Chief Investigator: Mick Withford

CI short biography

A/Prof. Withford was awarded a PhD from Macquarie University in 1995 for his investigations of the effects of gas additives on copper vapour laser performance. His continuing work in this field led to the development of a new sub-class of metal vapour, termed kinetically enhanced copper laser, in 1998. His current research area is *miniaturization science and engineering* encompassing studies into both laser / materials interactions and advanced processing methodologies, and their application to photonic device development. Projects include prototyping periodically poled crystalline materials, fibre Bragg gratings in both photosensitive and non-photosensitive glasses, and femtosecond laser direct writing of waveguides and lightwave devices in passive and active glasses. Dr. Withford leads both the Macquarie University node of Australian Research Council (ARC) Centre of Excellence: Ultrahigh-bandwidth Devices for Optical Systems (CUDOS) and NCRIS Node *OptoFab* incorporating fabrication facilities at the Bandwidth Foundry, the University of Sydney, the University of Adelaide, and Macquarie University.

Awards, honours, major international visits

In 2010 Withford visited labs and delivered seminars at Aston University and Heriot Watt University, UK. In 2010 he was also appointed to the Directorship of the MQ Photonics Research Centre, Macquarie University, replacing Founding Director Prof. Brian Orr. The MQ Photonics Research Centre currently has a membership of 35 Research / Academic staff and 38 postgraduate students.

Key areas of research contribution within the Centre

Withford is Science Leader for the Flagship project: Waveguide Amplifiers and Oscillators. In this role he is responsible for determining the broad research directions, building links with end-users such as DSTO and identifying commercial opportunities. He collaborates with CI Assoc/Prof. Judith Dawes on self assembly of 3-D photonic platforms for studies into radiation dynamics. He also collaborates with Dr Alex Fuerbach both investigating ultrafast laser interactions with photonic materials and developing novel fibre lasers with Dr Stuart Jackson from University of Sydney. Withford and Dawes also collaborates in a research project with partner investigators at the Astrophotonics group at the Anglo-Australian Observatory investigating optic fibre instrumentation for astronomy.

Researchers and students

A/Prof Judith Dawes
A/Prof Mike Steel
Dr Jon Lawrence
Dr Graham Marshall
Dr Alex Fuerbach
Dr Peter Dekker
Dr Martin Ams
Dr Gabriel Molina-Terriza
Dr Doug Little
Dr Nem Jovanovic
Dionne Haynes
Robert Williams
Chris Miese
Simon Gross
Geraldine Marien
Nick Cvetojevic
Alex Ariola
Thomas Meany
Jocelyn Liu
Yuwen Duan

Visitors

A/Prof David Lancaster – Defence, Science and Technology Organisation
Dr Esa Jaatinen – Queensland University of Technology
Christian Voightlander – Friedrich Schiller Universitat

