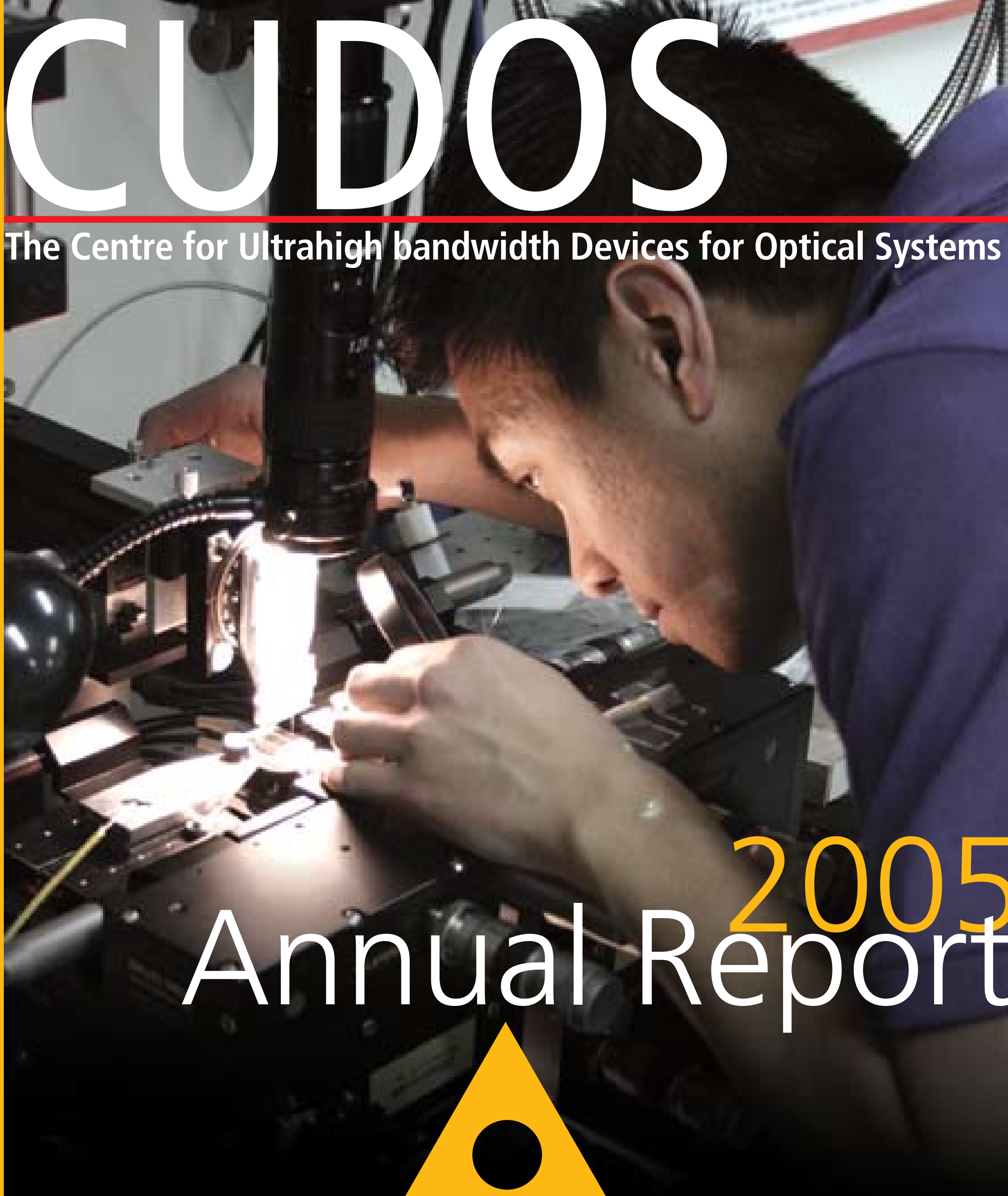
CUDOS

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



2005 Annual Report

Research Overview

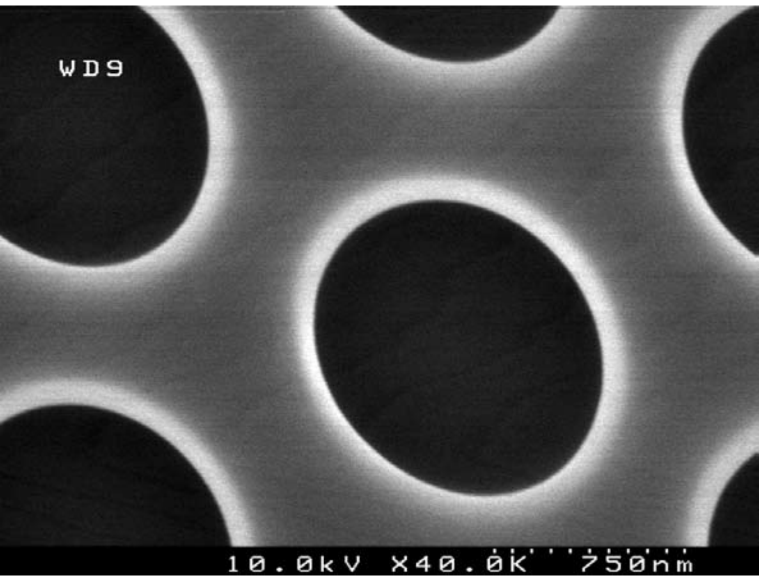
The CUDOS research portfolio is one of fundamental research in nonlinear photonics and microphotonics, structured in a strategic program aimed towards the ultimate realisation of a photonic integrated circuit. During 2005 we made major achievements in our fundamental science, and through our flagship projects we demonstrated significant progress towards our strategic goal of a PIC.

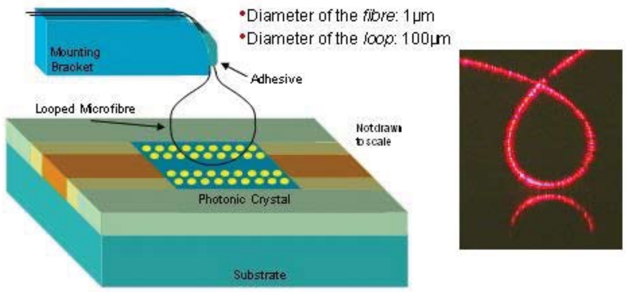
Flagship projects

The initiative to identify flagship projects within the CUDOS program was taken in 2004, with project teams forming late that year. Flagship projects are like headlines in our strategic program: they are multi-institutional, high impact programs with outcomes of demonstrable worth to the community, either in terms of scientific or socio-economic impact. Flagships integrate activities across the portfolio of our research projects, and at the same time drive new goals and targets for these research projects. As an example, consider the Optical Switch Flagship. The aim of this project is to develop a microphotonic demonstration of an optically-controlled switch for light travelling in a waveguide. In this context, "switch" means that light may be turned on or off, or switched from one waveguide to another. These are fundamental operations in an optical network. To control the switching optically rather than electronically is completely revolutionary. To achieve this, we need to bring together the following skills and scientific and technical areas of expertise:

