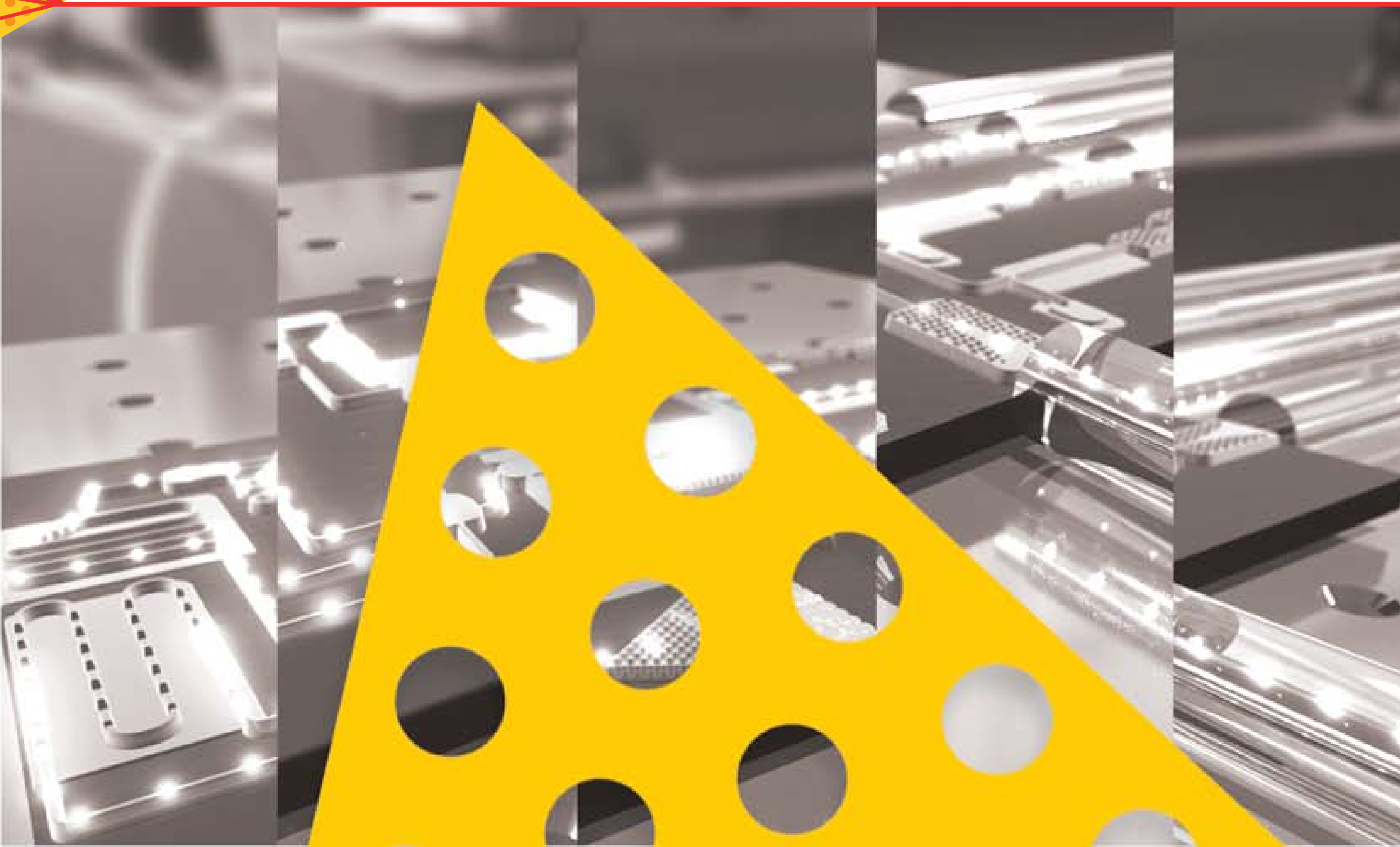
CUDOS

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

An Australian Research Council Centre of Excellence



Annual Report 2007

Flagship Project

SLOW LIGHT

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Four year vision/long term goal and motivation

We pursue research into slow light both for its intrinsic scientific interest, but also because interactions with the optical medium through which slow light travels are strongly enhanced. In particular, the strength of nonlinear interactions strongly increases, lowering the intensity requirements for nonlinear effects with obvious advantages for the operation of nonlinear signal processing devices.

CUDOS strategy/competitive advantage

One key challenge with many approaches to slow light is dispersion, which leads to a broadening of the slow-light pulses. CUDOS' unique approach relies on the nonlinear optical generation of a dispersionless soliton, thus preventing this broadening from occurring. Experiments are being conducted in both 1D Bragg structures in silica fibre and 1D and 2D photonic crystalline structures made in chalcogenide glass.