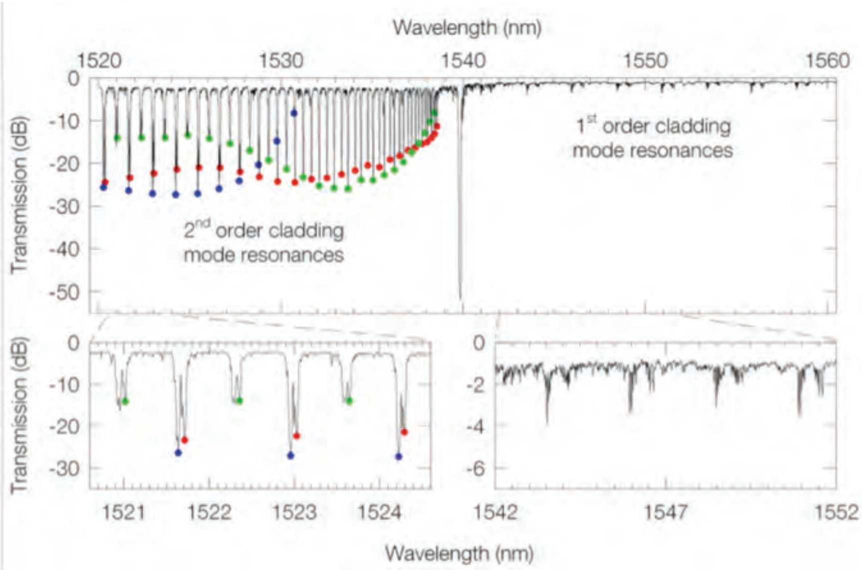
Achievements 2010

Flagship Project – Waveguide Lasers

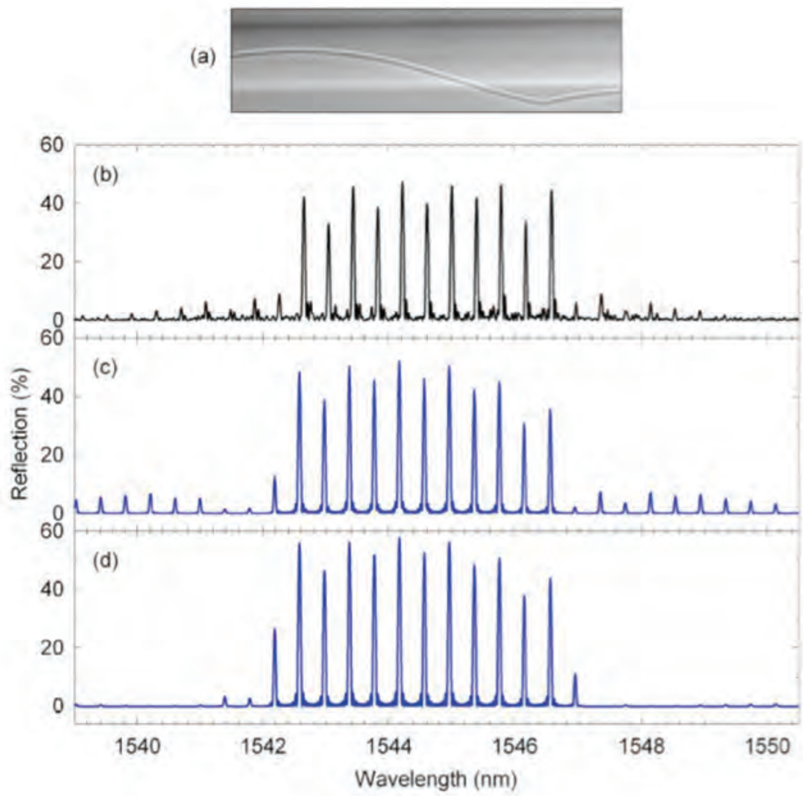
In 2010 we have continued to both consolidate our capabilities in waveguide laser fabricated via femtosecond laser inscription and engage with external partners and potential end-users for this technology. Our recent successes include demonstrations of waveguide laser action across the entire gain bandwidth for Ytterbium, a high power 2 micron laser and sophisticated sample grating in both fibre and bulk glass forms. These outcomes are detailed in the Flagship Report by Dr. Martin Ams. Related outcomes in astrophotonics, fibre gratings, fibre lasers and fundamental studies of ultrafast laser induced material modification are presented below.

Ongoing Investigations into Ultrafast Laser Written Point by Point Gratings.

We have continued our work on cladding modes in fibre gratings written by femtosecond laser processing in collaboration with Jens Thomas, Ria Becker, Prof. Andreas Tunnermann and Prof. Stefan Nolte of the Institute of Applied Physics in Jena. The cladding mode resonances of such FBGs can span a full octave in the spectrum and are very pronounced (deeper than 20dB). Using a coupled-mode approach, we have computed the strength of resonant coupling and found that coupling into cladding modes of higher azimuthal order is very sensitive to the position of the modification in the core. The system provides an unusually clear example of the dispersion properties of cladding modes and especially of the vector nature of their coupling. This work has recently been published as a Spotlight article in Optics Express. We are now focused on an accurate description of the spatial fields coupled out of the fibre which involves interference between several modes of different azimuthal order.



