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.

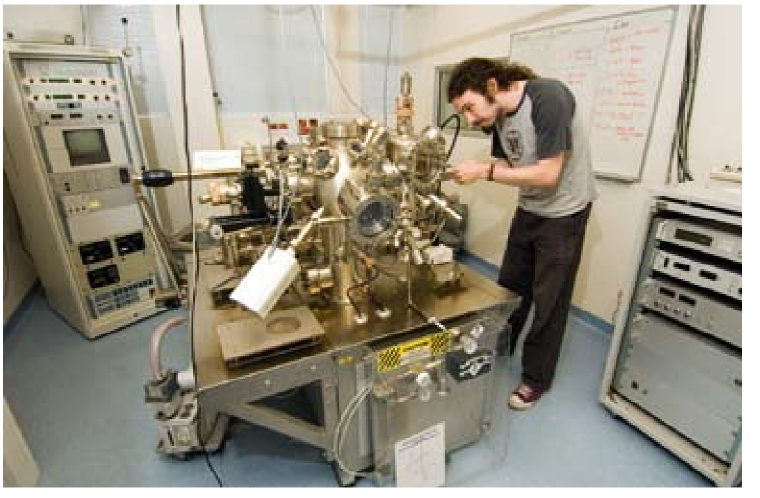

FIGURE 6

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.

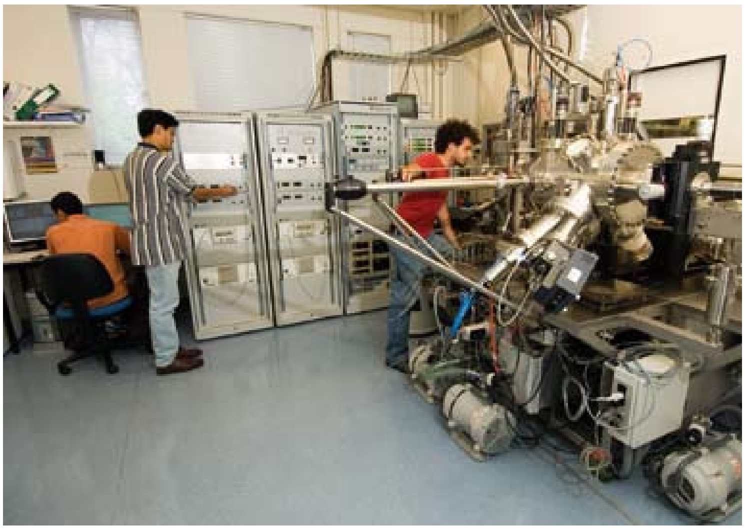

FIGURE 7

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

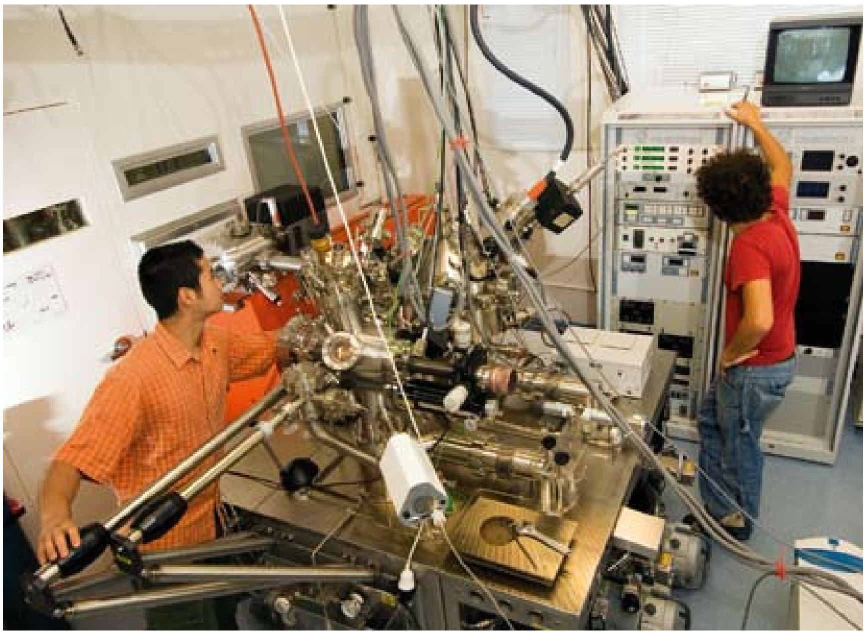

FIGURE 8

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