory, the Optoelectronic Research Laboratories, the Thin-Film Cell Laboratory, the Industry Collaborative Laboratory, Inkjet Processing Laboratory and Organic Photovoltaic (OPV) Laboratory. Off campus the Centre has a Thin-Film Cleanroom facility at Botany, 5km south-west of the main campus. Another important resource is the Semiconductor Nanofabrication Facility (SNF) jointly operated by the Faculty of Science and the Faculty of Engineering.

Additional equipment commonly used for solar cell work is found at the new MicroAnalytical Research Centre (MARC) and elsewhere on the University campus. Included in this category are TEM/SEM electron microscopes, focused ion beam (FIB) specimen preparation equipment, X-ray diffraction, Raman spectroscopy, AFM and surface analysis equipment. TEM, ellipsometry and a femtosecond time resolved photoluminescence measurement system are also regularly accessed at Sydney University.

During 2010, the development and acquisition of laboratory equipment and infrastructure continued with specific details about significant additions found under the laboratory headings which follow.

The Centre of Excellence has three computer networks. Both Kensington and Bay St Botany each have a research/admin network. The third network is for students enrolled in the Undergraduate Degree Courses in Photovoltaics and Renewable Energy. In 2010, the Kensington Research and Administrative network grew by 20% to consist of 5 file servers, 1 terminal server, 1 intranet server, 2 Internet web-servers (hosted on Central IT infrastructure), 2 licence servers (local and Central) and over 170 client workstations. At Kensington, an additional 31 computers are dedicated to the computer control of laboratory and other equipment. The Centre also has a 3 server computer controlled SCADA and PLC network for equipment control and monitoring the research laboratories and related infrastructure. Bay St Botany has 9 dedicated equipment controllers and the research/admin network supports 11 workstations.

The computer resources are used for measurement, modelling/simulations, equipment control,
document control, laboratory design support, Internet access, general administrative purposes and maintaining the Centre’s presence on the Internet.

Each postgraduate research student is allocated a dedicated personal computer and has access to shared computer resources.

The Centre upgraded Linux (Beowulf) 64bit cluster has an estimated computational power of 2 TeraFlops to support the demanding Density-Functional-Hartree-Fock and molecular dynamical computations. A second 128 core cluster has been installed for complementary investigations of energy efficiency and renewable energy via computational fluid dynamics techniques.

The Student Computer network comprises of two computer laboratories of total 78 m² with 5 servers, a UNSW custom CSE computer based IPQ router and 34 workstations. Students enrolled in the Undergraduate Degree Courses use these computers for computer-related coursework and Internet access. There is also an Internet capable web-server that gathers and displays data collected from solar arrays on the roof of the building. These data can be viewed using a web browser and can be made available for Internet access.

Students also have access to over 200 additional workstations made available through collaboration with the School of Computer Science and Engineering.

The Laboratory Development and Operations Team develops and maintains core Centre and laboratory facilities. During 2010, the team, under the leadership of Mark Silver, comprised of an additional 5 equivalent full-time and 11 casual employees, including: electrical engineers, a computer/network manager, electronic/computer/laboratory technicians and administrative staff.

**Bulk Silicon Research Laboratories**

The Centre houses the largest and most sophisticated bulk silicon solar cell research facility in Australia, incorporating both the High Efficiency and Buried Contact Cell Laboratories. Total laboratory processing space of over 580 m² (including the Industry Collaborative, InkJet Processing Development, Device Characterisation and Optoelectronic Research Labs) is located in the Electrical Engineering Building and is serviced with filtered and conditioned air, appropriate cooling water, processing gases, de-ionized water supply, chemical fume cupboards and local exhausts. There is an additional 819 m² area for the accommodation of staff, research students, school office and laboratory support facilities. Another 480 m² of combined roof space accommodates fixed PV arrays and 361 m² of accessible outdoor experimental space. Off site, areas totalling 700 m² are used for the storage of chemicals and equipment spare parts and a new 100 m² area for a nickel sintering belt furnace facility at 78 Bay St Botany.

The laboratories are furnished with a range of processing and characterisation equipment including 23 tube diffusion furnaces, 6 vacuum evaporation deposition systems, a laser-scribing machine, 2 laser doping machines, rapid thermal annealer, four-point sheet-resistivity probe, quartz tube washer, silver/nickel and copper plating facility, visible wavelength microscopes, 3 wafer mask aligners, spin-on diffusion system, photoresist and dopant spinners, electron beam deposition system, metallization belt furnace, nickel sinter belt furnace, manual and automatic screen printers and a laboratory system control and data acquisition monitoring system.