We have also exploited the inherent flexibility of the ultrafast laser inscription method to demonstrate a range of novel fibre Bragg grating devices. In particular, the point-by-point grating method enables us to engineer the coupling constant [1]. We fabricated a grating which exhibited a series of 11 narrowband resonances spaced by 50 GHz (or approximately 0.40 nm at 1545 nm). The grating had an interaction profile that consisted of ten consecutive symmetric sinc envelopes (each containing 6 complete 2π phase revolutions). A 20.7 mm long second-order grating with Bragg wavelength 1550 nm and modulation of 2.07 mm was fabricated using the point-by-point method. The reflection spectrum for this grating is the figure below and displays an array of eleven 50 GHz spaced reflection resonances, and a number of low reflectivity 'satellite' peaks outside of the main envelope. It can be seen that the reflection strength of the peaks follows an alternating high / low pattern centred about a 'low' at the central Bragg resonance. As our gratings are in a weakly-coupled regime, the reflection spectrum can be approximately modelled by obtaining the Fourier transform (FT) of the target modulation profile and this method reproduces the pattern of the 11 main peaks. The FT approach also indicates that the alternating low- and high-peak heights are caused by the odd- and even-harmonic resonances that arise with the truncation of the sinc interaction modulation profile at an integer 2π multiple.



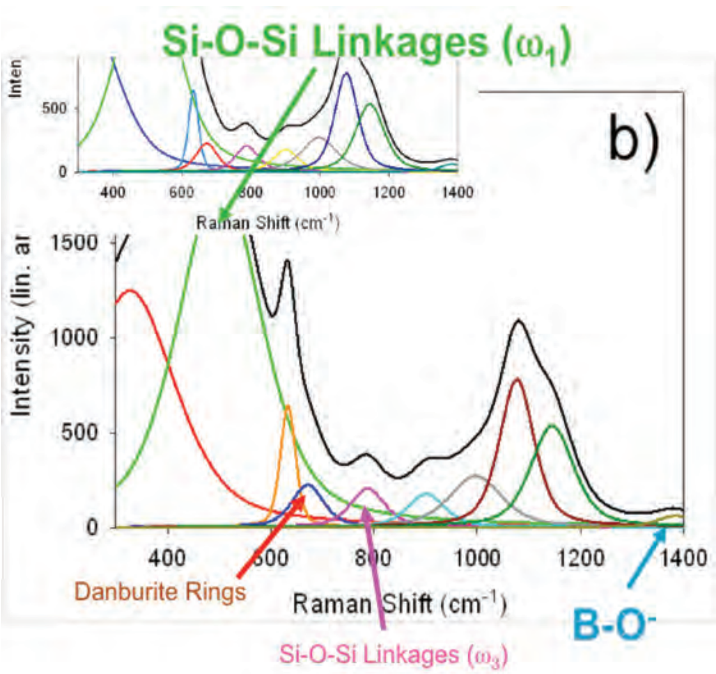
Combined phase and amplitude modulation grating. (a) A micrograph montage shows the sinc form of the lateral displacement of the grating about the core centre. The horizontal axis of the image is compressed by a factor of four and shows the displacement of the grating from the core centre, across the core/cladding boundary, to the first phase shift at the inversion of the sinc profile. (b) Reflection spectrum from the grating. (c) Modelled reflection spectrum for the same grating presented in (b). (d) Modelled reflection spectrum fro idealized PbP grating with no core-centre overshoot.

In a collaboration with Stuart Jackson and Ryuichiro Goto from the University of Sydney, we combined our expertise on point-by-point femtosecond direct-write gratings with our collaborators' unique, single-polarization-guiding all-solid photonic bandgap (ARROW) fibre to realise an integrated, narrow-linewidth, single-polarization fibre Bragg grating reflector. This enabled us to build a highly robust and simple polarized all-fibre laser which produced 7.2 W linearly-polarized output with 0.025 nm linewidth.