Collaborative links

This is a collaborative project between researchers at the University of Sydney, the Australian National University and the University of Technology Sydney. Different aspects of the theoretical work are carried out at the three universities. The experimental work is a collaborative effort, with chalcogenide samples fabricated at the ANU, grating writing performed at the University of Sydney, while chalcogenide photonic crystal slabs are fabricated at the ANU.

More recently, collaboration with Prof. Krauss, group (St Andrews University) has been developed for realising silicon and chalcogenide photonic crystal slabs. The group is also working with Dr Morten Ibsen at Southampton on the fabrication of long gratings in silica fibres, and with Prof. Kuipers' group at AMOLF (Amsterdam), on the characterisation of slow light devices using a heterodyne NSOM. A more general collaboration between CUDOS and the European consortium, SPLASH (Slow Photon Light Activated SwitcH), has been built which also involves Polimi in Milan (Prof. Andrea Melloni) and Glasgow University (Prof Marc Sorel, Prof. Richard de la Rue). This collaboration is supported by a DEST-International Science Linkage grant commencing October 2007.

Goals for 2007

The aims for 2007 were the experimental demonstration of large delays in long one dimentional periodic structures (gratings) written on silica fibres, and the first demonstration of the propagation of undistorted pulses (Bragg solitons) within Bragg grating chalcogenide waveguides. In addition, we aimed to observe these effects directly by detecting the evanescent field (both phase and amplitude information) of the pulses within the chalcogenide waveguide using a heterodyne NSOM. The last objective was focused on the exploration of new designs and structures for the routing and switching of slow light pulses.

Achievements and highlights for 2007

Slow light in Fiber Bragg gratings without broadening

We observed the excitation of gap solitons in a 30 cm silica fibre Bragg grating using 0.68 ns pulses at kW peak power. These emerge with a tunable delay of up to 3.2 ns (almost 5 pulse widths) without broadening (see Fig. 1) [1]. These delays are twice as large as observed previously, thanks to the availability of Bragg gratings fabricated at the University of Southampton which are 30 cm long, rather than 10 cm as previously, and with twice the index contrast of the previous gratings. Based on the delay we conclude that the solitons propagate through the grating at an average velocity of 0.32 c/n, where c/n is the velocity of light in the absence of the grating.

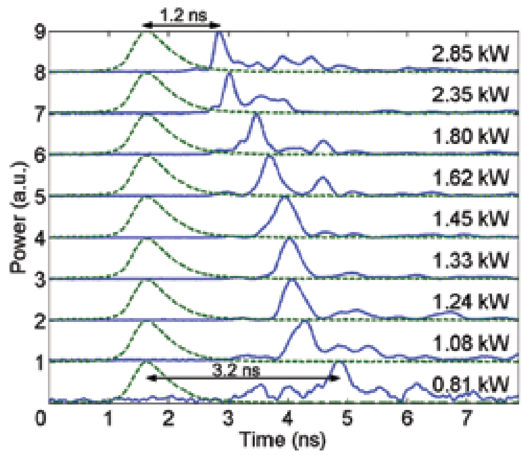

Fig 1: Transmitted (solid) and reference (dashed) pulse at various input peak powers. The delay can be tuned between 1.2 ns and 3.2 ns when decreasing the input peak power from 2.85 kW to 0.81 kW.

Bragg soliton effects in 1D Bragg grating chalcogenide waveguides

We demonstrated for the first time Bragg soliton effects at low pulse energies within a highly nonlinear chalcogenide (As_2S_3) rib-waveguide of 7 μm^2 cross-section area with a 37 mm long Bragg grating. The Bragg grating produces a 9.3 nm wide photonic bandgap (see Fig.2(a)) and results from 0.42% photo-refractive index modulation. For peak powers of 70 W (pulse energy of 170 pJ), and at an appropriate detuning from the grating's Bragg

