The University of New South Wales

The Centre has three major research laboratories at the University of New South Wales: the Atomic Fabrication Facility (AFF), the National Magnet Laboratory (NML) and the Semiconductor Nanofabrication Facility (SNF). These facilities are located within close proximity to each other in the Newton building and offer a broad range of nano-scale device fabrication and measurement capabilities.

Consolidated within the Newton building, the Centre also has 700 m^2 of office space with conference facilities supporting 50 staff, students and visitors. There is a Microsoft Windows based computer network of 70 personal computers (PCs) including 25 used for data collection, data processing and control of equipment in the laboratories. The backbone of the PC network is a cluster of Linux servers that perform file serving and web hosting duties. Three visualisation workstations are available for simulating semiconductor devices and electromagnetic and RF fields.

To complement the plant areas within and adjacent to the three facilities, there is a large services compound which supports all laboratories and several other areas within the School of Physics. This compound incorporates: a bulk liquid nitrogen vessel, large scale diesel generator to supply backup power via an uninterruptible power supply to crucial equipment in the AFF, helium recovery compressors with gas storage, gas bottle storage and outgoing chemical waste storage. All of these areas operate under the UNSW OHS Management System (OHMS) which requires the control of systems of work as per Australian Standards including AS 4801, 4360, design and other relevant standards.

FIGURE 1

Operation of the Sirion and XL30 EBL systems at the UNSW Semiconductor Nanofabrication Facility.

Semiconductor Nanofabrication Facility (SNF)

Now in its 14th year of operation, the SNF houses cleanroom laboratories containing a comprehensive collection of micro- and nano-electronic equipment for fabricating an array of silicon (Si) and gallium arsenide (GaAs) devices. The SNF is jointly operated by the School of Electrical Engineering and the School of Physics at UNSW.

Extending over 300 m^2 and three floors, the SNF contains four laboratory areas offering differing cleanroom environments. Each floor has 50 m^2 of environmentally controlled class 3.5 cleanroom, maintained by a vertical laminar air handling system. In addition, there is also approximately 135 m^2 of class 350 cleanroom space. A further plant area accommodates the air conditioning units and the laboratory services including: ultra-pure recirculating de-ionised water, high purity gaseous nitrogen, vacuum, cooling water and exhaust extraction.

The lower floor cleanroom houses equipment geared for nano-scale device fabrication. The key instruments within this laboratory are two electron beam lithography (EBL) systems which are used for nano-lithography and high resolution imaging. The systems (FEI XL30 and FEI Sirion) offer state-of-the-art resolution capabilities as well as high throughput. They each have an imaging resolution of better than 2 nm and are capable of producing line-widths below 10 nm. The Sirion system is a 30 kV Schottky emitter based FEG-SEM with an imaging resolution of 1.5 nm at $>$ 10 kV. It is fitted with a fast, electrostatic beam blanker and Nabity Pattern Generator which enable ultra-high resolution electron beam lithography to be performed.

The lower floor class 3.5 area also holds systems and services for UV lithography, metal deposition, atomic force microscopy (DI3100) and wet chemical processing.

The upper floor cleanroom is furnished with an array of facilities for producing micro-scale silicon devices. Equipment and services include: high temperature silicon diffusion and oxidation furnaces,

FIGURE 2

Prof Andrew Dzurak and Dr Fay Hudson with PhD student Susan Angus.

FIGURE 3

High temperature silicon processing.

UV lithography facilities, a rapid thermal annealing station and wet chemical process lines.

The class 350 environments contain a collection of plasma processing and chemical vapour deposition systems, bonding stations and measurement tools complementing the class 3.5 facilities. The SNF laboratories are maintained by 3 full-time and 1 part-time professional and technical staff. In 2007 a new OHS Officer position was created to support the safe workplace culture within the SNF, NML and AFF facilities.

SPECIAL GASES SYSTEM

A suite of deposition, dopant and etching tools are served by the Special Gases System which stores and distributes the process gases to the laboratory. These gases include: PH_3, SiH_4 GeH_4, B_2H_6, SF_6, NH_3, H_2 and CH_4. A rooftop gas shed houses gas cylinders, distribution pipes, exhaust extraction and environmental control items. Highly sophisticated gas monitoring and automatic safety equipment is used due to the hazardous nature of some of the gases.

The process tools connected to the Special Gases System underwent a complete professional hazop and safety upgrade during the course of 2006 as part of the Centre's ongoing commitment to continuous improvement. This resulted in improvements to both the safety and the operability of the processing tools and the Special Gases System itself.