Finally, building on our recent work on non-uniform point-by-point fiber Bragg gratings, and in collaboration with visiting PhD student Christian Voigtländer from the Friedrich-Schiller University in Jena, we explored the possibilities of local phase and amplitude control in our gratings to realise apodized FBGs. Gaussian apodized gratings were achieved with relative ease, and by employing a coupled-mode thoery model we were able to design and implement gratings with sinc apodization profiles, exhibiting steep band-edges, relatively flat-top reflection peaks, and excellent side-lobe suppression.

Deeper insights into femtosecond laser induced index change

We have completed a comprehensive study [2,3], combining Raman spectroscopy and refractive index profilometry, that has advanced our insights and predictive capability of ultrafast laser induced index change. In general we have noted that low repetition rate lasers typically generate non-bridging oxygen centres and break the R-O bonds in glass (where R = P, B, Si etc depending on the type of glass). By contrast, high repetition rate laser which induced index change by a cumulative heating effect induce expansion and contraction of R-O-R linkages in the glass matrix leading to glass densification. The image below indicates the bonds that are modified during femtosecond laser irradiation of borosilicate glasses.

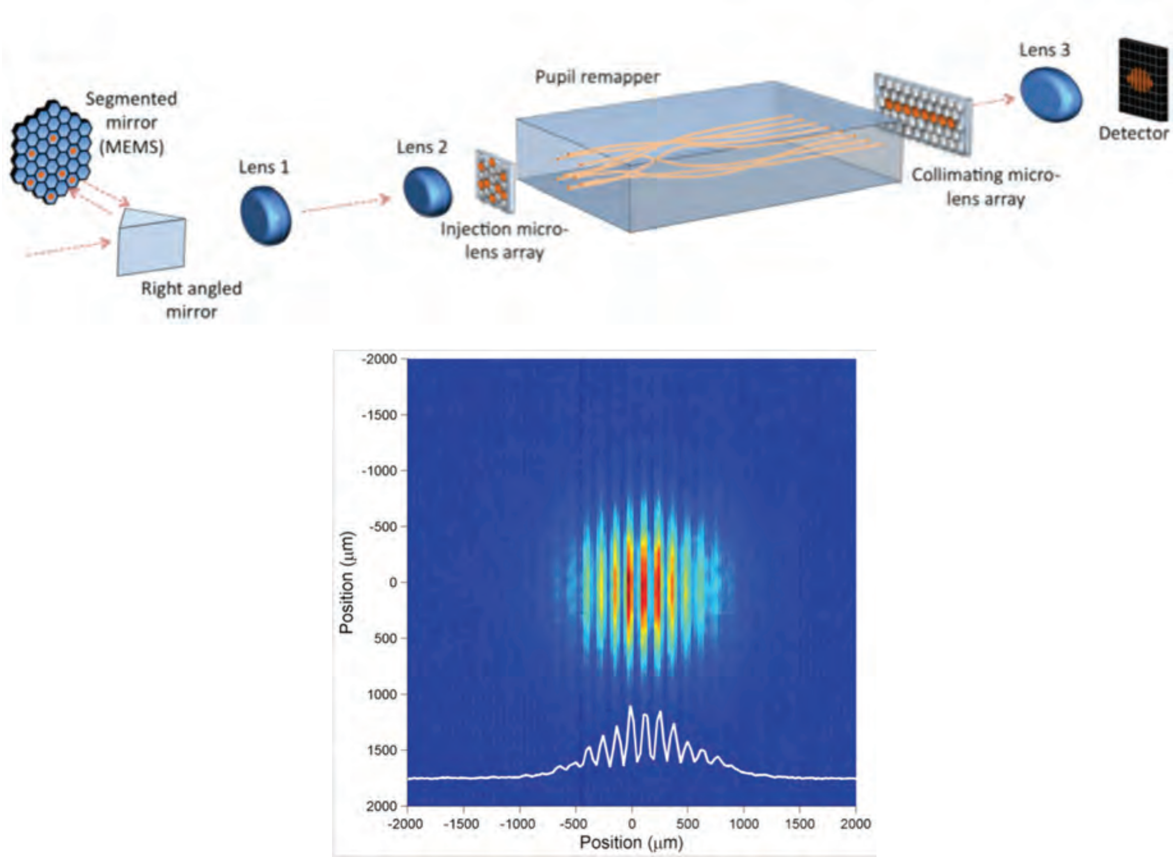


Astrophotonics

In 2010 the number of astrophotonic projects within the CUDOS@MQU group has grown dramatically, a factor that reflects the evolving strategic link (including several co-funded positions) between Macquarie University and the Australian Astronomical Observatory (AAO). Four (out of a total of 5) of these projects are briefly reviewed here.

