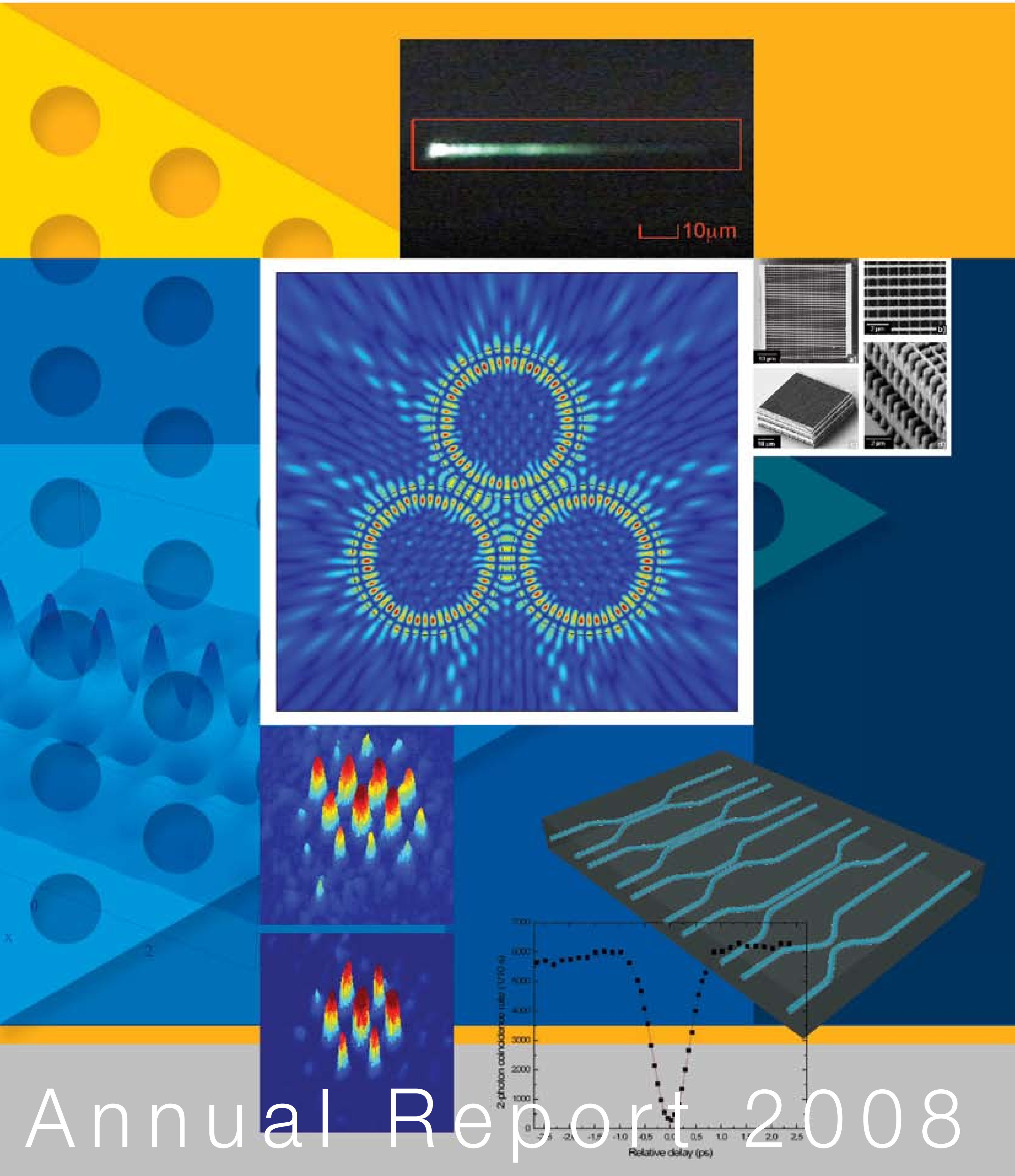
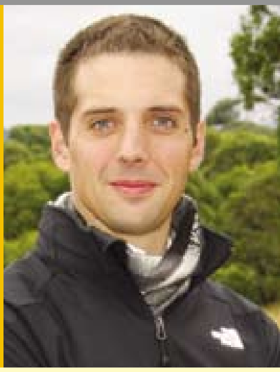
CUDOS

