Flagship Project

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:

- To suggest, design, and study theoretically novel types of nonlinear periodic structures with tunable characteristics and active control of their dispersion/ diffraction properties;
- 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 Nonlinear Photonic Structures to explore the nonlinear spatiotemporal dynamics of light pulses. The focus of the project is to achieve full control of light propagation by utilising new dynamically reconfigurable photonic structures such as fluid infiltrated photonic crystal fibres and microfluidic planar structures to enable potential applications in photonic signal processing and optical sensing.
2. Nonlinear Microwave Photonics 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 RF frequency measurement 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

Tuneable Microphotonics team.

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.

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.

Goals for 2010

In 2010 we set goals as a means of pursuing our science vision, and also to moving closer to technology platforms that will support our industry partners. Our 2010 targets were:

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 nonlinear optic options to 'remote' IFM system such that it can be integrated as a photonic chip.

Achievements and highlights for 2010

Tunable waveguide arrays

Power independent nonlinear modes in waveguide arrays

The continuing collaboration between the Nonlinear Physics Centre, ANU and RMIT University on Lithium Niobate waveguide arrays has lead to some remarkable results on the studies of Truncated Nonlinear Bloch waves. Such waves exhibit some unique properties, in particular that their width is determined by the width of the input excitation, while remaining independent on power. The experiments were performed in Lithium Niobate waveguide arrays fabricated by Ti indiffusion by RMIT University [Fig.1(a)] and the experiments were carried out at the ANU. In Fig.1(b) we show the experimentally observed process of localisation under the defocusing nonlinearity of the lithium niobate and in Fig.1(c) the calculated dependence of the intensity profile vs. the nonlinear parameter γ. This work was published by the premier physics journal Physical Review Letter [1]

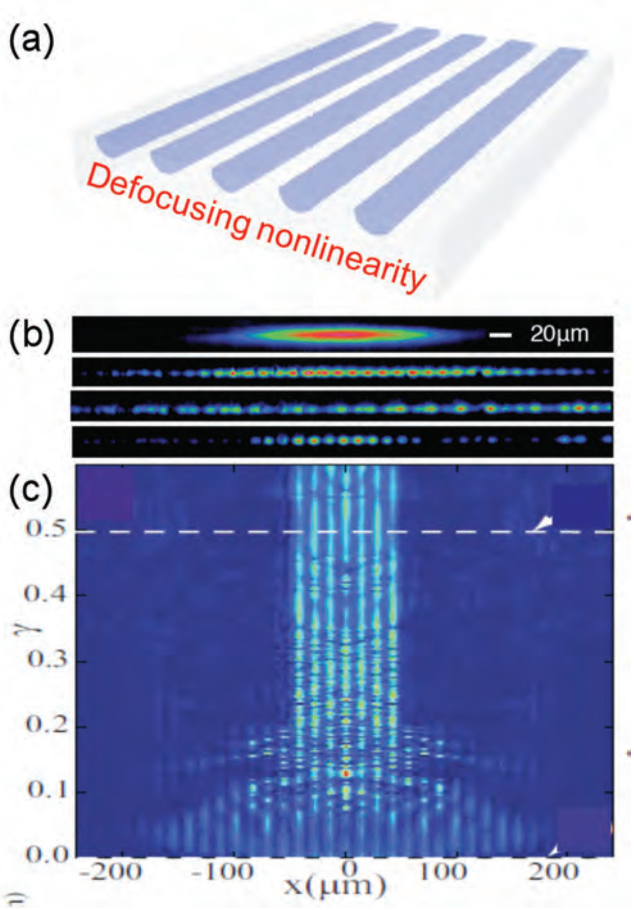

Fig 1: (a) Sketch of the waveguide arrays. (b) Input beam profile; linear diffraction at the output; nonlinear defocusing at low nonlinearity (time); and beam localization at high nonlinearity. Beam power, 1 mW. (c) Dependence of the output intensity profile on the nonlinearity γ. The beam spreading is arrested at a critical nonlinearity, $\gamma \approx 0{:}15$.