- Design of photonic circuits in which optical nonlinearities are observed at modest input powers. In principle, this means investigating highly nonlinear optical materials (eg chalcogenide) in configurations with very intense pulses of light – this requires tight waveguiding and resonant configurations to build up large circulating optical powers. This research is done by the Photonic Circuits group led by Martijn de Sterke at Sydney.

▼ **Photonic crystals of exceptional quality, produced by CUDOS researchers at ANU**





▲ **Schematic of a looped taper used for high efficiency coupling to photonic crystal waveguides, with an illuminated looped taper (at right)**

- Sophisticated simulation tools are required to perform physically-intuitive parametric calculations that optimise the guided wave configurations. These tools are developed and provided to the researchers, both theory and experimental, by the Computational Modelling group led by Lindsay Botten at UTS.
- The fabrication of wafers of nonlinear optical material, and the subsequent patterning and etching of these wafers to produce waveguides, photonic crystals and defects in those crystals, is undertaken by two groups led by Barry Luther-Davies at the ANU: Nonlinear Materials and PC fabrication by FIB. The experimental program is tightly coupled to the theory and modelling efforts at UTS and Sydney.
- Finally, the measurement and evaluation of the devices produced by the ANU team is undertaken by the experimental team at Sydney led by Ben Eggleton. A key innovation in this aspect of the work was the development of a novel evanescent coupler based on a taper microstructured optical fibre.

Each of these activities is a scientific research project whose outcomes are novel and publishable in their own right. The integration of these activities produces a project of substantial impact that exemplifies the *raison d'étre* of a Centre of Excellence – to bring together teams with scale and focus on areas of national significance.

