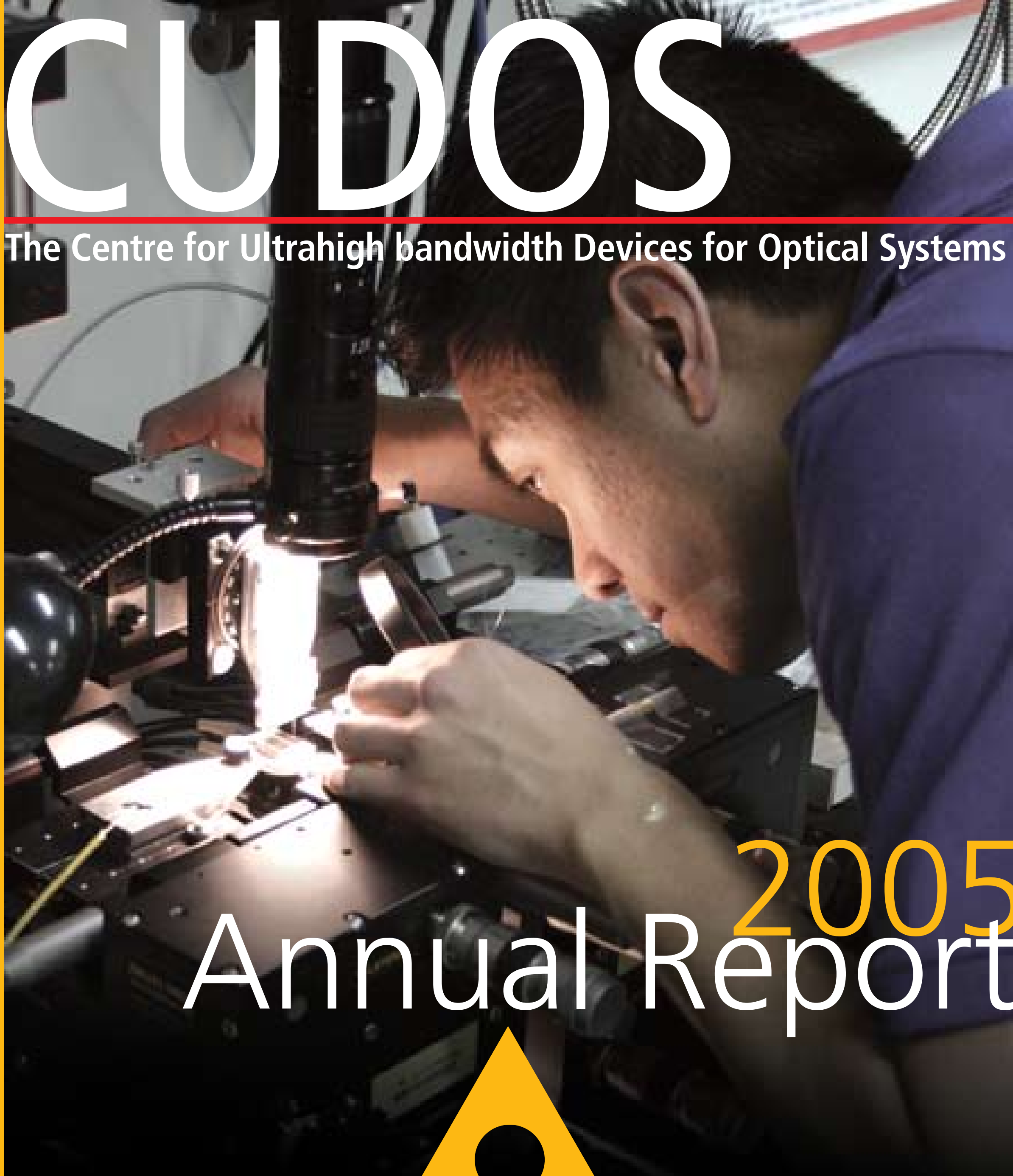
CUDOS

The Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS)



2005 Annual Report

University of Sydney

The research laboratories of the University of Sydney School of Physics node of CUDOS consist of six individual laser laboratories, a large common area housing an extensive suite of high bit-rate test equipment as well as a number of other projects and work stations, a laboratory devoted to the tapering of optical fibres and a clean room housing an automatic alignment system. The facilities are all housed within the School of Physics on the Camperdown campus of the University of Sydney.