During 2007 the Special Gases System was further reticulated into the SNF Extension area in preparation for new tools scheduled for installation in this area (detailed below). A hazop review of the Special Gases System was conducted to ensure the safety of this modification.

AUSTRALIAN NATIONAL FABRICATION FACILITY

The Australian National Fabrication Facility (ANFF), established via DEST's National Collaborative Research Infrastructure Strategy (NCRIS), commenced operation in 2007. Total funding for ANFF nationally exceeds $90m, including components from DEST, state governments and host institutions. The ANFF-NSW Node (hosted by the SNF) has secured $6m of this funding over the period 2006–2011, including $3m from DEST, $2m from the NSW State Government and $1m from UNSW. The majority of this funding will be directed towards the completion of SNF Extension clean-rooms and the purchase of new process tools to be located there. The new facilities of the ANFF-NSW Node are expected to be available to users from late 2008.

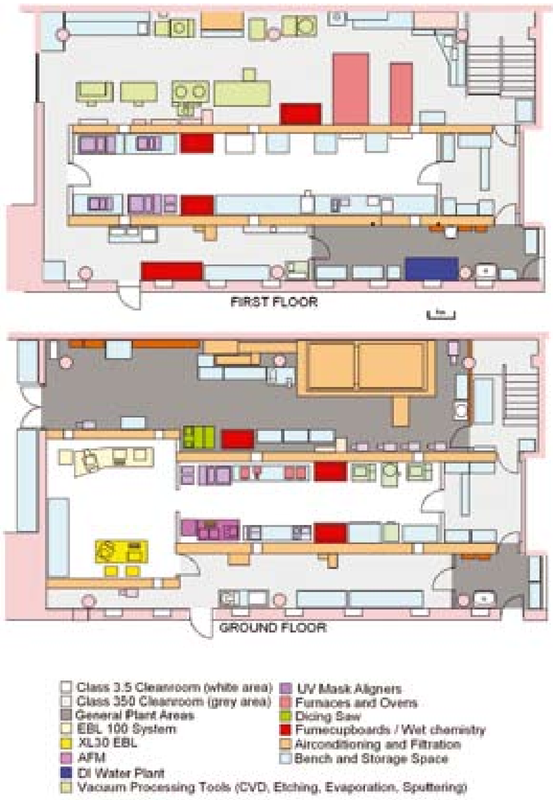

FIGURE 4

Floor plan and layout of the Semiconductor Nanofabrication Facility.

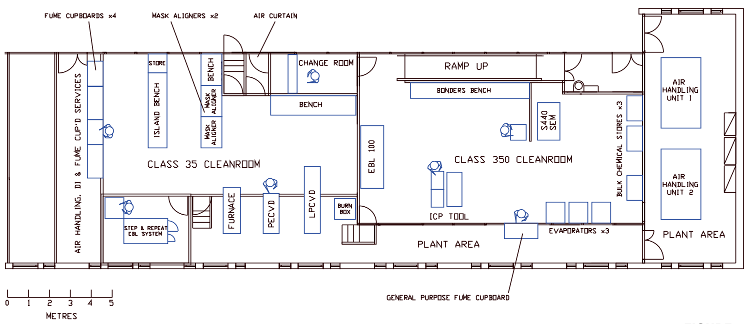

FIGURE 5

Extension of the Semiconductor Nanofabrication Facility.

SNF EXTENSION

In November 2005, construction commenced on a large extension to the SNF adjacent to the upper level cleanrooms. The project involves four stages and will ultimately comprise 93 m^2 of class 35 cleanroom, 108 m^2 of class 350 cleanroom and 113 m^2 of plant and service zones. UNSW engaged specialist consultants to ensure all foreseeable OHS design risks were minimised at the planning stages. Equipment to be installed includes: three EBL platforms (EBL100 and a Leica S440 SEM which will be converted into an EBL), a large area step and repeat EBL system (Raith 150TWO), an inductively-coupled-plasma reactive ion etcher (ICP-RIE), low pressure chemical vapour deposition (LPCVD) system, five HEPA filtered downdraft fume cupboards, two UV mask aligners, diffusion furnaces, a plasma enhanced chemical vapour deposition (PECVD) system, bonders and vacuum deposition system. Operation of these new cleanrooms is expected to commence in late 2008.

