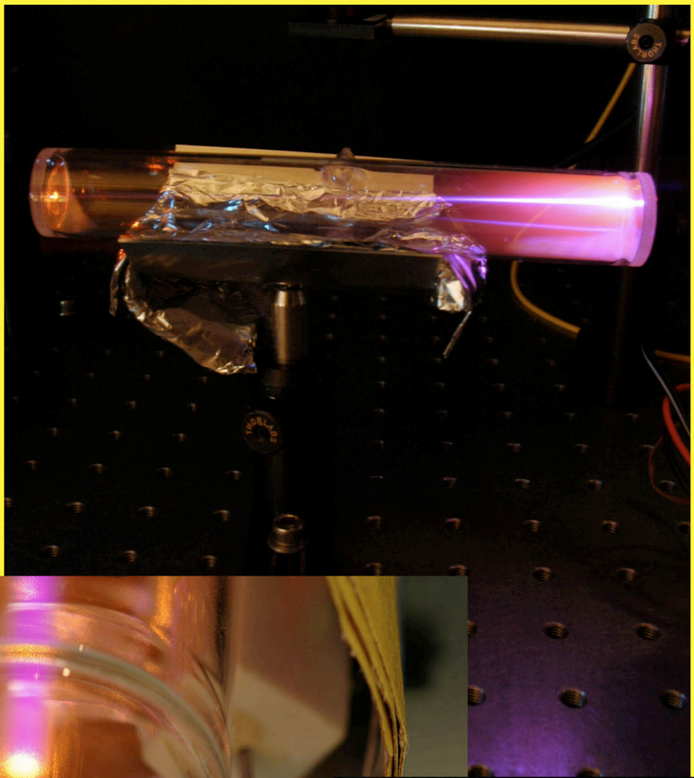
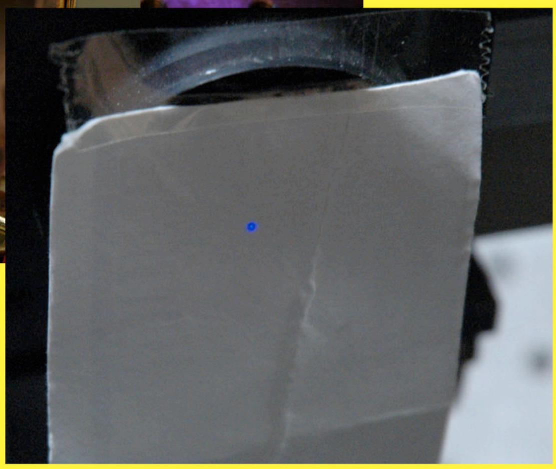
Australian Optical Society

NEWS





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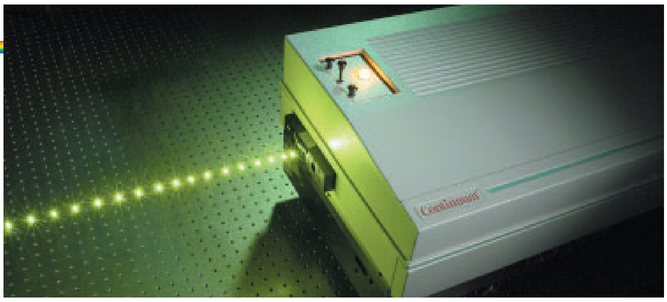
“Laser ... inter eximia naturae dona numeratum plurimis compositionibus inseritur”*

Pliny, Natural History, XXII, 49

Lastek 2005: New Lasers from new Suppliers

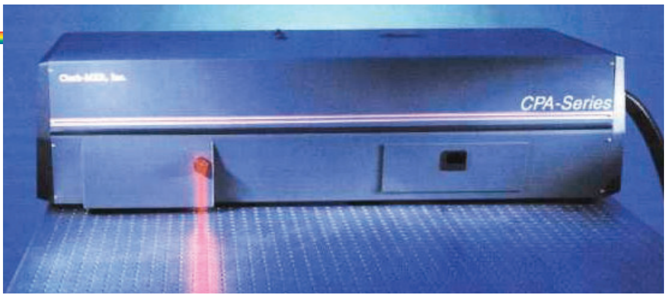
Continuum:

Continuum is a global leader in innovative flashlamp pumped solid state Nd:YAG lasers, OPOs (optical parametric oscillators), dye lasers and custom laser systems for scientific, commercial and industrial applications.



