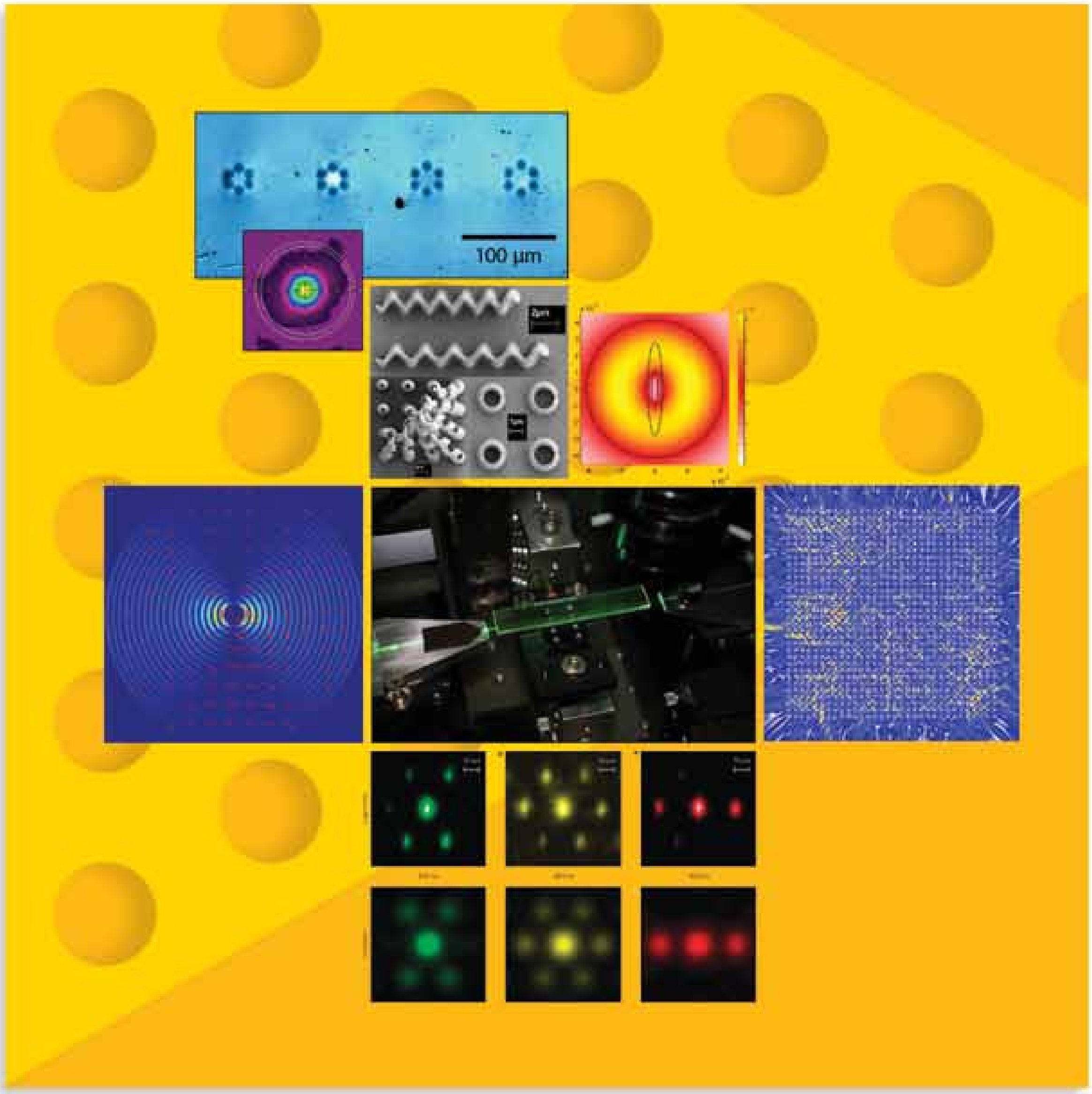
ANNUAL 2009 REPORT



CUDOS

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

TUNEABLE MICROPHOTONICS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Science Vision