The laser scribe tool, shown in Figure 4.2.3, has a 20 watt Nd:YAG laser for infrared operation (1064 nm) and an optional frequency doubler for green operation (532 nm). The work stage is CNC controlled allowing 1 micron positional accuracy and table speeds approaching 25 cm/second across an area of 15 cm by 15 cm. The tool is used primarily for Buried Contact Cell Laboratories.
Contact solar cell fabrication, cutting 35-micron wide laser grooves as deep as 100 microns into silicon wafers and scribing wafers in preparation for cleaving. It can also be used to cut other suitable materials, such as stainless steel.

**Device Characterisation Laboratory**

This laboratory is located on the lower ground floor of the Electrical Engineering Building. Associated with it is the Optoelectronic Research Laboratories, reception area, seminar room, offices for Centre staff interacting with the public and industry, including the Business & Technology Manager, Finance Officer, External Relations and Design Assistance Division Manager.

The Device Characterisation Laboratory houses characterisation equipment including “Dark Star”, the Centre’s station for temperature controlled illuminated and dark current-voltage measurements, the Centre’s Fourier-transform infrared spectroscopy system (FTIR), frequency dependent impedance analyser, ellipsometer, Sinton photoconductance lifetime equipment, wafer probing station, open circuit voltage versus illumination measurement system (Suns-Voc), 4 point resistivity probe, spectral response system and spectrophotometer with integrating sphere.

In 2008, a multi function wafer mapping tool, shown in Figure 4.2.4, was installed. This unit provides state of the art capability for the measurement of carrier lifetime, bulk resistivity, emitter sheet resistance and Light Beam Induced Current (LBIC) on wafer samples.

Additions in 2009 included a high speed commercial flash cell tester with 156 mm square wafer capability as shown in Fig 4.2.5, a replacement UV/VIS/NIR spectrophotometer and a commercial Luminescence Inspection System (LIS) from spin off company BT Imaging.

**Optoelectronic Research Laboratories**

This facility has six optical benches and several visible and near-infrared semiconductor diode lasers along with other optical and electrical instrumentation. The facility is used for photoluminescence (PL) and electroluminescence measurements in the visible and infrared spectral range up to wavelengths of 2500nm, luminescence experiments with simultaneous two-colour illumination, quasi steady state photoluminescence lifetime measurements and Sinton lifetime testing with the conventional flash-light replaced by a high-power light emitting diode array.

This facility also houses the Centre’s world-leading first photoluminescence imaging system. Other equipment includes a silicon CCD camera (for sensitive PL measurements), spectroscopic PL systems, PL lifetime measurement unit, and LBIC measurement system. Areas separate from the Device Characterisation Laboratory were necessary in order to meet stringent standards for safe laser use. It shares cryogenic cooling equipment with the Device Characterisation Laboratory.

**Thin-Film Cell Laboratory**

This 40 m² laboratory is equipped with a range of equipment for thin-film deposition and patterning, including a plasma-enhanced chemical vapour deposition (PECVD) system, a sputtering system, larger area plasma etcher, reactive ion etcher (RIE), a resistively heated vacuum evaporator, helium leak detector and an optical microscope with digital image acquisition system. Also used by the laboratory is an electron-beam vacuum evaporator for silicon which is physically located within the Bulk Silicon Research Laboratory. This Si evaporator is also equipped with an ionizer unit and a sample heater, enabling fast-rate Si homoepitaxy at temperatures of about 500-600°C by means of ion-assisted deposition (IAD). The IAD is also equipped with a residual gas analyser to permit real time process monitoring. Other equipment of use in thin-film projects is located within the Semiconductor Nanofabrication Facility.
The PECVD system, shown in Fig. 4.2.7, has a 40 x 20 cm² process platen and can handle large-area silicon wafers as well as smaller pieces. Two types of plasma excitation (remote microwave and direct RF) are available. The machine is used for the low-temperature deposition of thin dielectric films (silicon nitride, silicon dioxide, silicon oxy-nitrides) and of amorphous silicon. The dual-cylinder, remote microwave plasma source produces excellent-quality silicon nitride and silicon dioxide films, with precise control over the stoichiometry at temperatures up to 500°C. Amorphous and microcrystalline silicon films can also be deposited in the system.

In 2008, the thermal evaporator was upgraded to also support e-beam evaporation. This capability greatly expands the range of materials which can be deposited and is of great interest to 3rd generation researchers. In 2009 a new 4 point probing station was added to the laboratory. In 2010 the computer support system for the optical microscope was upgraded to improve the usability of the digital camera fitted.