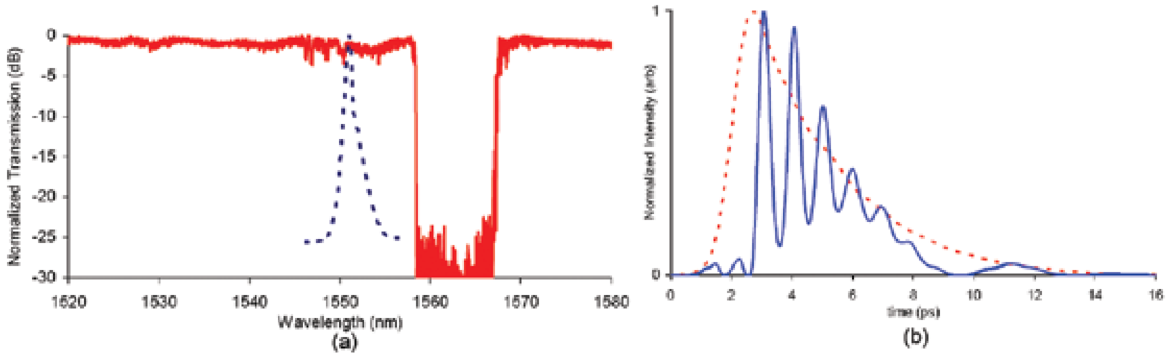

Fig 2 (a) Normalized transmission spectra of the Bragg grating chalcogenide waveguide (solid) and input pulse (dashed) (b) Reconstructed pulse shapes from FROG spectrogram showing input (dashed) and output (solid) pulses.

resonance, a single 4 ps input pulse emerges from the grating as a train of 450 fs short pulses (see Fig 2(b)). The balance of the nonlinearity and dispersion seeds the formation and splitting of a high-order soliton into a train of six 450 fs fundamental solitons. This effect is achieved at pulse energies 500 times lower than previous reports using AlGaAs filters and 10,000 times lower than those using Bragg gratings in silica fibre. Simulations using the coupled mode equations qualitatively match the experiment, and indicate the pulse delays that can be expected as the pulse is tuned closer towards the bandgap in the slow light regime.

Preliminary heterodyne NSOM measurements on the propagation of pulses within bare chalcogenide waveguides have been carried out to explore how self phase modulation effects could be retrieved within the evanescent field information of the mode. This paves the route for investigating directly more complex phenomena in the presence of a periodic structure, where nonlinearity and dispersion balance each other.

Slow light switching in nonlinear Bragg-grating couplers

We theoretically demonstrated switching of slow-light pulses in nonlinear couplers with phase-shifted Bragg gratings [2]. At low powers, a periodic tunneling of the slow light pulses between two shifted Bragg grating waveguides was observed (Fig. 3(b)), but the pulses are spectrally broadened due to dispersion. At higher powers (Fig. 3(c-e)) this broadening is compensated by the nonlinear self-action of light consistent with the formation of gap solitons, which preserve a constant pulse width as they propagate. As the coupling length between the waveguides is extended by increasing the input power, all-optical switching of the slow pulses between the two output waveguides of the coupler is demonstrated (Fig. 3(c) and 3(d)). Most remarkably, the propagation velocity of these gap solitons and the corresponding pulse delay can be actively tuned by varying the input power (Fig. 3(e)). These results could be implemented in either 2D photonic crystals or 1D Bragg grating geometries.

Coupling of slow light pulses with restricted dispersion in anti-symmetric photonic crystal couplers

We have designed a directional photonic crystal coupler where dispersionless routing of slow light pulses is realized [3]. The coupler relies on parallel and anti-symmetric photonic crystal waveguides separated by an even number of rows of holes (Fig. 4(a)). This symmetry allows the co-existence of forward and backward modes whose group velocity and band-edge dispersion are exactly matched, even in the regime of slow light (Fig. 4(b)). As a result, the beating of these modes provides slow light switching between the waveguides (Fig. 4(c)). The coupling distance, after which the pulses are fully switched between the parallel waveguides, is remarkably short (a few unit cells) and remains constant and independent on the group velocity. This latter property enables dispersionless tunneling of slow light pulses, where the dynamics as shown in Fig. 4(c) is preserved even under the variation of the speed of light by several orders of magnitude.

