CUDOS

Research Overview and CUDOS Facilities

Annual Report 2004

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

An Australian Research Council Centre of Excellence

Research Overview

Ben Eggleton, Research Director.

Research Director: Ben Eggleton

In my overview last year I emphasised the integrated structure of CUDOS research, and how crucial the contributions from each research node were to achieving our overall five year program goals. Our roadmap for the CUDOS research program targets the development of basic capabilities in the first year, the development of prototype devices and concepts and enabling technologies in the second year and the first demonstrations of microphotonic devices in year three. Years four and five will be focused on validation of our concepts and on exploring the rich mix of optical physics expected in these microphotonic components.

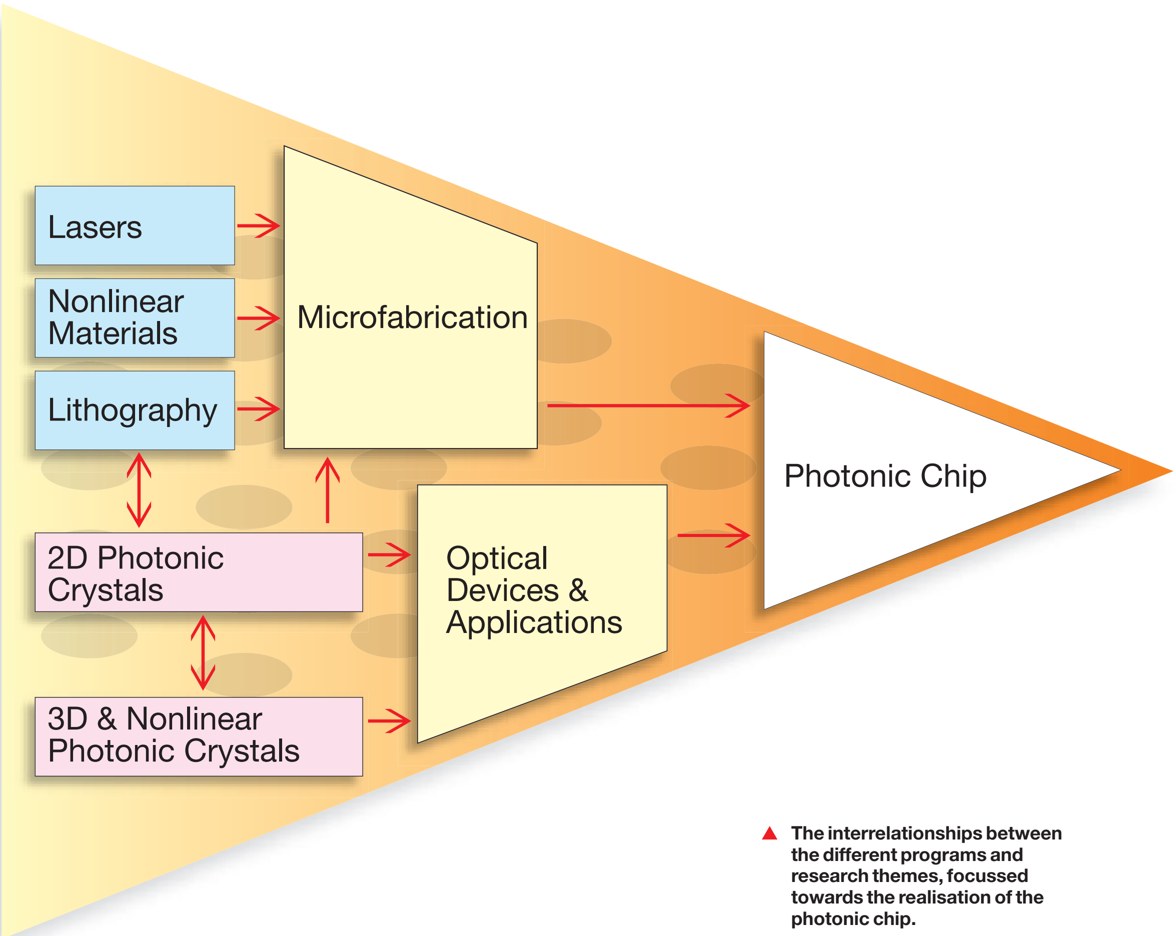
I am delighted to report that this year we have made demonstrable and substantial progress along this path, and that the strong collaborations across the Centre have been the basis of this progress.