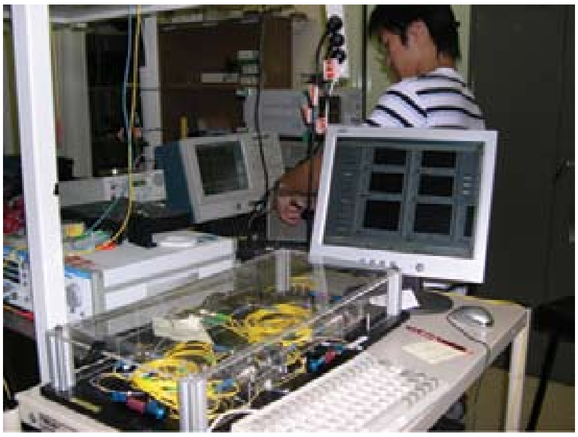
▲ **The School of Physics at the University of Sydney, home to the CUDOS laboratories.**

BERT (Bit Error Rate Test) system

▲ **Martin Rochette, a researcher visiting CUDOS on a Canadian Travelling Fellowship, makes an adjustment to a component in the 40 Gbit BERT system he assisted in assembling whilst in Sydney.**

An Agilent 81250 ParBERT system, in conjunction with custom-assembled pulse slicer, data modulator and high speed detection comprises the CUDOS 40G BERT test station. A large quantity of specialised optical test and manipulation hardware, including tunable continuous wave and high speed pulsed optical sources, optical filters and attenuators are assembled for use by researchers who are engaged in testing transmission impairments in novel photonic structures, as well as new concepts in data regeneration using nonlinear optical means. The system operates at 40 Gb/s and will be extended to 160 Gb/s during 2006.

Optical sampling of high speed pulse trains (160 Gbit/s)



▲ **A vacation student, Eric Lo, works on development of the optical sampling system constructed within the CUDOS laboratories at the University of Sydney.**

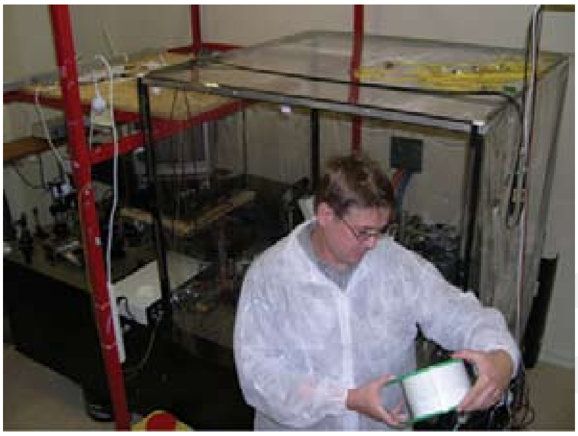
A system has been constructed and is currently under evaluation for optical sampling of high bit rate pulse trains at rates in excess of 40 Gbit/s, as electrical measurement systems cannot respond to the high speed short optical pulses in such bit streams. This system is complementary to a commercial frequency resolved optical gating (FROG) system used for pulse characterisation in the CUDOS laboratories.

Automatic fibre-waveguide alignment system

▲ **The fibre-waveguide automatic coupling alignment system installed in a Class 350 clean room within the laboratories at CUDOS, University of Sydney.**

A Newport AA-Modal 18 axis automated waveguide alignment station has been installed into a Class 350 clean room situated within one of the laboratory spaces in the School of Physics. Used in conjunction with a dedicated optical source and detector, this system is being used for testing the effectiveness of fibre-waveguide coupling schemes using purpose-built optical fibre taper devices.

UV fibre Bragg grating (FBG) prototyping and characterisation facility



▲ **Ian Littler, Senior Research Fellow within CUDOS, works on the UV fibre Bragg grating writing system in the CUDOS laboratories.**

Fibre Bragg gratings are written in-house in the laboratories at the School of Physics using a resilient custom-built UV-laser based near-field grating writing system. These gratings are used both as utilities in other optical propagation research projects, and also form the basis of a number of projects investigating the fundamental physics of the interaction of light with gratings. A swept-wavelength source (SWS) system is used for characterisation of the optical loss of the gratings written with this system and this system has been extended by CUDOS researchers to permit measurement of the dispersion.