Phase transition due to interplay between beam localisation and parametric driving in periodically poled LiNbO3 waveguide arrays

A complete spatiotemporal control of light propagation can be only achieved in photonic structures featuring ultra-fast nonlinear response. Therefore we studied the propagation of short laser pulses (7ps) in a array of periodically poled Lithium Niobate waveguide array [Fig.2(a)]. In such arrays, the input beam experiences strong phase shift due to the periodic exchange of energy between the fundamental wave and the second harmonic. However, when the coupling of the SH light between neighbouring waveguides is strong then this coupling can strongly influence the phase structure of the SH component. While the conditions for strong SH coupling was believed impossible due to its shorter wavelength, we have found that it can be fulfilled by exploring SH generation to the higher order modes of the waveguides as shown in the bottom of Fig.2(a). In this case, we have a strong competition between two effects: waveguide coupling that drives the SH field profile to be out-of-phase and parametric conversion from the fundamental to the SH that is driving the an in-phase SH profile. Due to this competition, we have predicted and demonstrated experimentally [see Fig.2(b)] a sharp phase transition of the SH field profile from unstaggered to staggered phase. The results obtained in collaboration with Friedrich-Schiller-University Jena have been published in the premier journal Physical Review Letters [2].

Research on LiNbO3 waveguide arrays will continue within the next phase of CUDOS in the context of quantum nonlinear interactions.

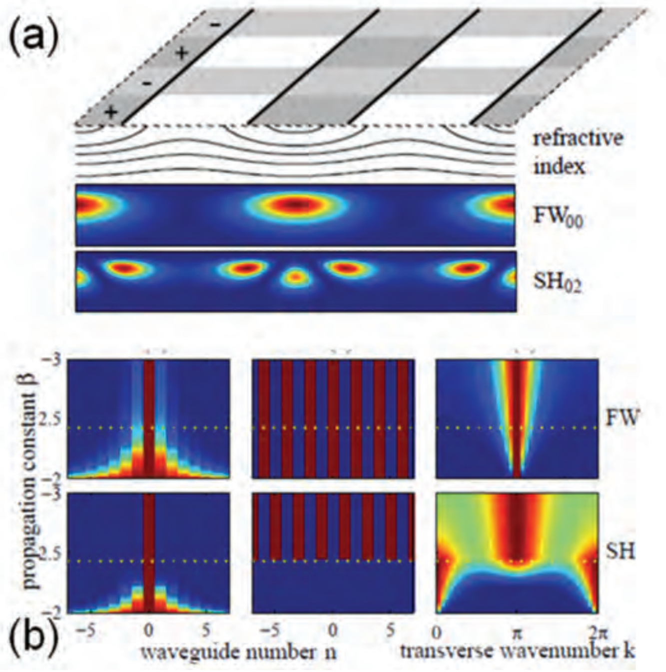

Fig 2: (a) Sketch of the periodically poled lithium niobate sample depicting the refractive index profile and the intensity distribution of the FW and SH modes. (b) Absolute values of the mode amplitudes (left); phases distribution (middle) [blue corresponds to 0 and red to π]; and absolute values of the spatial Fourier spectra (right).

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. 3. 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.