Progress toward the photonic chip

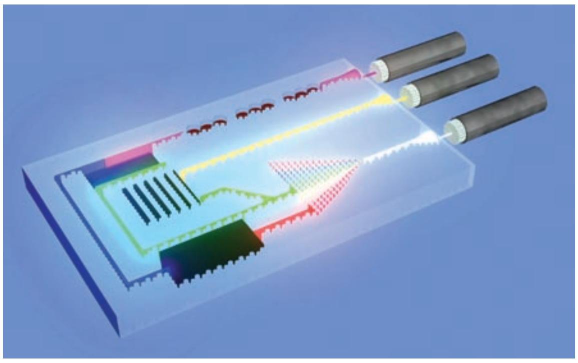
The inter-relationships between the different areas of disciplinary expertise are shown in the diagram. Our five year strategic effort is aimed at the demonstration of micron-scale photonic components performing multiple ultrahigh-speed all-optical signal processing functions on a single photonic chip. Photonic chips will be the key enabling technology for next generation optical systems and their development and incorporation into ultrafast optical networks is truly a "Grand Challenge" for the current generation of researchers.

Our aims in year two were to:

- Demonstrate **all-optical solutions** to real network functions like monitoring, signal re-generation and switching,
- Develop **new materials and device geometries** that allow these functions to be miniaturised and "microfabricated" onto a chip.



The interrelationships between the different programs and research themes, focussed towards the realisation of the photonic chip.



▲ **The photonic chip will be developed by combining skills in microfabrication and in optical applications, built on a foundation encompassing the broad range of disciplinary knowledge and expertise across all CUDOS nodes.**

- Develop **novel micro-fabrication technologies** to build photonic chips that perform a multiplicity of integrated optical functions.

We have made outstanding progress in each of these areas during 2004. Highlights are discussed below, grouped into the three key areas:

All optical processors

- All-optical monitors rely on ultra-fast nonlinearities to measure the amount of chromatic dispersion in a network. Dr Justin Blows has demonstrated the world's first optical monitor for optical signal to noise, and plans to continue this project by developing monitors for polarisation mode dispersion and amplified spontaneous emission. These monitors are fibre based but he is working closely with the micro-fabrication teams in CUDOS to develop miniaturised devices based on the same principle.
- Optical regenerators rely on ultra-fast nonlinearities to regenerate signals that have been distorted during transmission through a communications network. CUDOS researchers have developed a 2R regenerator architecture to Re-amplify and Reshape a distorted signal. The CUDOS approach builds on the ultra-strong nonlinearities of materials including lithium niobate and chalcogenide glasses and the ability to fabricate Bragg grating filters in waveguides. During 2005 we will move to proof of concept demonstrations of photonic chip regenerators and validate these devices in a 40 Gb/s high-speed optical communications testbed.
- Optical switches are key functions for all-optical routing in communication systems. CUDOS researchers have used nonlinear effects in photonic bandgap structures to achieve novel approaches to all-optical switching and routing.

New materials and device geometries

- Optical switching is a nonlinear process requiring nonlinear optical materials. Chalcogenide glasses are an attractive candidate, having high nonlinearity and low optical loss. CUDOS has a unique approach that capitalises on the chemistry expertise of our Partner Investigator Professor Richardson (Clemson University) and the novel deposition process developed by Prof Luther-Davies at ANU. We have successfully incorporated low-loss waveguides and photonic bandgap structures into these chalcogenide substrates.

CUDOS Facilities

CUDOS continues to benefit from new facilities that have enhanced research competitiveness. Substantial support for these facilities has come from the NSW Government, University support and from success in internal grant applications across the collaborating Universities. As examples, the experimental team at the University of Sydney has installed the following facilities purchased with grants from the University's internal major grants scheme:

- **A $300,000 facility for optical alignment of waveguides and photonic devices, housed in an environmental clean room.**
- **A $450,000 bit error rate test set for measurements of network functions at speeds of up to 40 Gb/s. Agilent Technologies provided assistance to enable this item to be purchased at a very substantial reduction in the list price.**

Macquarie University's team has benefited from internal support to fit out a new suite of experimental laboratories. Professor Luther-Davies' group at ANU has benefited from access to over $500,000 worth of lithography equipment provided from University funds, while the ANU also contributed around $650,000 to the focused ion beam facility that has been a keystone of the CUDOS research program in photonic crystal fabrication.