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



Annual Report 2008

INTEGRATED WAVEGUIDE OSCILLATOR



Contributing staff: Peter Dekker, Michael Steel, Alex Fuerbach – MQ, Dragomir Neshev, Andrey Sukhorukov – ANU, Mark Pelusi – Sydney

Students: Douglas Little, Christopher Miese, Robert Williams – MQ, Sangwoo Ha, Aliaksandr Minovich – ANU

Project Manager: Graham Marshall ('08), Martin Ams ('09)

Science Leader: Mick Withford

Long term goal and motivation

The femtosecond laser direct-write technique is a unique tool for the creation of integrated optical waveguide systems. Using this technique it is possible to fabricate arbitrary networks of waveguide devices in a wide range of optical media including passive, active and highly-nonlinear glasses. The ability to combine different waveguide functional forms such as splitters, amplifiers, gratings and lasers in three-dimensional 'circuits' is enabling novel research in fields such as telecommunications, quantum information, bio-photonics and micro-sensing. Our work leads the international field in the development of active integrated optical systems. Examples of devices developed at Macquarie include waveguide amplifiers and monolithic lasers.

The miniaturisation and integration of components for optical communication and sensing networks is recognised as an essential step in the development of these technologies. These goals lie at the core of the CUDOS research program. This Flagship project encompasses these goals in its aims to develop integrated optical systems for amplifier and laser applications while enabling the experimental realisation of coupled non-linear waveguide devices designed by our colleagues at ANU. In collaboration with external research partners in the defence sector we will continue to conduct internationally leading research towards:

- The development of miniature arrays of laser sources for environmental health sensing and civil defence applications.
- The application of three-dimensional 'circuitry' to the miniaturisation of optical devices enabling higher bandwidth fibre communications links.
- The study of fundamental optical physics through unique waveguide manufacturing capabilities developed at Macquarie University.

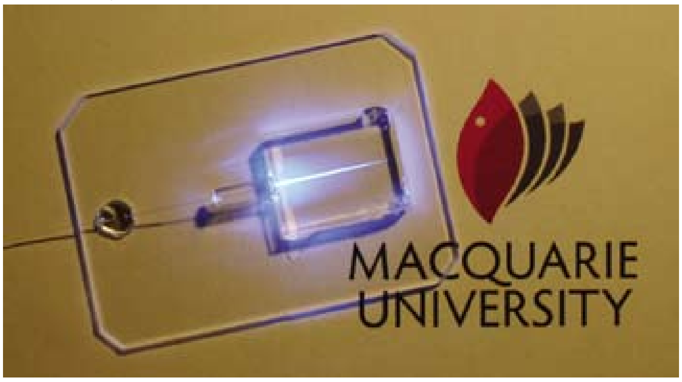


Fig 1. Image shows the monolithic Yb doped DFB waveguide laser. The device is single-end pumped from the left via a pigtailed diode laser. Due to the presence of an asymmetric phase change the bulk of the output power is directed to back into the fibre pigtail. Note the characteristic blue cooperative luminescence in the Yb doped host glass.

Integrated Waveguide Oscillator team.

CUDOS approach

Macquarie University is an international leader in the field of laser materials processing. Our expertise has enabled the development of world-class facilities dedicated to the field of direct-write photonics. Through several ARC and internal university funding programs we have strategically invested in ultrafast laser, nanopositioning, sample processing and optical diagnostics systems to enable us to create device fabrication and characterisation facilities that are uniquely flexible and almost without equal in our field. Our combined approach of fundamental light/materials interaction research and practical device development has enabled us to conduct insightful research and demonstrate world leading photonic device results. We have the following capabilities:

- rigorous and precise sample preparation (automated lapping and polishing)
- monitored 3D air-bearing motion control of host samples
- accurate and precise device fabrication with features sub diffraction limit
- transmission and reflection readings and spectra
- captured near-field and far-field mode distributions
- insertion, coupling, propagation and polarisation-dependent loss determination
- induced refractive index profiles (profilometry/phase contrast)
- device gain and laser characteristics
- advanced fibre pigtailing

Collaborative links

Within CUDOS

- University of Sydney – high bandwidth testing of waveguide amplifiers.
- Australian National University - expertise in the theoretical underpinnings and design of coupled waveguide devices.