Tunability is a core issue for the operation of all-optical photonic devices and circuits. Highly resolved wavelength selectivity and precisely defined dispersion must be actively tuned and stabilized to be practically useful. Further, if the nonlinear response itself can be tuned then a new range of all optical switching devices may be realized. The general goals of this project can be summarized as follows:

1. To suggest, design, and study theoretically novel types of nonlinear periodic structures with tunable characteristics and active control of their dispersion/ diffraction properties;

2. To demonstrate experimentally the spatial and/or temporal manipulation of light in microphotonic periodic structures

Project Goals

This Flagship program encompasses these general goals in its aims to explore the fundamental science of nonlinear optics while also connecting these breakthrough discoveries to practical applications, particularly in defence. In collaboration with external industry partners, we will continue to conduct internationally leading research towards:

1. Tunable Complex Nonlinear Heterostructures to explore nonlinear spatiotemporal light control. This is achieved by utilising new dynamically reconfigurable platforms such as fluid infiltrated photonic crystal fibres and microfluidic planar structures to enable potential applications in photonic signal processing and optical sensing.

2. Microwave Photonics on a Chip to harness the demonstrated breakthrough technology created within CUDOS and apply it to a specific set of photonic signal processing problems faced by radar warning systems for defence platforms. Technologies of interest include compact wavelength measurement and filtering and tunable delays integrated with fast nonlinearities for signal mixing.

CUDOS strategy/competitive advantage

CUDOS is a proven world leader in nonlinear photonic technology, both in terms of physical concepts (lead by The Nonlinear Physics Centre at ANU) and practical ultra-broadband systems (The University of Sydney). By combining these centres with the platform capabilities of RMIT University and their context within the Australian electronic warfare research environment, CUDOS will bridge the gap between fundamental science and practical application. This unique combination of expertise will provide a wealth of new photonic technology to advance the Australian defence capability and industry, but will also identify new insights and challenges faced by industry which will stimulate innovation at the most fundamental level.

Tuneable Microphotonics team.

Collaborative links

This project spans three major CUDOS nodes. The Nonlinear Physics Centre at ANU providing nonlinear concepts in tuneable microphotonics and experimental verification of these concepts; RMIT University providing fluid infiltrated polymer platforms and microwave photonic applications and context; and The University of Sydney providing nonlinear photonic systems expertise. This project has a strong collaboration with Defence partners, particularly DSTO and has pursued interactions with DMO and BAE Systems with the aim of providing microwave photonics on a chip as a solution to challenges in modern electronic warfare self defence systems.

Goals for 2009

In 2008 we set goals as a means of pursuing our science vision, and also to moving closer to technology platforms that will supprt our industry partners. Our 2009 targets were:

1. Demonstrate Temporal-Spatial behaviour in liquid crystal infiltrated photonic cavities
2. Access fast nonlinearities in fluid infiltrated photonic crystal fibre using fluid for dispersion engineering and explore applications in photonic information processing
3. Develop planar polymer fluid infiltrated platform with engineered fluid and photonic interfaces and explore applications in biosensing
4. Demonstrate a suite of microwave photonic applications of CUDOS nonlinear photonic technology of specific relevance to the Australian defence industry and pursue single chip integration of such systems.

Achievements and highlights for 2009

Tunable complex nonlinear heterostructures

Fluid Infiltration of photonic crystal fibres

New advances at the Nonlinear Physics Centre, ANU in the experimental studies on liquid infiltrated photonic crystal fibres as a tunable platform have demonstrated some most fundamental properties of the nonlinear behaviour of the 2D periodic photonic structures. By taking advantage of the precise temperature tunability of the liquid infiltrated fibres it was possible to trace the switching of the nonlinear behaviour of the structures from focusing to defocusing.