- The building blocks of the photonic chip are photonic wires and circuits that control light on the micron-scale. The theory group of Professor McPhedran and Professor de Sterke has demonstrated a number of optical devices in photonic crystal circuits. Their calculations require sophisticated numerical simulation approaches and advanced mathematical approaches with rapid calculations. Professor Botten's group has addressed this requirement through development of a suite of numerical tools that are used routinely across CUDOS to design and analyse photonic devices. Several of the concepts demonstrated in theory are now being developed by the fabrication teams.
- In 2004 Professor Min Gu's team at Swinburne reported the experimental realisation of 3D-photonic crystals with embedded planar defects that were introduced in the middle of a woodpile lattice as an offset in the layer spacing. This is the first step towards the realisation of photonic circuits embedded in true 3D photonic bandgap materials.

Micro-fabrication technologies

- Fabrication of micron-scale devices requires sophisticated and expensive hardware. Prof Luther-Davies and his team at ANU have pioneered a novel fabrication process that uses a Focussed-Ion-Beam (FIB) to mill photonic crystals with outstanding geometrical characteristics into chalcogenide films with no etching steps, while Dr Moss has applied the same approach to mill gratings in silicon on oxide waveguides. Dr Withford and his team at Macquarie produced 3D photonic crystals with strong bandgap effects made from a quite different 'self-assembly' process.
- Bragg gratings are being fabricated in chalcogenide waveguides using a Sagnac interferometer developed at the Sydney University laboratory. Ultra-strong complex Bragg gratings have been produced in these chalcogenide waveguides for the first time.
- Photonic wires and waveguide couplers are crucial for optical circuit interconnects. Both were demonstrated during the year, with wires being made from highly tapered microstructured fibres and waveguides produced deep in bulk optical materials using a femtosecond laser.

CUDOS fundamental science

The need for outstanding science is implicit in the ambitious goals that we have set ourselves. There is a wealth of outstanding research presented in this year's report. Some highlights that exemplify the leading role that CUDOS is taking in the fields of nonlinear photonics and microphotonics include:

Nonlinear photonic crystals

- Prof Kivshar and Prof Krolikowski are world leaders in the area of nonlinear photonic bandgap materials. The structures they are exploring provide a fertile field for nonlinear physics, enabling the observation of truly fundamentally new phenomena, as evidenced by the publication of five papers in Physical Review Letters during 2004. The principles that are being demonstrated are key to the CUDOS goals of all-optical switches and routing functionalities. In parallel with this effort the Sydney group of Prof Eggleton and Prof de Sterke are exploring temporal propagation in nonlinear photonic crystals. These experiments are being performed in fibre Bragg gratings fabricated in the CUDOS laboratories and have revealed a range of fundamental phenomena, including slow light, soliton compression and pulse train generation.

ARROW photonic crystal fibres

- The CUDOS team at Sydney University are pioneering a novel class of photonic crystal fibre, referred to as an ARROW fibre. These fibres, which support a range of nonlinear propagation effects, are fabricated by incorporating high-index materials into the air-holes of the fibre to form micro-resonators in the cladding region that confine light to the core. These fibres combine the dispersive properties of photonic bandgap fibres (which guide light in the central air-region and exhibit ultra-low nonlinearity) with the high-nonlinear properties of index-guiding solid core fibres.The combination of strong dispersion and nonlinearity enable soliton propagation at new wavelengths. The evolution of soliton propagation was characterised at the zero-dispersion wavelength of these fibres and the experimental results were simulated by solving the nonlinear Schrödinger equation.

Looking Forward

During the second half of 2004 the CUDOS project leaders met at a "retreat" in the Blue Mountains. Explicitly on the agenda was the target of identifying new projects, in most cases amalgams of existing activities, whose outcomes (over a 3 year timescale) would be of a scale and significance that a reader of a major daily newspaper could understand their implications. Four "Flagship projects" were identified and project champions stood forward to take on the responsibility of forming teams and detailed project plans. Reports on progress in these will feature prominently in next year's Annual Report.