In a development project complementary to the UV grating writing facility, researchers at the School of Physics are working on a system for imprinting resonant grating structures into photosensitive chalcogenide waveguides created at the Australian National University. This material is highly photosensitive and can be excited with relatively low power green light from a frequency doubled DPSS laser system. The preliminary results of this work have been highly promising and plans are underway to extend the system to longer sample lengths with the purchase of a precision translation stage. This work supports the creation of optical regenerators and optical "slow-light" buffers on photonic chips.

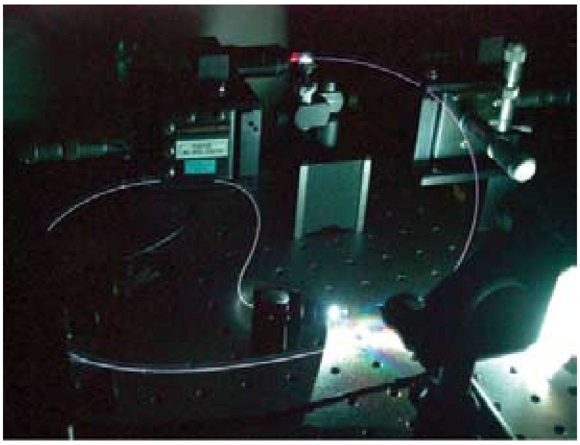
Raman facility

An 80 MHz 8 ps Nd:YVO4 laser installed in one of the CUDOS laboratories is used to pump a dedicated optical parametric oscillator, generating pulses tunable in the wavelength range of 1398 – 1608 nm. This source is used for investigating Raman and other resonant optical nonlinearities within waveguide samples of chalcogenide glass supplied by researchers at the Australian National University. This measurement capability is also complemented by a pair of Raman fibre lasers emitting high energy CW light in the S-band (1455 and 1480 nm) as well as high-power optical amplifiers, and a large amount of ancillary test and measurement equipment.

In-fibre dispersion measurement

A system has been assembled for measuring the optical dispersion of short lengths of optical fibre over a broad wavelength range. This system employs a white light supercontinuum source and measures the dispersion using an interferometric technique and has been used to measure the dispersion of several photonic crystal fibres.