Research performance

The statistics for the Centre's research output for 2005 are impressive: over 80 publications in refereed journals, with our Chief Investigators presenting over twenty invited talks at national and international meetings. Our performance in each of these categories exceeds the ARC's performance metric by more than a factor of 2. The impact factor of the journals in which our research results were published during the year, averaged over all publications, exceeded 3.4 (over 4.5 for the top 40 publications) – again, well in excess of our target indicator. Taken together, these figures demonstrate that the Centre is performing exceptionally strongly in an area of high scientific interest.

Research highlights

- **Photonic crystals and PC devices:** The Centre now has the ability to produce high quality photonic crystals in two dimensional planar geometries through the work of Darren Freeman and Barry Luther-Davies at the ANU. These 2D PCs are comparable to the best structures available in silicon and are fabricated in chalcogenide, which has substantial advantages compared to silicon in terms of the magnitude and response time of the nonlinear response. Darren and Barry recently demonstrated the first resonant optical cavity in a 2D PC, characterised in the Sydney laboratory.

  Three dimensional photonic crystals with defects (to produce miniature etalons) and inclusions to both increase the refractive index and enhance the nonlinear optical response, were produced by Min Gu's team at Swinburne.

  The ability to fabricate such high quality photonic crystals has been, and will be, crucial to a range of CUDOS projects as well as being significant achievements of research excellence in their own right.

- **Superprism:** One of the first properties hypothesised in photonic crystals that marked these materials as being completely different to "ordinary" optical materials was the superprism effect. In ordinary glass, the prismatic effect resulting from the mild dispersion in refractive index across the spectrum produces visible separation of the colours. In a photonic crystal the dispersion, and hence the angular separation, is magnified to an astonishing degree. Observation of this effect, which occurs at frequencies near the band edge of the crystal and only in certain directions, has been a focus of intense experimental effort internationally. With strong guidance from the theory groups at ANU, Sydney and UTS, Min Gu's group at Swinburne has now reported the first observation of the effect in a polymer material. This is a major achievement and, apart from its intrinsic scientific interest, has allowed the Centre to begin thinking of ways in which a compact multiplexing or de-multiplexing device could be developed based on this effect.

- **Coupling to photonic crystals:** Much of our work involves coupling light from optical fibres, either single mode or microstructured core fibres, to planar waveguides in materials of high refractive index – chalcogenide, silicon and so on. Like the superprism effect, this problem has received a lot of international attention since it represents a fundamental limitation to experimental activity and ultimately is a problem that must be solved if photonic integrated circuits are to become a reality. The Sydney and UTS groups have done much theoretical work on this problem, and have developed an understanding of the key aspects that is second to none. Recently, Christian Grillet applied some interesting developments arising from work by Eric Mägi and Cameron Smith to achieve high efficiency coupling with excellent spatial resolution from a silica fibre to a chalcogenide rib waveguide. Eric and Cameron had developed a microstructured fibre taper with a localised region where the mode changed from strongly confined to evanescent.

- **Negative refraction:** Yuri Kivshar and his team have succeeded in observing, and controlling, negative refraction of light in an optical lattice. Negative refraction first surfaced as a mathematical curiosity, but recent experimental observations in a range of meta-materials have confirmed that the effect does indeed exist. This takes the study of this strange phenomenon to a new level where not just observation but control has been achieved.

- **Direct writing of waveguides in bulk materials:** The high intensity in a femtosecond laser beam produces permanent changes to the refractive index of a material into which it is focused via a two photon process - without thermal damage. The threshold for the interaction is high, so by carefully controlling the laser power the index change can be restricted to a region that is small compared to the focal volume of the laser. Mick Withford and Graham Marshall's team at Macquarie have exploited this effect to write optical waveguides into bulk material. By controlling the pulse rate of the laser and the speed of the translation stage, they also wrote an even pitch of periodic refractive index changes into the core of both single mode fibres and micro-structured fibres to form a Bragg grating.

These are just a few highlights, but they emphasise the strong scientific base and the development of platform technologies that are a feature of the substantial scope of our research. Flagship projects, on the other hand, exemplify the strategic focus of our research program.

Sydney Node

Ben Eggleton

Sydney Group

The CUDOS program at the University of Sydney occupies a suite of sixteen offices and laboratory space of around 150m^2 in the School of Physics. During 2005 the group had three Chief Investigators including the Research Director, eleven researchers paid either partially or fully from the CUDOS grant, fourteen postgraduate students, six visiting scientists, and two administrative staff including the Chief Operations Officer.