External to CUDOS

- Australian defence - user-driven perspective on requirements and applications for compact waveguide oscillators.
- Aston University in the UK - In 2007 Dr Graham Marshall took part in an Australian Academy of Science funded collaborative research project with Professor Ian Bennion at Aston University on the applications of high-repetition rate laser materials processing. This work resulted in an invited journal article reviewing light matter interactions and the challenges underlying the femtosecond laser direct-write technique [1].

Goals for 2008

The project goals for 2008 included the demonstration of a monolithic waveguide oscillator and its subsequent power scaling to 10 mW, the measurement of bit error rates in pigtailed waveguide amplifiers, the development of coupled waveguide devices, and the creation of 'lossless' optical signal splitters. In parallel with the device research, the project team continued to improve the manufacturing and diagnostics facilities at Macquarie University with particular emphasis on the fabrication of short period Bragg gratings of very high quality. In light of the successes of 2007 we predominantly focussed on further developing waveguide devices in 2008 that exhibited low loss such that our goals could be realised.

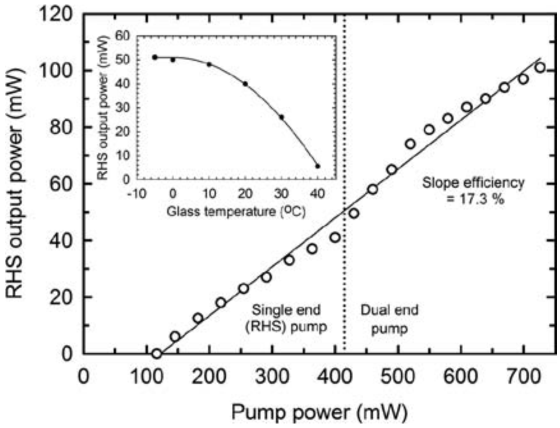


Fig 2. Output power of a 9.5 mm, 1032 nm waveguide laser at room temperature, as a function of pump power for single- and dual-end pump geometries. Inset shows the effect of bulk glass temperature on laser output power.

Achievements and highlights for 2008

These project goals can be broadly categorised as device or infrastructure targets and are:

- *First demonstration of laser written monolithic waveguide laser (WGL) systems*

  – 1 mW monolithic Er:Yb WGL @ 1537 nm [10]

  1st report of a monolithic laser written using the fs laser direct-write technique. This device had modest output and lased for 30 mins before erasure of the Bragg gratings put the device below threshold.

- *Power scaling of waveguide laser platform*

  – 100 mW monolithic Yb WGL @ 1032 nm [8]

  The application of new, higher gain materials and a reduction of the guided mode size lead to unprecedented power scaling of the laser platform. Improvements in mode-matching to optical fibres and grating fabrication techniques enabled these improvements. Multiple wavelength devices were fabricated in arrays demonstrating the flexibility and robustness of the manufacturing technique.

  Following demonstrations of packaged waveguide laser devices, we hosted a demonstration roadshow to the Australian Defence Materiel Office. The multi-wavelength laser sources and optical circuitry capabilities of the platform are of particular relevance to sensing, optical signal processing and countermeasure applications within the Defence Force.

- *Investigation of coupled non-linear waveguide systems in coordination with ANU.*

  Dr Martin Ams visited the ANU labs to help coordinate the characterisation of coupled waveguide devices fabricated at MQ

- *Initial bit error rate studies.*

  Tests of a packaged waveguide amplifier device were performed in collaboration with the University of Sydney node. These are the first measurements of error-rates in a laser written amplifier. Our original device showed no significant system penalty and investigations are on-going.

- *Commissioning of a high power oscillator laser system for rapid and more flexible waveguide fabrication.*

  A Femtolaser XL system with pulse addressability combined with a 3 axis air-bearing motion control system is now in operation.

Two new PhD student projects based on this system have been implemented.

- *Diagnostic facilities commissioning, namely the application of a refractive index profilometer and QPm software.*

  A Rinck Electronik profilometer was installed to provide sub-micron resolution measurements of waveguide refractive index profiles.