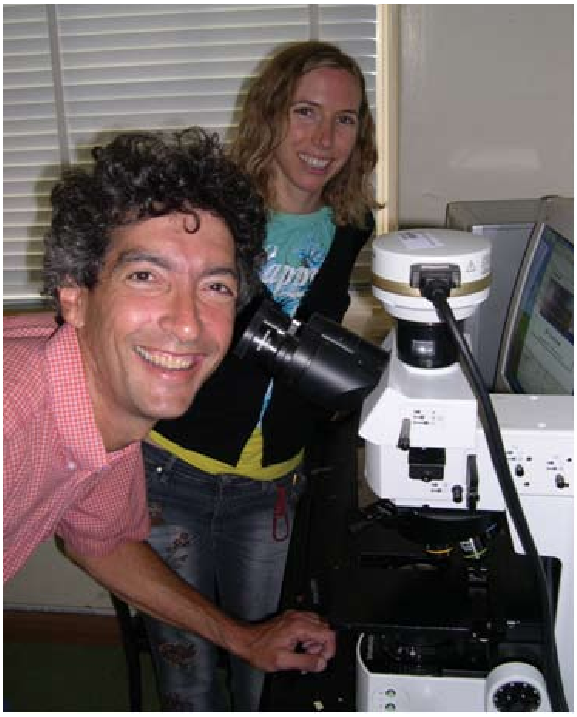
Femtosecond supercontinuum pulses



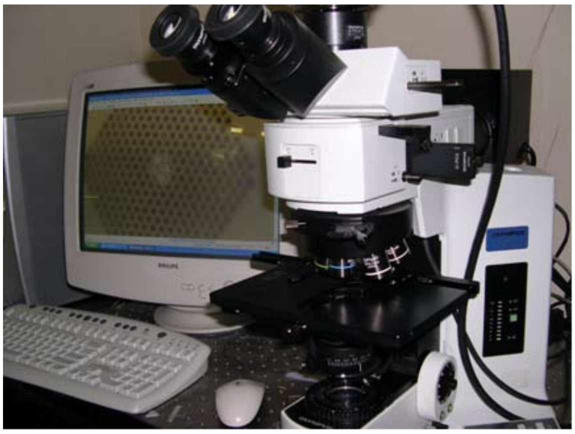
▲ **A white light supercontinuum is generated in a short length of specialty optical fibre in the CUDOS laboratories.**

Research is underway into ways of optimising the generation of broadband white light supercontinuum by using tapering of photonic crystal fibre in the coherent (femtosecond) regime. 80 fs pulses from a mode-locked Ti:sapphire laser are used to generate the nonlinear spectral broadening, and a specialised extended wavelength optical spectrum analyser (Ando AQ6315E) and purpose-built frequency-resolved optical gating (FROG) acts to characterise the output pulse characteristics. This work is carried out in complement to the sophisticated physical system modelling capabilities developed by the researchers at CUDOS.

High resolution microscopy



▲ **Mark Cronin-Golomb, visiting researcher from Tufts University, and Christelle Monat, researcher within CUDOS, in front of the high magnification microscope.**



▲ **An image of the cross-section of a holey PCF fibre imaged on the 1500X microscope.**

An Olympus BX71 microscope with up to 1500x magnification and 12 megapixel camera with diffential phase contrast is used to measure the properties of prototype waveguide devices and tapered photonic crystal fibre devices.

Fibre taper facilities

▲ **Cameron Smith, Masters student in CUDOS, works on one of the optical fibre taper stations.**

In the CUDOS laboratories there are several purpose-built systems designed for the controlled tapering of optical fibres to sub-micron dimensions using the flame-brushing technique. These tapers are of interest both in their own right (for example, for creation of enhanced supercontinuum) and also as couplers in photonic chip access projects. The tapering capability is to be extended to permit the tapering of optical fibre drawn using the highly nonlinear chalcogenide glass.

ANU Nonlinear Physics

Two fully equipped experimental nonlinear optics laboratories were established in the first year of the Centre. The laboratory equipment, which was partially supported by CUDOS funds, comprises

- Three laser tables and continuous wave laser sources including 5W Verdi-V from Coherent as well as a number of other low power (<100mW) solid state lasers;
- A femtosecond laser system based on Verdi-V pumped Mira 900 from Coherent. This is a new facility, established in 2005. The system will be used, for instance, in the studies of short pulses propagation in periodic structures such as PPLN or liquid crystals-infiltrated microstructured fibers infiltrated with liquid crystals;
- A Hamamatsu X8267M optical beam shaping system based on liquid crystal two-dimensional spatial light modulator. This device has 1024x768 pixels and a phase shift of more than 2π in the wavelength range 400-600nm. The system is applied to the generation of optically induced photonic lattices as well as nontrivial (phase and amplitude modulated) beam profiles such as optical vortices or Bloch states of different symmetry points of the periodic structures.