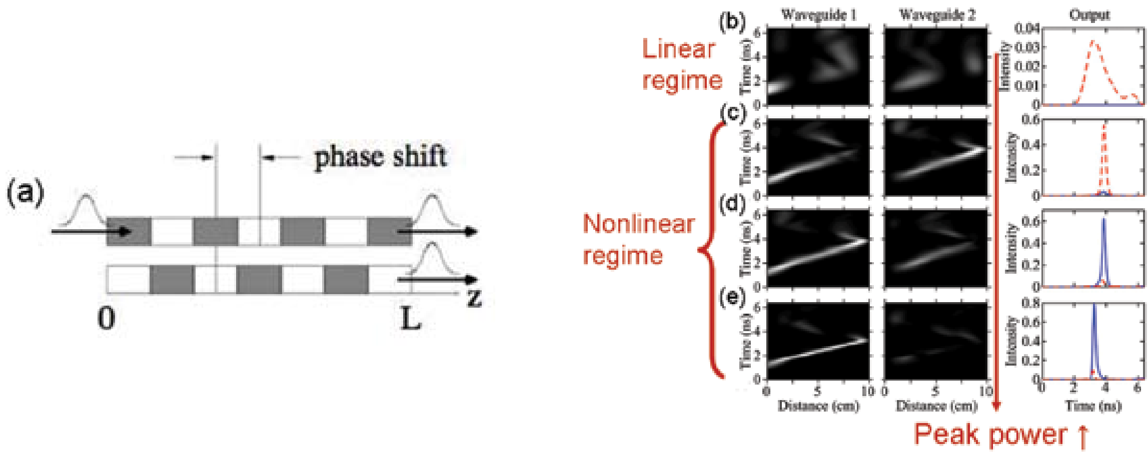

Fig 3: (a) Schematic view of the waveguide coupler with phase-shifted Bragg gratings. (b-e) Pulse dynamics inside the nonlinear coupler for increasing peak input intensities, from top to bottom. Shown are the density plots of intensity in the first (first column) and second (second column) waveguides. Output intensity profiles normalized to peak input intensity at the first (blue solid line) and second (red dashed line) waveguides are shown in the third column.

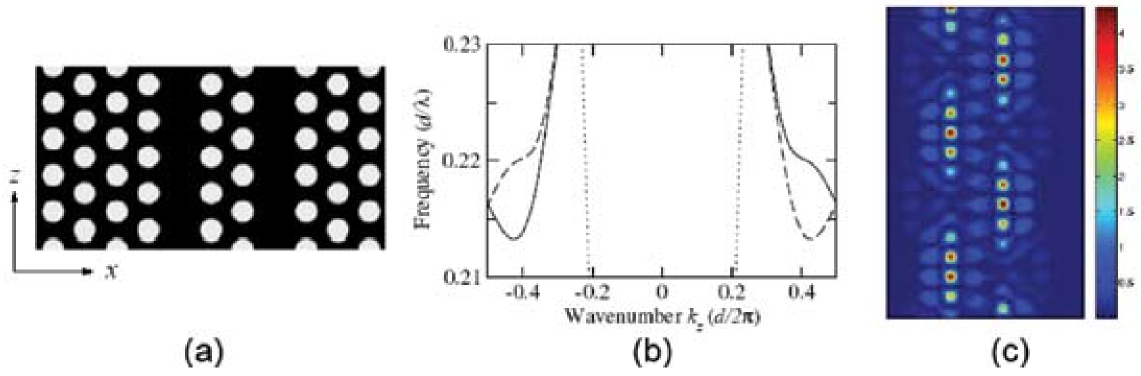

Fig 4: Example of one realization of antisymmetric photonic-crystal slow light couplers. (a) The coupler geometry. (b) Dispersion of the fundamental modes of the coupler which both display low group velocity at a wavenumber k_z of around -0.4 and 0.4, respectively. (c) Intensity of the simultaneously excited modes calculated by FDTD, showing a periodic beating of the light between the two waveguides.

Targets for 2008

We plan to continue to investigate slow light within various architectures, namely one dimensional (1D) grating realised on silica fibres and chalcogenide waveguides and two-dimensional (2D) photonic crystals (chalcogenide and silicon). In fundamental studies of slow light, we will investigate the practical limitations of 1D periodic structures for slow light applications, with a particular interest on random gratings. We will also pursue the theoretical work on slow light effect in multimode fibres [4].

We aim to experimentally demonstrate the actual enhancement of nonlinear effects due to slow light. These experiments will be carried out on silicon photonic crystals in collaboration with St Andrews University. In parallel, strong efforts will be devoted to the development of a fabrication process for realising chalcogenide photonic crystals using e-beam lithography techniques. We will then explore how the photosensitive properties of this material can be exploited as an alternative, flexible and elegant method to post-process slow light structures within 2D photonic crystals.

The activity on slow gap solitons within nonlinear material including a periodic index modulation will be further developed. We aim to demonstrate a fractional delay of 2 for low power pulses propagating in chalcogenide Bragg grating waveguides with minimized distortion. We will also work towards the observation of combined dispersion-nonlinear effects in periodic structures with the heterodyne NSOM at AMOLF in Amsterdam.

Lastly, we will focus on the design/realisation of practical devices exploiting slow light. First, we will target the experimental demonstration of slow light couplers, following the 2007 theoretical studies on both antisymmetric photonic crystal waveguides and Bragg grating couplers. We will also investigate new designs for realising slow light control and switching using Fano-Feshbach resonances in 2D photonic crystal structures.

References

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