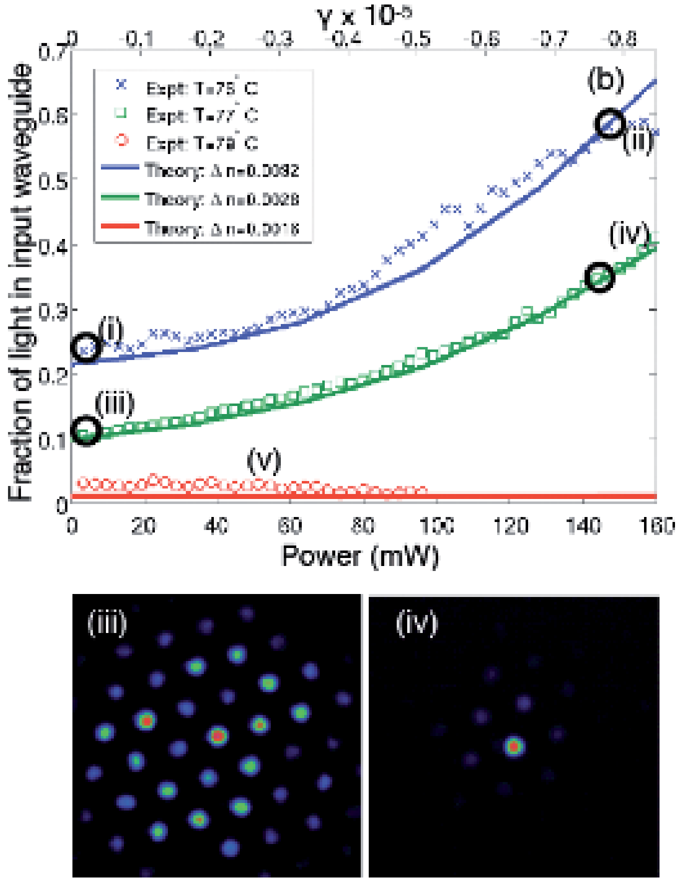

Fig 1. (Top) Fraction of light into the input waveguide with increase of the incoupling power, for three different remperatures (refractive index contrast) of the system. (Bottom) typical intensity profiles for the point (iii) and (iv) as marked on the plot on the top.

This switching is illustrated in Fig. 1 that shows the fraction of light power into the coupled into the input waveguide as a function of the input power and three different temperatures of the system. Increasing of this fraction corresponds to beam focusing, while decreasing to beam-defocusing. These studies provide the first experimental confirmation for a crossover of periodic systems to continuous when the refractive index contrast is decreased (with the increase of the temperature).

Planar polymer fluid infiltrated platform

Collaborative work between RMIT and ANU has lead to the development of a flexible planar fluid infiltration platform realized using combined photolithography and lamination, as shown in Fig. 2. Demonstration of the temperature dependence of the discrete diffraction has been achieved experimentally in this platform. The obtained results show that this platform provides opportunities for realisation of new types temperature sensors [1].

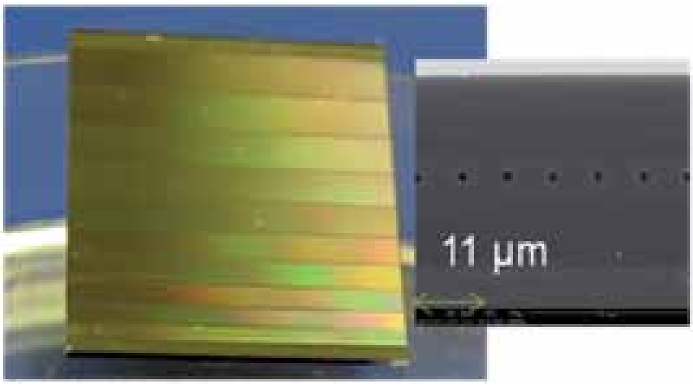

Fig 2. Top view (left) and SEM image (right) of the polymer waveguide array before infiltration.

Liquid crystal infiltrated photonic structures

A continuation of the work on enhancement of light interaction in periodic structures with infiltrated liquid-crystal defects has shown dramatic reduction of the threshold power for nonlinear effects. By placing the liquid-crystal defect layer asymmetrically it is possible to achieve an optical diode operation in infiltrated structures, as shown in Fig. 3. Due to the first order transition the system switches from "off" to "on" state for light send in one direction remaining in "off" state for light send in opposite direction.