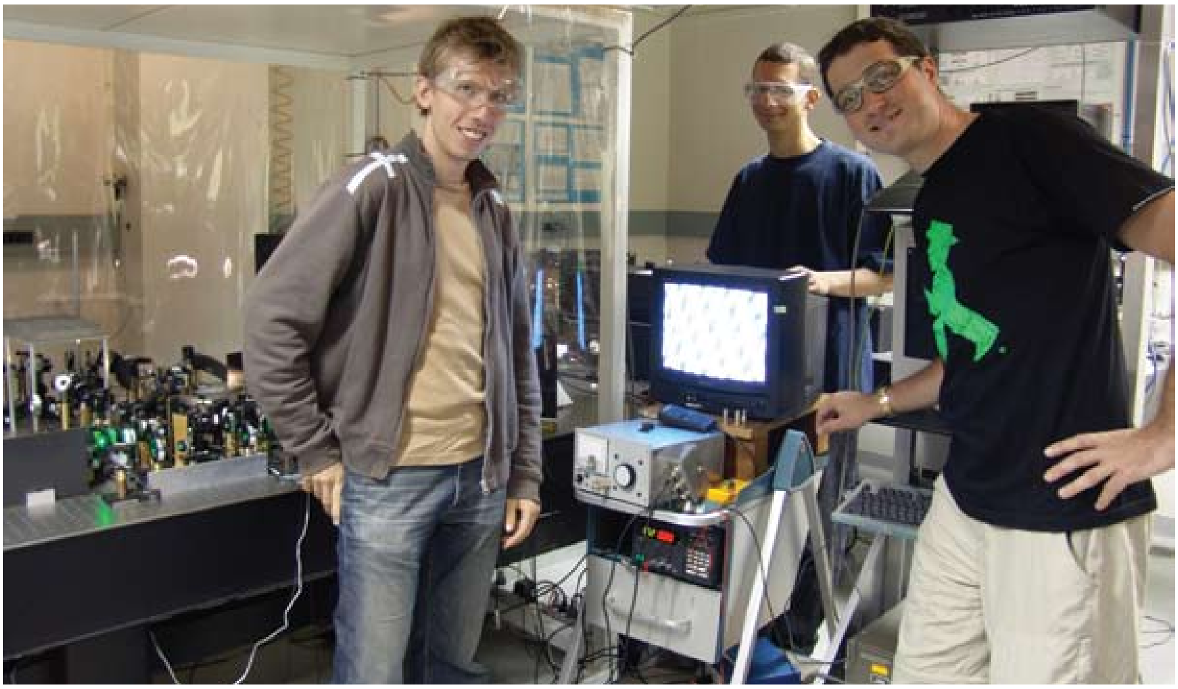
In addition, the group has access to planar technology through our collaboration with Dr Arnan Mitchell and Professor Michael Austin, from RMIT, Melbourne. This facility enables us to fabricate titanium in-diffused waveguide structures in lithium niobate wafers.

ANU Laser Physics Centre

The CUDOS team in the Laser Physics Centre (LPC) at the Australian National University fabricates planar optical waveguides and photonic crystal structures from chalcogenide glasses in support of the CUDOS program. The resulting structures are supplied to other researchers within CUDOS involved in device development and testing, particularly those at the University of Sydney. LPC's offices and laboratories occupy some 1500m^2 of space are located in the John Carver, Cockroft and Huxley buildings in the Research School of Physical Sciences and Engineering at ANU.

The main laboratories supporting the CUDOS program comprise a glass chemistry laboratory; the laser deposition laboratory used for thin film production; a lithography laboratory dedicated to patterning sub-micron patterning of optical waveguide structures; the plasma etching laboratory; and the ion mill facility located in the ANU's electron microscopy unit.

A new 50m^2 glass chemistry laboratory is dedicated to the production of bulk chalcogenide glasses with novel compositions. The laboratory contains a dry nitrogen glove box for mixing the raw materials before sealing into evacuated ampoules and rocking and annealing furnaces for glass melting and post processing. Glass boules from this laboratory are cut and polished before assessment for suitability for device fabrication. Glass characterization involves techniques such as spectrophotometry; photo-thermal deflection spectroscopy; differential scanning calorimetry; Raman spectroscopy; refractive index measurements; determination of optical nonlinearity



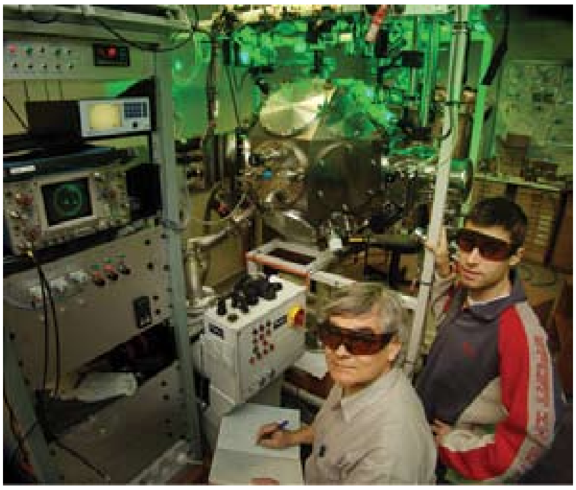
▲ **Dragomir Neshev in the ANU Nonlinear Physics Laboratory with students.**

via four wave mixing and Z-scan measurements across the visible and IR; and compositional analysis such as Energy Dispersive X-ray Analysis (EDX).