- *Improvements to device substrate preparation:*

  We commissioned new optical sample preparation and polishing facilities in our glass-processing workshop. A Logitech PM5 polishing machine was installed allowing for automated flatness quality control during lapping and polishing materials processing.

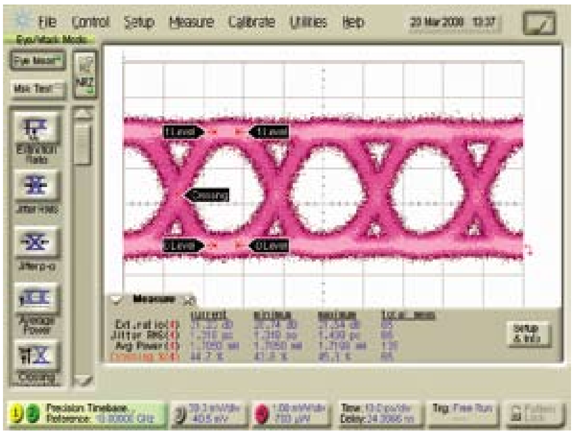


Fig 3. Eye-diagram from the first measurements of error-rates in a packaged laser written amplifier performed in collaboration with the University of Sydney node. The amplifier device showed no significant system penalty.

Targets for 2009

- Development of simultaneous operation multi-wavelength laser devices (4 wavelengths powered by a single pump source)

  – Reduction in lasing threshold to ~ 20 mW

  – 2D laser arrays pumped through a single port

  – Multiple laser lines from a single sampled WBG

- Demonstrate linewidth narrowed WGLs (approaching 10 MHz)

  – Commission a self heterodyne detection system

  – Accurately measure laser linewidth

- Collaborations:

  – CUDOS ANU:

  • Sangwoo Ha visit to Macquarie in March 2009

  • Collaborative investigation into slow light switching in coupled waveguide Bragg gratings

  – Sydney University (Mark Pelusi):

  • Reinvestigate C-band amplifier characteristics and complete BERT tests

  – New collaboration with Hubert Curien Labs, University of St Etienne, France (Dr Razvan Stoian):

  • Samples exchanged seeking to investigate fundamental mechanism of temporal beam shaping on photo-ionisation rates (a continuation of the Douglas Little PhD)

Published Papers

Invited

1. M. Ams, G. D. Marshall, P. Dekker, M. Dubov, V. K. Mezentsev, I. Bennion and M. J. Withford, *"Investigation of ultrafast laser photonic material interactions: challenges for directly written glass photonics"*, IEEE Journal of Selected Topics in Quantum Electronics 14, pp. 1370-1381, 2008

2. M. Ams, G. D. Marshall, P. Dekker and M. J. Withford, *"Photonic waveguide devices directly written into dielectric materials using femtosecond laser pulses"*, Paper 4A2a-6 in Progress in Electromagnetics Research Symposium (PIERS), Hangzhou, China, 2008

3. M. Ams, D. Little, R. J. Williams, G. D. Marshall, P. Dekker, J. A. Piper, J. M. Dawes and M. J. Withford, *"Overview of laser microfabrication techniques for photonic devices"*, Paper TuC-2 in the Opto-Electronics and Communications Conference (OECC) and the Australian Conference on Optical Fibre Technology (ACOFT), Sydney, Australia, 2008

4. A. Politi, J. C. F. Matthews, A. Laing, A. S. Clark, J. Fulconis, G. D. Marshall, P. Dekker, M. Ams, M. J. Withford, W. J. Wadsworth, T. Rudolph, M. J. Cryan, J. G. Rarity, A. Stefanov, S. Yu and J. L. O'Brien, "Quantum information science with photons on a chip," Paper 258 in the 18th National Congress of the Australian Institute of Physics (AIP), Adelaide, Australia, 2008

5. G. D. Marshall, M. Ams, R. J. Williams, P. Dekker and M. J. Withford, *"A new approach to fabricating glass photonics"*, Paper 263 in the International Commission for Optics (ICO 21) Congress, Sydney, Australia, 2008

6. M. J. Withford, G. D. Marshall, M. Ams, N. Jovanovic, P. Dekker, A. Fuerbach and J. A. Piper, *"Ultrafast laser direct writing of resonant photonic devices"*, Paper 6879A-19 in SPIE Photonics West, San Jose, USA, 2008