Atomic Fabrication Facility (AFF)

The Atomic Fabrication Facility (AFF) was established in 2001 and is situated on the ground floor of the Newton Building. It contains 4 interlinked laboratories all dedicated to the development of atomically precise devices in silicon with the ultimate goal of developing a scaleable quantum computer (QC) prototype using a combination of Scanning Tunnelling Microscopy (STM), Scanning Electron Microscopy (SEM) and Molecular Beam Epitaxy (MBE). This facility has been constructed to house an Omicron Variable Temperature STM (VT STM) and a combined STM-SEM/MBE system. This multi-chamber system has been designed in collaboration with Omicron NanoTechnology GmbH and MBE Komponenten GmbH in Germany to combine a high quality SiGe MBE system with a dual STM-SEM system. This unique ultra-high vacuum (UHV) microscope and crystal growth system will allow the atomic fabrication of the complete qubit architecture and occupies two of the rooms of the AFF laboratory.

VT-STM LABORATORY

The majority of work on understanding the phosphorus in silicon surface chemistry has been carried out on the Variable Temperature Scanning Tunnelling Microscope. This instrument was installed in 1998 and consists of a custom-configured, triple-chamber UHV STM/MBE system, also manufactured by Omicron NanoTechnology GmbH in Germany. In 2000, this facility was upgraded with the addition of a silicon sublimation source (SUSI) for high quality silicon MBE growth and in 2001, a second silicon evaporation source was directly attached to the STM stage. This silicon source deposits high-quality silicon films with monolayer or sub-monolayer thicknesses and allows for direct STM observation of the silicon growth dynamics. The first chamber of this system houses the STM which can be operated at temperatures ranging from 25 K to 1100 K. The STM tool is used to image the silicon surface and perform atom-scale lithography. The second UHV chamber houses the SUSI silicon source for the MBE growth of thin epitaxial silicon films with thicknesses ranging from sub-monolayer to several tens of nanometers. Facilities to analyse surface structure and contaminants are provided in the third UHV chamber which incorporates both Low-Energy Electron Diffraction (LEED) and Auger Electron Spectroscopy (AES). In 2006, the system was equipped with a long-working distance optical microscope to allow positioning of the STM probe to specific sample areas with micrometer accuracy and since then the system has been used also for the fabrication of nanoscale Si:P devices.

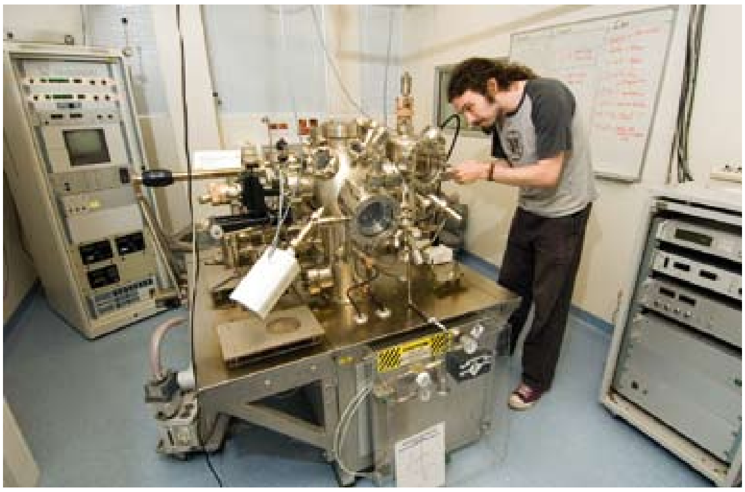

FIGURE 6

The VT-STM system for high resolution studies of the Si(100):phosphine surface chemistry.

MBE LABORATORY

A multi-chamber STM-SEM/MBE system is installed in the AFF which provides the necessary registration and high purity silicon growth capabilities required for multi-qubit fabrication. Specifically, the MBE component is capable of device quality Si and SiGe growth onto 4" wafers. Using liquid nitrogen cryoshrouds, this instrument achieves very low base pressures and low background doping levels. A liquid nitrogen gravity feed tank, necessary to provide a continuous flow of liquid nitrogen at a constant pressure and a constant fill level in the MBE cryoshrouds, was installed in 2004. The MBE system has been designed with silicon and germanium beam flux control and a separate sample preparation chamber for outgassing of samples before introduction into the MBE system. The MBE system is also compatible with growth on 1 cm^2 samples on small sample plates as required by the STM-SEM. To minimise vibrations from the crystal growth system affecting the atomic resolution of the STM, the MBE system is located on a separate concrete base. This is isolated from the main floor of the laboratory using piers drilled 10 m down into the foundation bed-rock. In addition, the two main chambers of the STM-SEM/MBE system are housed in separate rooms to reduce acoustic interference between them. In 2005, a low temperature oxide chamber, funded by the New South Wales Government, was installed onto the load lock of the MBE system for the development of high quality silicon dioxide barrier layers. The system is equipped with a RHEED, a resistive silicon sublimation source (SUSI) and a neutral atomic oxygen source extracted from a RF plasma. In 2006 the oxide chamber was upgraded with liquid nitrogen cryoshrouds to achieve very low base pressures. The instrument is routinely used to deposit silicon dioxide at room temperature for gating atomically precise devices in Si.