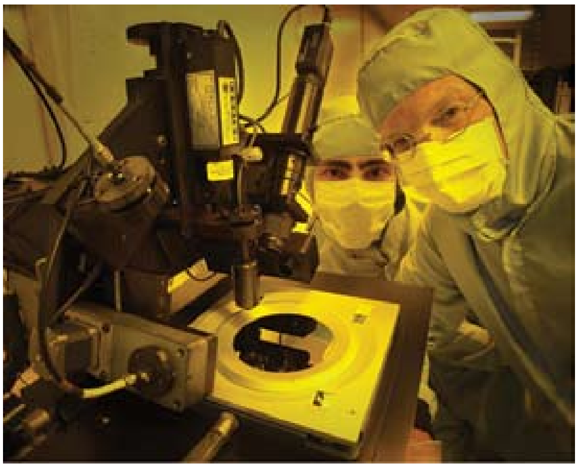
Glass samples are turned into thin films deposited onto various substrates using LPC's ultra-fast pulsed laser deposition (UFPLD) facility. In 2005 a new custom deposition chamber was commissioned, designed for pulsed laser deposition of micron thick films with high uniformity over 100mm diameter wafers. Film uniformity better that ±0.25% over the wafer is achieved.

The films produced by UFPLD can be assessed using a similar range of diagnostic tools as are applied to the bulk glass. Additionally, refractive index and thickness are mapped using an SCI Filmtek 4000. Films can be post processed in a range of vacuum annealing ovens prior to patterning to create optical waveguides. The photolithography laboratory uses an SVG-800 dual track coating and development system in conjunction with a Karl Suss MA6 exposure tool to transfer waveguide patterns into photoresist masks with sub-micron resolution. Pattern transfer into the glass is then accomplished using an Oxford Instruments RIE-100 ICP plasma etching tool. The resulting structures undergo characterization for linear and nonlinear optical properties using a range of waveguide testing facilities.

The production of photonic crystal membranes requires dimensional control at the nanoscale not possible using the facilities in the photolithography laboratory. As a result the CUDOS team has developed a unique capability for directly patterning structures into free standing chalcogenide glass membranes using the ANU's Orsay Physics focused ion beam mill (FIB). Extensive hardware and software development in particular allowing "on-the-fly" correction of any mechanical drift at the few nanometer level that inevitably occurs in the FIB over hour-long milling times sets the machine aside from FIB facilities elsewhere.



▲ **The pulsed laser deposition facility being operated by Andrei Rode and PhD student Nathan Madsen.**



▲ **Wafer mapping using the SCI Filmtek 4000 (Barry Luther-Davies and Darren Freeman).**

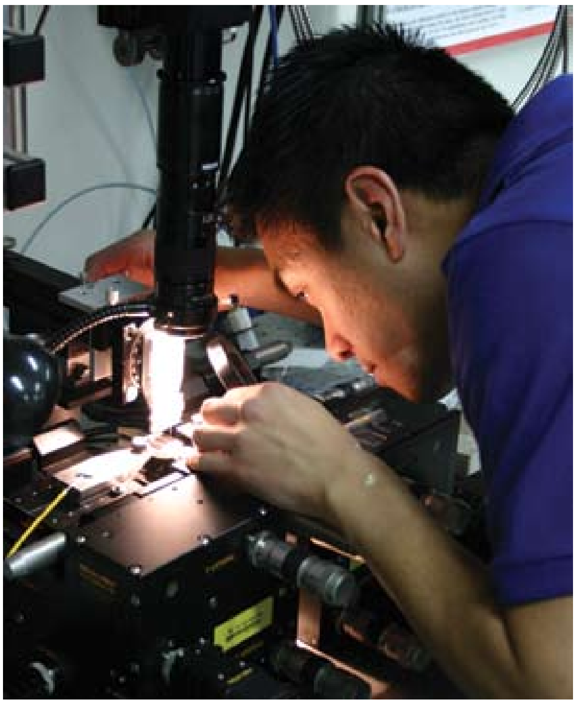
▲ **Track coating and lithography tools in the LPC clean room (Steve Madden).**