Contributed

7. M. Ams, G. D. Marshall, P. Dekker, J. A. Piper and M. J. Withford, *"Ultrafast laser written active devices"*, Laser & Photonics Reviews, Accepted 29th October 2008

8. M. Ams, P. Dekker, G. D. Marshall and M. J. Withford, *"Monolithic 100 mW Yb waveguide laser fabricated using the femtosecond-laser direct-write technique"*, Opt. Letters 34, pp. 247-249, 2009

9. D. J. Little, M. Ams, P. Dekker, G. D. Marshall, J. M. Dawes and M. J. Withford, *"Femtosecond laser modification of fused silica: the effect of writing polarization on Si-O ring structure"*, Opt. Express 16, pp. 20029-20037, 2008

10. G. D. Marshall, P. Dekker, M. Ams, J. A. Piper and M. J. Withford, *"A Directly-Written Monolithic Waveguide-Laser Incorporating a DFB Waveguide-Bragg Grating"*, Opt. Letters 33, pp. 956-958, 2008

11. M. Ams, G. D. Marshall, P. Dekker and M. J. Withford, *"Active waveguide devices directly written into glass materials using a femtosecond laser"*, Paper 237 in the 18th National Congress of the Australian Institute of Physics (AIP), Adelaide, Australia, 2008

12. G. D. Marshall, M. Ams, J. C. F. Matthews, A. Politi, P. Dekker, J. L. O'Brien and M. J. Withford, *"Optical Quantum Circuits Created Using the Femtosecond Laser Direct Write Technique"*, Paper 646 in the 18th National Congress of the Australian Institute of Physics (AIP), Adelaide, Australia, 2008

13. J. C. F. Matthews, A. Politi, A. Laing, A. Stefanov, M. J. Cryan, J. G. Rarity, S. Yu, G. D. Marshall, M. Ams, M. J. Withford and J. L. O'Brien, *"Multi-Photon Quantum Optics on a Chip"*, Paper P1-8 in Quantum Communication, Measurement & Computing (QCMC), Calgary, Canada, 2008

14. M. Ams, G. D. Marshall, P. Dekker and M. J. Withford, *"A compact, monolithic, 36mW Yb-doped DFB waveguide laser fabricated using femtosecond laser direct-write techniques"*, Post-deadline Paper 1677 in the European Optical Society Annual Meeting 2008, Paris, France, 2008

15. G. D. Marshall, P. Dekker, M. Ams, J. A. Piper and M. J. Withford, *"Monolithic Waveguide-Lasers Created in Bulk Glass Using the Direct Write Technique"*, Paper MD5 in Advanced Solid State Photonics (ASSP), Nara, Japan, 2008

Flagship Project

TUNABLE MICROPHOTONICS

Project Manager: Arnan Mitchell

Science Leader: Yuri Kivshar

Contributing staff: Ben Eggleton, Ross McPhedran, Boris Kuhlmey, Mark Pelusi, Feng (Sydney), Yuri Kivshar, Wieslaw Krolikowski, Dragomir Neshev (ANU). Arnan Mitchell (RMIT), Mick Withford, Graham Marchall (Macquarie)

Students: Bill Corcoran

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 device 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 active control of their dispersion and diffraction properties and tunable characteristics
- To demonstrate experimentally the control of light in microphotonic periodic structures, mainly on the two-dimensional platform

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 research partners such as DSTO we will continue to conduct internationally leading research towards:

1. Spatio-Temporal Tunable Nonlinear Effects: We explore the behaviour of light in coupled waveguide structures which exhibit unusual non-local nonlinear coupling and ultimately aim to experimentally investigate spatially and temporally confined optical pulses (often termed 'optical bullets').
2. Tunable Complex Nonlinear Heterostructures: We utilise new platforms such as fluid infiltrated photonic crystal fibres and microfluidic planar structures as flexible and reconfigurable platforms. We aim to explore nonlinear optical behaviour in strongly nonlinear platforms with potential applications in photonic signal processing and optical sensing
3. Microwave Photonics on a Chip: We will 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 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 capabilities with the platform capabilities of RMIT University applied to 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.