**Inkjet Processing Development Lab**

This laboratory houses the Centre’s inkjet printing development systems. The laboratory is used to develop solar processing “inks” (chemical solutions) and for printing them onto a solar wafer under computer control. The aim is to develop low cost processing techniques for creating fine structures in solar cells. It is anticipated that the inkjet printing is capable of replacing processes such as laser scribing and photolithography for forming fine patterns for contacting but at a cost of at least 10 times cheaper. Equipment includes two ink jet material deposition printing systems, capable of depositing a wide range of materials onto different substrates, a surface tension meter and viscometer. In 2009 a commercial aerosol deposition system capable of very fine scale patterning was purchased.

**Semiconductor Nanofabrication Facility**

The Centre also owns equipment within, and has access to, the Semiconductor Nanofabrication Facility (SNF) at the University. This is a joint facility shared by the Faculties of Science and Engineering and houses a microelectronics laboratory and a nanofabrication laboratory for e-beam lithography. The SNF provides an Australian capability for the fabrication of advanced nanoscale semiconductor devices and their integration with microelectronics. SNF research projects form an integrated effort to fabricate innovative semiconductor nanostructures using the latest techniques of electron beam patterning and scanning probe manipulation. A major applied objective of the facility is the development of a prototype silicon nuclear spin quantum computer. The capabilities of this facility were expanded to house the, NCRIS funded, Australian National Nanofabrication Facility. In 2010 the facility added a new large area e-beam lithography system and new e-beam evaporator for non MOS-compatible metals deposition.
In 2003, the Centre added a 120 m² cleanroom facility in Bay Street, Botany to its infrastructure, greatly improving its experimental capabilities in the area of thin-films. This cleanroom is equipped with several fume cupboards, two tube furnaces, an electron-beam vacuum evaporator, a thermal vacuum evaporator, a glass washing machine, a rapid thermal processing (RTP) machine and a 5-chamber cluster tool. The cluster tool presently features four plasma-enhanced chemical vapour deposition (PECVD) chambers and one lamp-heated vacuum annealing chamber. The PECVD chambers enable the low-temperature deposition of dielectric films (silicon oxide, silicon nitride, etc) and amorphous silicon films (either n- or p-doped or undoped). Furthermore, samples can be hydrogenated by PECVD using hydrogen plasma at substrate temperatures of up to 480°C. During 2004, the Centre purchased a low-pressure chemical vapour deposition (LPCVD) system, an infrared NdYAG laser scribe and a box furnace for sample annealing. The LPCVD system is capable of depositing doped crystalline silicon on glass and with its additional remote plasma source is currently engaged in hydrogenation work. The NdYAG laser, located outside the clean room, is used for scribing silicon films and other suitable metal and dielectric materials.

In 2006, a state of the art multi-target sputter machine was installed. In 2008 this vacuum tool was upgraded from four to five separate targets. Each target is able to be operated independently of one and other, allowing users to cosputter a thin film from more than one target and deposit multilayers without breaking vacuum. Three power supplies are available with substrate biasing. The custom made system can handle substrates up to 150mm x 150mm. Excellent film purity is assured as the system incorporates a load-lock. Computer control can be used for most operations, including substrate heating, allowing precise multilayers to be deposited repeatedly.

During 2007, a new computer controlled multi pocket, multi source UHV electron beam evaporator system was delivered. This equipment provides the capability for high "industrial" rate silicon and other thin film deposition.

In 2009, an optically assisted IV measurement system was installed for the determination of static hot carrier distributions. The LPCVD computer control system was also upgraded to provide enhanced throughput. A line beam diode laser system was also installed, outside the clean room, for work on low thermal budget defect annealing.

In 2010, the first stage of a multi-chamber sputter system has been ordered to allow our 3rd Generation Group to carry out significantly different functions on a sample without exposing it to the atmosphere between each process. Processes include sputter-depositing different dopants in separate chambers, vacuum annealing, also PECVD layers. This purchase will be “Stage I” in that one chamber will be purchased; a loadlock chamber and other peripherals have been configured from decommissioned stock. Stage II will involve the purchase of a second processing chamber and a transfer/loadlock chamber.

The addition of computer control to our hydrogenation tool provides more reliable process repeatability and accuracy of set process parameters. The processor inputs all process parameters for each "layer" defining each step before starting the process. This upgrade also frees processors’ time in that they need not be in attendance to change settings when beginning each process layer.

Organic Photovoltaic Laboratory (OPV)

In 2010 fit out of a new OPV laboratory in the Chemical Sciences Building commenced and OPV equipment currently located in other Centre laboratories is being integrated into the new facility. A recent arrival has been the inert atmosphere, four glove boxes with integrated spin coater. The new laboratory includes the Centre’s first fume cupboard with integral hydrofluoric acid scrubber as well as support space for vacuum evaporation, annealing and sample storage.