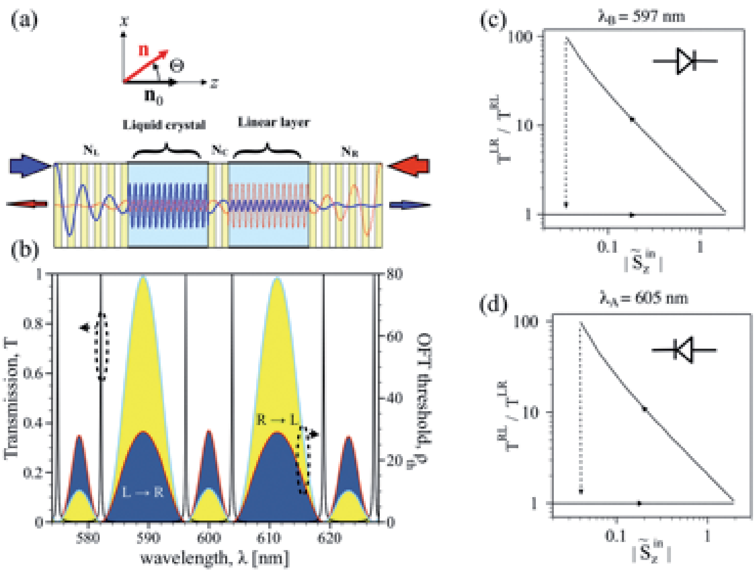

Fig 3. Reversible optical diode based on double photonic crystal cavity infiltrated with liquid crystal. (Left) The variation of the Fréederickzs threshold inside the photonic band gap for light impinged from different directions. (Right) The ratio of transmission coefficients in opposite directions at different wavelengths.

By placing liquid crystal defect layer asymmetrically inside the periodic structure the nonreciprocal response of the whole structure can be achieved. In addition to that, we suggested that by using a pair of defects, one of them being a nonlinear liquid crystal defect layer, the nonreciprocal response can be reversed by varying the input wavelength, resulting in reversible optical diode operation [2]. We have experimentally demonstrated that a one-dimensional photonic crystal with a homeotropic nematic liquid crystal defect behaves as a polarization-sensitive nonlinear all-optical device [3].

Microwave Photonics on a Chip

The collaboration between RMIT and The University of Sydney has achieved further advancement in the use of nonlinear optics for microwave photonic signal processing in 2009. We have established convincing theory and experimental verification of our all-optical frequency measurement system [4] and extended this single frequency to several parallel frequency measurements only with a moderate increase in component count [5]. This result brings us a step closer to realise a complete all optical suite for instantaneous frequency measurement that could be realised on a nonlinear photonic chip.

The project has also pioneered the concept of microwave photonic signal processing exploiting discrete time optical carriers [6]. Unlike, traditional microwave photonic systems where RF signals are carried by CW optical carriers, we have used pulsed carriers similar to those used for digital signals in the nonlinear photonic signal processing flagship project. The combination of time and wavelength division multiplexing along with the increased instantaneous signal strength allows for far more flexible linear and nonlinear signal manipulation. Further exploration of this concept will be a major focus for this project in 2010.

Targets for 2010

Tunable complex nonlinear heterostructures:

1. Study new opportunities for light localisation in 2D periodic photonic structures, including localised nonlinear surface states and defects.
2. Develop fluid infiltrated planar refractive index sensors using analogues of fibre geometries, but taking advantage of design flexibility and longitudinal variations
3. Investigate the optomechanical effects of light on the orientational ordering of liquid crystals to control the dynamical response of infiltrated photonic structures

The microwave photonics on a chip program will:

4. Extend parallelism of our all-optical frequency measurement system and quantify the sensitivity, resolution and dynamic range to demonstrate unambiguous high resolution measurement of frequency and amplitude
5. Explore novel signal processing concepts based on the discrete time microwave photonics.
6. Pursue single chip integration of such systems in collaboration with our industry partners.

Published papers

1. E. Zeller, F. Bennet, et al. E-CLEO/EQEC 2009
2. A.E. Miroshnichenko et. al. Appl. Phys. Lett. 96, 063302 (2010).
3. E. Brasselet, A.E. Miroshnichenko, Opt. Lett. 34, 488-490 (2009).
4. L. Bui, et al. Opt. Express 17 22983-22991 (2009)
5. Sarkhosh et al. IMS USA (2010) (accepted)
6. L. Bui et al. MWP Spain (2009), *Dayaratne et. al,* Photonic Technology Lett. 2010 (submitted)