The Sydney group has strong programs in both theory and experiment. On the theory side, the group collaborates closely with the UTS modelling team to investigate a range of problems in photonic crystal circuits. Students working on these problems are jointly supervised by UTS and Sydney academics. Mike Steel (RSoft) spends two days per week working with the group as an Honorary Associate and is a key contributor to a range of projects.

The experimental effort has concentrated on projects ranging from fundamental studies of nonlinear short pulse propagation through to development and evaluation of a range of photonic device concepts. Device concepts are aimed at applications in transparent optical networks and include optical regeneration and generation of 160 Gb/s pulse trains by nonlinear pulse compression techniques. The Sydney and ANU groups collaborate closely on the chalcogenide program, where Professor Luther-Davies' team provides expertise in chalcogenide film production and waveguide and photonic crystal fabrication. The Sydney team provides expertise in device design and optimization, optical grating writing, optical coupling and characterisation of the functional performance of the devices that are produced.

The group continues to benefit from strong support from the University. During 2005 we were awarded over $300,000 towards the purchase of a 40 Gb/s electrical bit error rate test system, to which an optical front end was added by Dr Martin Rochette to provide a unique optical network measurement system for evaluation of ultrahigh bandwidth photonic device concepts. We have been advised that an application under the ARC Linkage (Infrastructure) grant scheme, submitted collaboratively with NICTA and RMIT University, to upgrade this system to operate at 160 Gb/s has been successful.

Our fibre tapering facilities continued to be developed during 2005 and now underpin several projects. Most recently we succeeded in using carefully controlled fibre tapers under tight mechanical positioning control to couple light into a chalcogenide photonic crystal waveguide. This is a key achievement for a number of our Flagship projects.

The group benefited from interactions with a number of visiting scientists and students during the year. Professor Mark Cronin-Golomb from Tufts University spent a one-year sabbatical working on applications of optical tweezers, while Professor Marc Dignam completed his sabbatical and returned to Queen's University, Kingston after a fruitful collaboration with Martijn de Sterke and Ross McPhedran on radiation dynamics. Dr David Fussell, who obtained his PhD during 2005, is now working as a post doctoral fellow with Professor Dignam. Dr Klaus Finsterbusch (Münster) is spending eighteen months working on nonlinear pulse propagation effects in chalcogenide rib waveguides with support from a German travelling fellowship.

Three other students completed their degrees during 2005. Ms Trina Ng submitted her MSc thesis while Tom White has been awarded a highly competitive University of Sydney postdoctoral position for six months and will spend this time with CUDOS. Audrey Lobo also submitted her thesis and now works at the Commonwealth Treasury Department. Mehrdad Shokooh Saremi spent one year with CUDOS under a co-tutelle agreement with Ferdowsi University, Iran. He successfully defended his PhD thesis on his return to Iran.

Our honours students had a successful year, with both Rob Hansen and Dane Austin being awarded first class honours. Dane was also awarded a University Medal. The group also supervised the final year undergraduate projects of 4 Engineering students, and takes on around a half dozen outstanding second and third year science students over each summer vacation.

During 2005 we said farewell to Dr Justin Blows, who left research to start a new career as a patent attorney. Dr Clare Lyngå resigned to take up a position in the Australian public service while Dr Alex Fuerbach left to take up an Australian Postdoctoral Fellowship at Macquarie University. Alex maintains links with CUDOS through the femtosecond laser research he is conducting at Macquarie. We welcomed Dr Mark Pelusi, a graduate of Professor Tucker's optical networks group at Melbourne University with extensive industry experience, who has joined us to work on our optical network applications projects. Dr Christelle Monat (Lyon) has joined the CUDOS group to work on the microfluidics project. Although this work is funded under a separate Discovery grant, Dr Monat collaborates closely with CUDOS team members.

Our group has developed a strong rapport with research groups in Quebec, which traditionally has been a centre of photonics expertise (both academic and industrial) in North America. Dr Martin Rochette (University of Laval) continues his work with us with the support of a Canadian Travelling Postdoctoral Fellowship, while we had Mr Dominik Pudo (McGill) spend three months with us as part of his PhD studies. Mr Neil Baker and Mr Michael Lamont, both from Canada with photonics industry experience, joined us as PhD students. We also benefited from the contributions from Mr Rhys Adams (Ecole Polytechnique Montreal) during his three-month stay in Australia. Professor Andrew Kirk (McGill) arrived at the end of 2005 to commence a six month sabbatical with us.

We congratulate Dr Boris Kuhlmey, who has been awarded an Australian Postdoctoral Fellowship. Boris will commence his Fellowship in 2006 working within CUDOS.