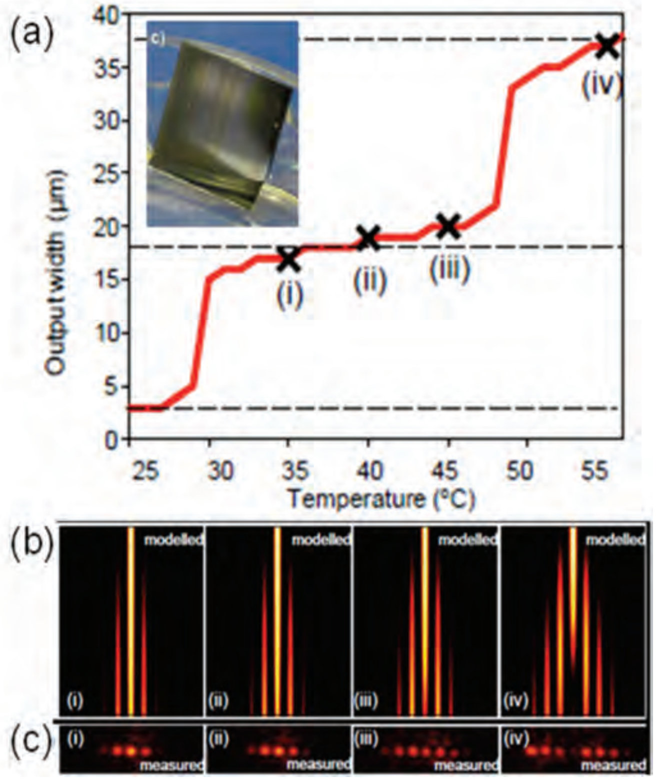

Fig 3: (a) The width of the output containing 70% of the optical intensity as temperature is increased; (solid line) BPM simulations and (x) measured width, dotted lines indicate 1, 3 and 5 cores occupied by the propagating light; b) Modeled distributions predicted by BPM of the optical distribution at along the waveguide array at (i) 35°C; (ii) 40°C; (iii) 45°C and (iv) 55°C; c) measured responses recorded by imaging the exit facet of the fluid infiltrated array at different times during cooling corresponding to temperatures of (i) 35°C; (ii) 40°C; (iii) 45°C and (iv) 55°C. Inset: experimental infiltration of hollow waveguides.

Optomechanics of liquid crystals for dynamical optical response of 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. The coupling between ordinary and extraordinary components of the light plays a key role in the process. In the presence of periodic structure this coupling can be significantly enhanced leading to strong interaction between different defect modes. The key result of our studies (Fig.4) is the demonstration of the repetitive dynamical switching beyond the Fredericksz transition [3]. Furthermore, it was shown that by exploring the properties of the Fano resonances [4] such nonlinear interaction can be further enhanced.

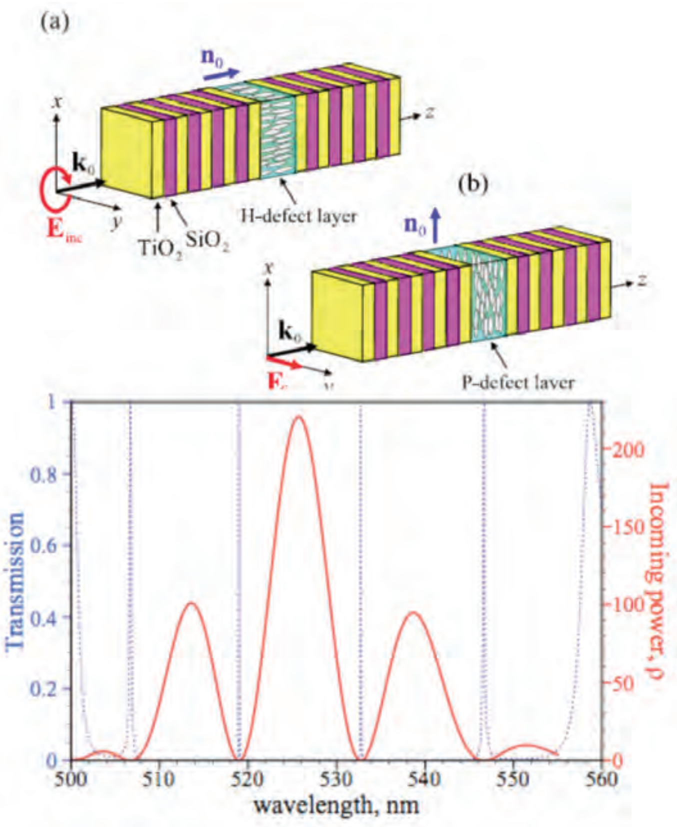

Fig 4: light induced reorientational effects in planar nematic liquid crystals cell embedded into a one-dimensional photonic crystal.