Macquarie University

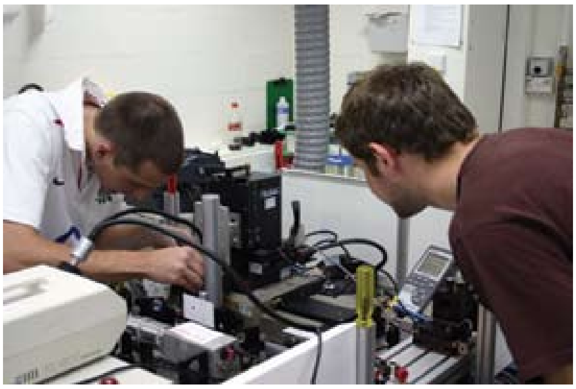
The research laboratories of the CUDOS @ Macquarie Node include our newly refurbished photonics laboratories (total space 115 m^2) housing a suite of micro-processing and micro-characterisation equipment. The group also has access to a clean room and profilometers. These facilities are all housed within building E7B on the Macquarie University campus. In addition, the CUDOS @ Macquarie group led a University based consortium seeking funding for a new scanning electron microscope with an Energy Dispersion System for identification of the chemical components in our substrates. This device was installed in the adjoining building in 2005 and is freely accessed by CUDOS staff and students.

Photonics Laboratory

This laboratory hosts several major facilities enabling both micro-processing and micro-characterisation of photonic components. The first of these is the ARC LIEF funded femtosecond laser microfabrication facility: This is a general facility shared by a range of CUDOS projects: laser machining glasses and crystals, direct writing fibre gratings and direct writing planar waveguide structures inside bulk glasses. The key components of this facility are a kHz pulse rate Hurricane femtosecond laser, frequency doubler and tripler, and two high precision XYZ (Aerotech: 10 nm resolution, 25x25x25mm and Aerotech: 10 nm resolution, 100x100x100 mm travel). Secondly, this laboratory houses a micro-characterisation and assembly facility used for the characterisation, over the entire C-band, of photonic crystal and guided wave devices. This facility combines high precision 12 axis alignment stages (Melles Griot Nano-Max), optical probes (JDS swept wavelength system), imaging system and fibre pigtailing capability in an integrated system. Other systems available in this laboratory include a CO2 laser glass processing rig used for fabricating fibre tapers for evanescent probing as well as shaping and fusing glass components.



▲ **Andrew Lee working with the femtosecond laser facility.**



▲ **Graham Marshall sets up the translation stages in the femtosecond facility.**

Photonic Laboratory II

We are currently in the process of building a second femtosecond laser processing facility incorporating a MHz pulse rate, high pulse energy oscillator on loan from Femtolasers Produktions GmbH and Garching University, Munich. This system will be used to investigate the interaction between ultrashort laser pulses and optical materials. This laboratory will become operationable in 2006.

Diagnostic Laboratory

This laboratory hosts conventional (Olympus BH2), stereo and Differential Interference Contrast microscopes (Olympus BX71) used for optical characterisation of a range of microstructured devices. Also included in this laboratory is a fibre annealing station and Abbe refractometer.

Glass Processing Laboratory

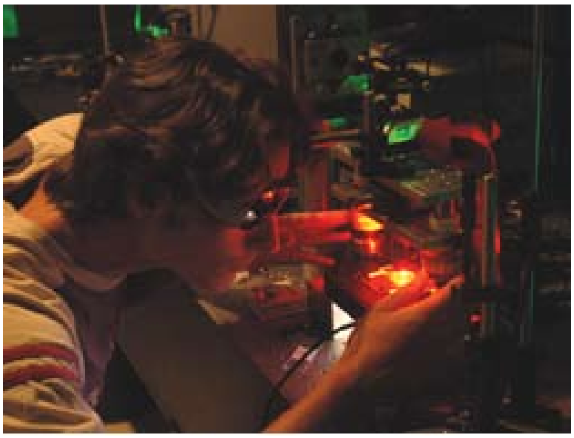
This laboratory supports the growing needs for mechanical processing of glass and crystalline materials by the CUDOS group. Systems available for this purpose include a high temperature oven, diamond face grinder, optical polisher, ultrasonic drill, diamond coring drill, diamond saws and computer controlled wafer dicer. In addition, the laboratory houses laminar flow hoods for miscellaneous processing needs and glove box used for self assembly studies. The laboratory also houses a computer controlled electric field poling station, incorporating a programmable high voltage power supply (Trek 20/20B) and Perspex electrolyte cells, for producing quasi phase matched crystals.