One of our joint projects is investigating the application of fibre Bragg gratings (FBGs) in time resolved astronomy, the study of astrophysical phenomena that show variations in their spectral lines on very short timescales. In this case the FBGs converts the shift in wavelength of a particular spectral line into an intensity or power modulation at that particular wavelength. Doing so, it may be possible to significantly improve the temporal resolution, without degrading the spectral resolution. A corresponding behaviour of the gratings has been found between the model and the experimental results, supporting the accurateness of the model and suggesting that FBGs will be useful for the observation of small spectral shifts on very short timescales. FBGs promise to be able to nearly instantaneously observe shifts as small as 1pm for an average signal to noise ratio (SNR) of 80. This is a huge improvement compared to the observed shifts of 50-68 pm for SNR of 50 to 90 obtained with high resolution Echelle gratings in the case of astronomical objects such as Chemical Peculiar stars and T-Tauri stars.

In 2010 the CUDOS@MQU direct write team also played a lead role in a joint project with the University of Sydney, Grenoble University and the Australian Astronomical Observatory developing an integrated pupil remapping system (see image below) that allows one to remap the light from a 2 dimensional pupil plane of a telescope, into a 1 dimensional linear array, by using optical waveguides. In this way, the stellar light at the pupil plane is sampled by the optical waveguides. The output of these optical waveguides can then be interfered to extract information about the phase of the object the telescope is looking at. From this it is possible to determine that there are exoplanets around parent stars or even study the structure of newly forming regions. The system, termed "Dragonfly", has exhibited high throughputs and minimum cross coupling, and was able to generate exquisite polychromatic fringes (see image), from which closure phases could be extracted. "Dragonfly" is scheduled for the first on telescope tests on the 20th/21st of May 2011 at the Australian Astronomical Telescope (AAT) at Siding Springs.



Schematic of the Dragonfly system and interference pattern generated between the output of 2 waveguides with polychromatic light form a super continuum source.

In yet another astrophotonic we have exploited the utility of the ultrafast laser direct write method to develop chip-based multimode guided wave devices that could integrate the multimode transport fibres used in astronomy with future downstream photonic devices such as spectrometers on a chip. In a preliminary study we have demonstrated up to 76% of the light can be transmitted through ultrafast laser written multimode guides and hope to improve this in the near future [4].

Finally, we have complete our investigations into Focal Ratio Degradation of multimode fibres used in astronomy. MSc student Dionne Haynes has developed a robust analytical approach that can deconvolve the contributions to FRD via modal diffusion and scattering. A paper on this work has been accepted in Monthly Notices of the Royal Astronomical Society.

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1. G. D. Marshall, R. J. Williams, N. Jovanovic, M. J. Steel and M. J. Withford, *"Point-by-point written fiber-Bragg gratings and their application in complex grating designs"*, Opt. Exp., Vol. 18 (19), pp. 19844-19859, 2010.
2. D. J. Little, M. Ams, P. Dekker, G. D. Marshall and M. J. Withford, *"Mechanism of femtosecond laser induced refractive index change in phosphate glass under a low repetition-rate regime"*, J. Appl. Phys., Vol. 108, Art. 033110, 2010.
3. D. J. Little, M. Ams, S. Gross, P. Dekker, C. T. Miese, A. Fuerbach and M. J. Withford, *"Structural changes in BK7 glass upon exposure to femtosecond laser pulses"*, accepted J. Raman Spectroscopy, 2010.
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