Research Facilities

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

The Centre has access to three major research laboratories at UNSW: the Atomic Fabrication Facility (AFF), the National Magnet Laboratory (NML) and the Semiconductor Nanofabrication Facility (SNF). These facilities are co-located within the Newton building and offer a broad range of nanoscale device fabrication and measurement capabilities.

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 with Linux servers performing file serving and web hosting duties. Three visualisation workstations are available for simulating semiconductor devices, electromagnetic and RF fields.

There is a large services compound supporting all laboratories, incorporating; liquid nitrogen, a diesel UPS, helium recovery, gas and chemical storage. All areas operate under the UNSW OHS Management System administered by an OH&S Officer.

Atomic Fabrication Facility

The Atomic Fabrication Facility (AFF) was established in 2001 and is a unique laboratory world-wide, being the only facility dedicated to the development of atomically precise devices in silicon. The ultimate goal of this facility is to develop a scalable quantum computer 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 three state of the art scanning tunneling microscopes, including an Omicron Variable Temperature STM (VT STM), a combined Multi-scan STM-SEM/MBE system and a Omicron Nanoprobe (4 point probe STM). Each of these systems has been designed in collaboration with Omicron NanoTechnology GmbH and MBE Komponenten GmbH in Germany to combine high quality silicon growth with high resolution STM.

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. The STM can be operated at temperatures ranging from 25 K to 1100 K and 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).

MBE LABORATORY

A multi-chamber STM-SEM/MBE system 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 low temperatures 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.

NANOPROBE LABORATORY

In 2006, the laboratory was expanded to house an 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 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.

PLANNED EXPANSION 2010

At the end of 2010 the AFF will expand again to bring in 3 additional scanning probe microscopes. One of these microscopes, a new Omicron VT-STM, is to meet the growing needs of the AFF team, and is partly funded by the Federation Fellowship of Professor Simmons and by strategic UNSW funds. The other dual VT and LT STM will arrive with the new academic hire, Professor Sven Rogge from DELFT. This will bring the number of STM systems in the AFF to six, providing the highest concentration of STMs in the southern hemisphere.

FIGURE 1
Transfer of a sample into the manipulator of the VT-STM.

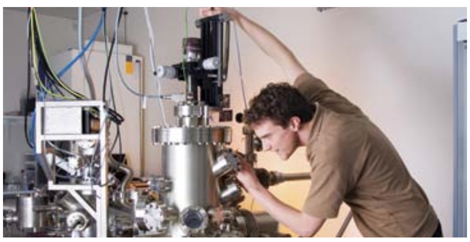

FIGURE 2
Sample loading in the Omicron Nanoprobe (4-probe) STM.

Semiconductor Nanofabrication Facility (SNF)

The SNF laboratory (Director, Professor Andrew Dzurak) contains equipment for fabricating a range of semiconductor and other devices. The SNF is jointly operated by the School of Electrical Engineering and the School of Physics. Covering more than 300m^2 over two floors, the SNF contains four laboratory areas offering differing cleanroom environments. Each floor has 50m^2 of environmentally controlled class 3.5 cleanroom. There is also 135 m^2 of class 350 cleanroom space. Plant areas accommodate the air handling, de-ionised water, lab gases, vacuum, cooling water and exhaust systems.

The lower floor class 3.5 cleanroom houses equipment for nano-scale device fabrication. The key instruments are two electron beam lithography (EBL) systems, 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 area also holds systems and services for UV lithography, metal deposition, atomic force microscopy and wet chemical processing.

The upper floor cleanroom contains facilities for producing micro-scale silicon devices. Equipment includes: high temperature silicon diffusion and oxidation furnaces, 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.

In addition, construction undertaken on an extension to the SNF throughout 2008 will deliver an additional 95 m^2 of class 35 (ISO6) cleanroom, 110 m^2 of class 350 (ISO7) cleanroom and 115 m^2 of service zones. Due for completion in mid 2009, this area will offer a range of nanofabrication equipment including a high resolution Raith150TWO electron beam lithography system, an inductively-coupled-plasma reactive ion etcher (ICP-RIE), a low pressure chemical vapour deposition (LPCVD) system, a plasma enhanced chemical vapour deposition (PECVD) system, metal deposition equipment, UV lithography tools and five HEPA filtered downdraft fume cupboards.

FIGURE 1
Operation of the Sirion and XL30 EBL systems at the UNSW Semiconductor Nanofabrication Facility.

FIGURE 2
Class 3.5 cleanrooms at UNSW SNF.

SPECIAL GASES SYSTEM

Deposition, dopant and etching tools are served by the Special Gases System which stores and distributes process gases to the laboratory. A rooftop gas enclosure houses gas cylinders, distribution pipes, exhaust extraction and environmental control equipment. Gas monitoring and automatic safety interlocks are incorporated due to the hazardous nature of some gases.

AUSTRALIAN NATIONAL FABRICATION FACILITY

The SNF hosts the NSW Node of the Australian National Fabrication Facility (ANFF) with Professor Andrew Dzurak serving as Node Director. Established via the National Collaborative Research Infrastructure Strategy (NCRIS), ANFF provides Australian researchers from both the public and private sectors with access to advanced fabrication equipment. The ANFF-NSW Node has secured $6m worth of funding from Commonwealth and State governments and from UNSW for the period 2006–2011. The majority of this funding is directed towards construction of the SNF Extension and the purchase of process tools to be located there. In addition, ANFF funds three staff at the NSW Node.

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 30 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.

All setups have been provided with new ultra-low noise and high bandwidth current amplifiers. This new equipment allows detection of currents in the pA range with 50 microseconds time resolution, or fA at low frequency. Work has also continued on reducing noise levels in all fridges with the application of room and low temperature filtering and cold thermal anchors applied to the various platforms.

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.

There is a quiet space in the NML for data analysis and small meetings.

FIGURE 1

National Magnet Laboratory at the University of New South Wales.