STM-SEM LABORATORY

Operating under UHV conditions, the STM-SEM and MBE chambers are physically connected even though they are housed in different, acoustically shielded laboratories in the AFF. A transfer line between the two systems (penetrating a dividing wall) is attached to a 3-tonne concrete block to prevent vibrations from the MBE reaching the STM. The STM system incorporates an SEM that allows registration markers to be easily found without damaging the STM tip. A specially designed optical position readout system is also incorporated to allow precise alignment of features during successive fabrication steps. Future plans for the SEM involve adapting it for Electron Beam Lithography, thus allowing registration of STM fabricated features with a pre-patterned substrate. This system is where most of the pioneering device work has been developed and was upgraded in 2007 with a newly designed manipulator for more accurate temperature control, a new electron-beam heater for sample preparation and a silicon sublimation source.

VACUUM TESTING LABORATORY

The AFF contains a general work area which houses a UHV test rig. The test rig is crucial for calibrating Knudsen cells and testing UHV components, ensuring that the cleanliness of the main MBE chambers is maintained. This laboratory also provides a workstation area for image manipulation and analysis. In 2006, this laboratory was modified to accommodate the VT-STM, whilst the VT Laboratory was reconfigured to house a new Omicron Nanoprobe system. This new four probe STM system is designed for *in-situ* electrical characterisation of nano, atomic-scale devices and is part of a separate, recently funded LIEF grant in collaboration with the Universities of Sydney (Crossley, Reimers, Hush, Stampfl) and Newcastle (Smith, Radny, King). This system is used for the development of new projects outside the Centre in quantum and molecular electronics as well as for fundamental characterisation of defect states of interest to qubit architectures.

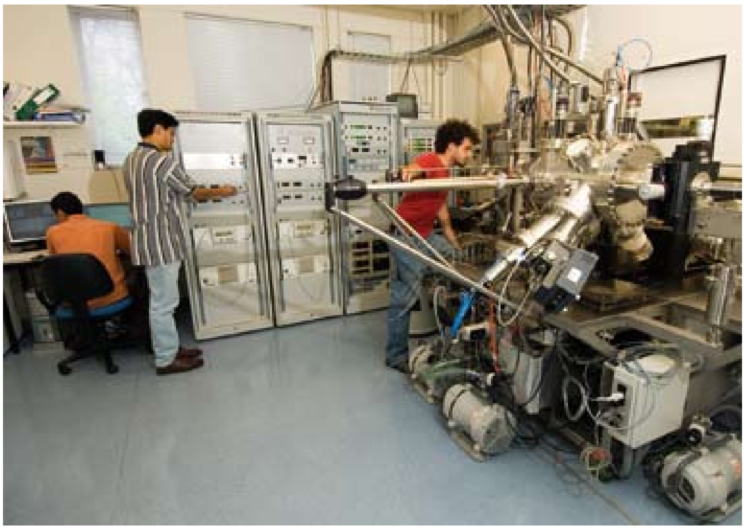

FIGURE 7
Transfer of samples from the recently commissioned oxide chamber through to the STM-SEM system.