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 2010. We have extended the all-optical frequency measurement concept developed in 2009 into a complete suite of system features. In particular, we have demonstrated i) parallel frequency measurements in a single HNLF [1]; ii) simplification of the transmitter through remoting frequency measurement to the receiver [2]; and iii) extension to many simultaneous measurements using a wavelength labelling technique. Our breadth and depth of research in this area has been recognised through two invited talks at international conferences [3,4]. This work also brings us to the stage of realising a complete sophisticated system for measurements of both frequency and amplitude of several simultaneous signals that could be integrated into a compact photonic chip.

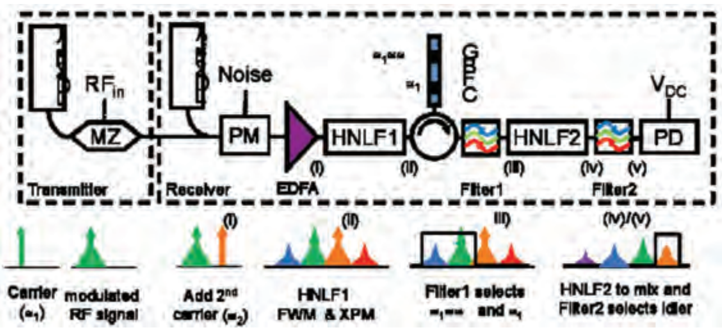

Fig 5: System configuration of the recently demonstrated 'remoted' all-optical IFM [6].

The momentum of this project will continue within the new CUDOS centre. Our investigations of ultrafast analogue photonic signal processing systems will continue within the within the Tb/s flagship project particularly in the context of signal correlation and analogue to digital conversion. A chip implementation of our nonlinear signal processing systems will be pursued under the Hybrid Integration project where with the support of an industry partner.

Publications

Published papers

1. F. H. Bennet, T. J. Alexander, F. Haslinger, A. Mitchell, D. N. Neshev, and Yu. S. Kivshar, "Observation of nonlinear self-trapping of broad beams in defocusing waveguide arrays," Phys. Rev. Lett. 106, 093901(1–4) (2011).
2. F. Setzpfandt, A. A. Sukhorukov, D. N. Neshev, R. Schiek,. Yu. S. Kivshar, and T. Pertsch, "Phase transitions of nonlinear waves in quadratic waveguide arrays," Phys. Rev. Lett. 105, 233905(1–4) (2010).
3. A. E. Miroshnichenko, and et al., "Optomechanics of liquid crystals for dynamical optical response of photonic structures," J. Opt. 12, 124006 (2010).
4. A. E. Miroshnichenko, S. Flach, and Y. S. Kivshar, "Fano resonances in nanoscale structures," Rev. Mod. Phys. 82, 2257 (2010).
5. N. Sarkhosh, H. Emami, L. Bui, and A. Mitchell, "Microwave Photonic Instantaneous Frequency Measurement with Simultaneous Parallel Operation within a Single Optical Fiber" IEEE International Microwave Symposium (IMS – 2010), paper 1250, 23-28 May, Anaheim, California, USA (2010)
6. L. Bui, and A. Mitchell, "Remoted Instantaneous Frequency Measurement System using Optical Mixing in Highly Nonlinear Fibre", Accepted for CLEO2010, Baltimore, USA (2011)
7. L. Bui , N. Sarkhosh, H. Emami, and A. Mitchell, "Microwave Photonic Instantaneous RF Frequency Measurement Systems Employing Optical Mixing", International Conference on Electromagnetics in Advanced Applications (ICEAA), 20-24 September, Sydney, Australia (2010) (Invited)
8. L. Bui, N. Sarkhosh and A. Mitchell, "Instantaneous Frequency Measurement using Optical Mixing", Asia-Pacific Microwave Photonics Conference (AP-MWP), paper TB1-6, 26-28 April, Hong Kong (2010), (Invited)