Other Facilities

The CUDOS group shares a nanosecond laser microfabrication facility incorporating a high power visible laser (Lightwave 18W 532nm laser) and high precision XYZ stages (Aerotech 250x250x250mm and continuous rotation) for laser machining and laser direct write lithography. In addition, members of CUDOS access a Class 35 (US Standard class 1,000) clean room. The facility has been designed to conform with Australian Standard AS1386.1 for non-laminar flow clean rooms. It includes a mask aligner, scriber, wet-chemical bench, vacuum deposition system and profilometer, meeting our lithographic needs. Access to microanalytical tools is also available in the form of a JEOL analytical SEM and a Weeco 3D Optical Profiler.

Swinburne University of Technology

Ti:Sapphire femtosecond lasers and an optical parametric oscillator have been used for the fabrication of photonic crystal structures in polymer materials and lithium niobate crystals. In order to apply advanced beam shaping techniques and new methods for the characterisation of the photonic crystals, new laser sources providing larger pulse energies and a tuning range that spans the whole visible and infrared regime where needed. For this purpose we have extended our femtosecond laser facilities with a regenerative amplifier system (Spectra Physics' Spitfire) combined with an optical parametric amplifier (Spectra Physics' OPA-800C). By choosing Spectra Physics we were able to combine the new system with our already available femtosecond oscillators and pump sources.



▲ **Jesper Serbin adjusts the alignment for the femtosecond processing facility at Swinburne.**

University of Technology Sydney

Computational modelling is integral to the research programs of CUDOS and comprises both the development of new tools, and the use of software systems that are in wide used in the photonics industry. In contemporary photonics research, 3D simulation is now mandatory, with actual design work requiring the simulation of real 3D systems in order to accurately characterise device performance. By its very nature, 3D modelling is very demanding and requires the use of large memory, parallel computer systems. While there are a numerous simulation tools in use in the industry, finite difference time domain (FDTD) codes are now in universal use, with these now regarded as the pre-eminent general purpose simulation tool in photonics and related areas, in which direct simulation of the electromagnetic field is required. With a FDTD code, the system response is determined by numerically integrating Maxwell's equations in both space and time, allowing a pulse or continuous wave to be evolved and analysed in any device geometry.

In CUDOS, FDTD simulation is undertaken on both PC workstations and with a dedicated parallel computing Linux Cluster which has been acquired by UTS with CUDOS funds. Our facility, which is co-located at ac3 (Australian Centre for Advanced Computing and Communications), comprises 32 Dell 1750 compute nodes (each with dual Intel Xeon processors running at 3.06 GHz and having 2Gbytes of memory) which are embedded within the large 187 node Linux cluster (acquired previously with ARC LIEF funds) – one of the major high performance computing (HPC) systems operated by ac3 for the NSW university research community. The cluster runs a parallelised version of the RSoft FullWAVE FDTD software (compatible with that which runs on workstations) as well as a number of locally written codes, and is used by both Sydney and UTS node researchers.

The rapidly growing need for 3D simulation has led to workloads which have saturated the present facility and the current software licenses. Access to additional processing power will be available though ac3 with the installation of a new "capability" HPC system in 2006 as a consequence of a successful application for ARC LIEF funding, led on behalf of the NSW research community by Lindsay Botten. At the time of writing opportunities to increase the number of FDTD software licences available to the CUDOS community are being investigated.

▲ **The entire Dell Linux cluster located at ac3, with the dedicated CUDOS facility occupying one full rack.**