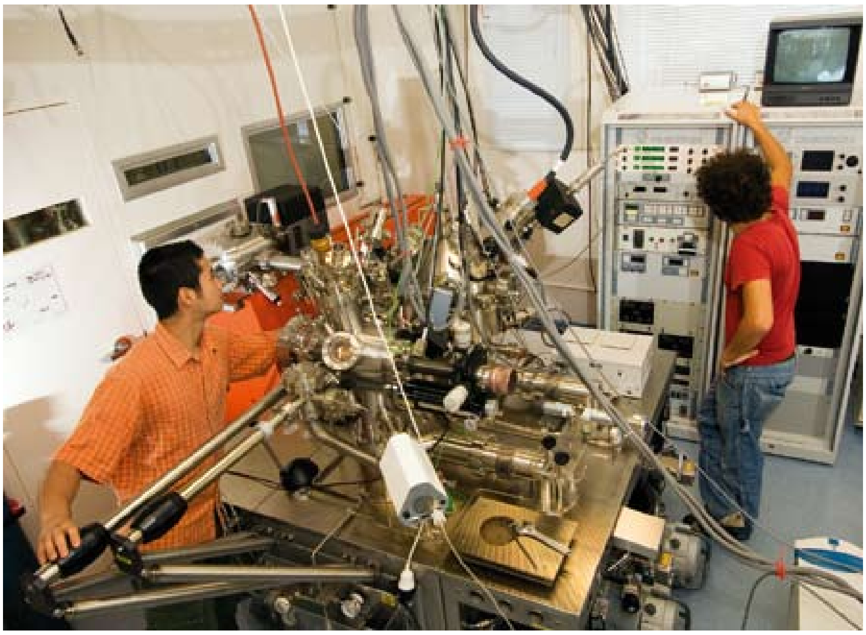

FIGURE 8
Loading a substrate with registration markers into the STM-SEM system.

National Magnet Laboratory (NML)

The National Magnet Laboratory (NML) houses sophisticated experimental facilities for performing characterisation and measurements of nano-scale devices. This 200 m^2 laboratory contains equipment capable of measuring voltage signals in the pV range, from DC to 50 GHz microwave frequencies. These measurements can be performed at temperatures ranging from 10 mK to room temperature, at constant magnetic fields up to 16 T or pulsed magnetic fields up to 60 T.

The laboratory is at present equipped with four dilution refrigerators with various configurations to enable a wide range of measurements. The laboratory is supported by two full time professional staff with extensive experience in cryogenics and measurement systems.

The 'DC' dilution refrigerator is housed in an electrically screened room and is configured to allow highly sensitive measurements of two independent samples simultaneously using DC and low frequency AC measurements.

Two 'RF' dilution refrigerators have been custom designed and configured to allow ultra-high speed measurements on picosecond timescales using radio frequency (200–600 MHz), fast pulse (30 ps) and microwave (0–50 GHz) techniques. RF fridge 1 is housed in a copper screened room. Supporting instrumentation includes: RF and microwave sources, cryogenic low noise amplifiers, two RF spectrum analysers, a network analyser and fast multi-channel oscilloscopes for data collection.

In addition to this equipment, a new 50 GHz fast pulsed RF source has been purchased to extend measurement capabilities of the laboratory. This source will be used in conjunction with an AWG arbitrary waveform generator for pulsed measurements.

An important addition to measurement capabilities in 2007, was the purchase of a SIM rack for each of the three dilution refrigerator measurement platforms. Each SIM rack includes modules for a voltage source, filtering and low noise current and voltage preamplifiers, extending the low noise, low frequency capability of each fridge. Work has also continued on reducing noise levels in all fridges with the application of room temperature filtering and cold thermal anchors applied to the various platforms.

FIGURE 2

RF fridge insert being withdrawn from a helium dewar.

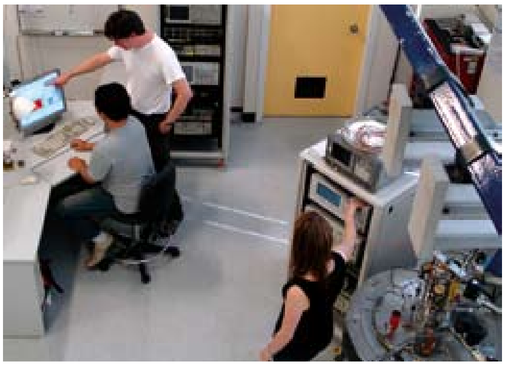

FIGURE 3

Cryogenic RF measurement platforms in the National Magnet Laboratory.

Located in a 30 m^2 laboratory which was refurbished in mid 2005 is the fourth 'plastic' dilution refrigerator which provides for longer-term DC experiments down to 100 mK, in magnetic fields up to 9 T. This system can also be used in pulsed magnetic fields up to 60 T.

Rapid characterisation of devices at liquid helium temperatures is achieved via seven device dipping probes which may be coupled to either of two comprehensive electronics racks under the control of data acquisition PCs enabling a variety of standard device tests to be performed. The tests include: DC transport, RF/microwave measurements and magnetic field studies. A RF dipping station allows for rapid testing of electrically detected magnetic resonance samples at 4 K.

Construction of a quiet space in the NML for data analysis and small meetings was also completed in 2007.

FIGURE 1

National Magnet Laboratory at the University of New South Wales.

FIGURE 4

RF fridge insert being withdrawn from a helium dewar.