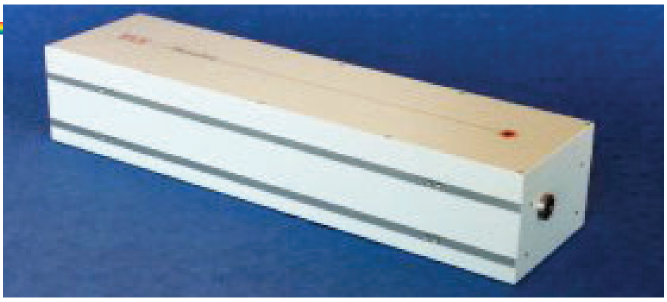
Clark-MXR:

Clark-MXR offer ultrafast regenerative Ti:S amplifier systems with unprecedented reliability and ease-of-use. Ingenious engineering design. Fully-integrated, compact package with small footprint. This is true ”no-tweak” ultrafast technology which lets you concentrate on your experiment rather than your equipment



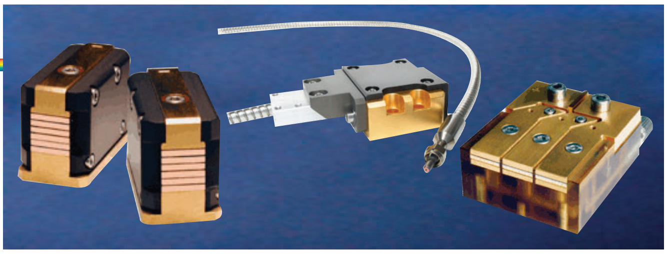
ELS:

Electonik Laser Systems introduce the revolutionary Versadisk thin-disk Yb:YAG laser system. This novel technology may be scaled up to high powers without compromising perfect beam quality. CW output with excellent spatial mode is offered at up to 100W in the IR, or up to 15W of green, ideal for pumping Ti:S lasers and other devices. Pulsed and mode-locked versions also available.



N-Light:

A vertically-integrated designer and manufacturer of high power laser diode bars and arrays, available in a wide-range of package options that includes high-power, water-cooled stacks as well as conductively cooled, fiber coupled packages.



*”The Laser ... is numbered among the most miraculous gifts of nature and lends itself to a variety of applications.”

LAS TEK

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MARCH 2005 **VOLUME 19 NUMBER 1**

AOS NEWS

ARTICLES

DEPARTMENTS

Cover Picture: A Rubidium vapour cell illuminated with infrared light at 780nm and 776nm wavelength, and producing blue up-converted coherent light, as seen on the white card. See article by Scholten et al. in this issue.

SUBMISSION OF COPY:
Contributions on any topic of interest to the Australian optics community are solicited, and should be sent to the editor, or a member of the editorial board. Use of electronic mail is strongly encouraged, although submission of hard copy together with a text file on floppy disk will be considered.

Where possible, diagrams should be contained within the document or sent as separate files. Figures on A4 paper will also be accepted. Note: all figures should be black & white or greyscale.

ADVERTISING:
Potential advertisers in *AOS News* are welcomed, and should contact the editor.

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DEADLINE FOR NEXT ISSUE
25th May, 2005

Australian Optical Society website
http://aos.physics.mq.edu.au

- News
- Membership
- Optics links
- Prizes/awards
- Conferences
- Jobs/Scholarships
- Affiliated societies
- ...and more

AUSTRALIAN OPTICAL SOCIETY

ABN 63 009 548 387

AOS News is the official news magazine of the Australian Optical Society. Formed in 1983, the Society is a non-profit organisation for the advancement of optics in Australia. Membership is open to all persons contributing to, or interested in, optics in the widest sense. See the back page (or the AOS website) for details on joining the Society.

AOS News - Editorial Board

Submission guidelines

The *AOS News* is always looking for contributions from its members. Here is a short summary of the how to make a submission.

What can you submit?

∗ ***Scientific Article***
A scientific paper in any area of optics.

∗ ***Review Article***
Simply give a run down of the work conducted at your laboratory, or some aspect of this work.

∗ ***Conference Report***
If you have been to conference recently, writing a short report would be greatly appreciated.

∗ ***News Item***
Any newsworthy stories in optics from Australia or abroad.

∗ ***Book Review***
If you have read an interesting (and relatively new) book in some field of optics please consider writing a review for the *AOS News*.

∗ ***Cartoon or drawing***
If you have some artistic bent why not consider submitting a cartoon!

How can you submit?

💻 The easiest way is by email. Either send the document text in your mail, and attach diagrams and/or a word processor file. We accept nearly all file formats. (Famous last words!).

🗐 If you don't have email access, or cannot send diagrams or pictures via email, we can accept hard copies. (One copy only is required).

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ABN 63 009 548 387

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President's Report

Since the last newsletter went out in December, the major event for the AOS has been the AIP Congressin Canberra at the beginning of February, in which the AOS took part. Indeed the optical sessions coordinated by the AOS formed the biggest part of the congress. The Optical Society of America was represented by its president-elect, Dr Eric van Stryland of CREOL in Florida. He made several OSA and AOS awards on the first day. The first was the OSA Meggers award to Prof. Brian Orr of Macquarie University for his outstanding work on molecular spectroscopy and as well for developing sources for that purpose. The second was the AOS Technical Optics Award, which was made to Dr Yabai He, also of Macquarie University, for his work in developing sources for spectroscopy, in particular optical parametric oscillators. The final awards made on the first day was the AOS Postgraduate Student Prize which was awarded to two people. The judging committee felt that there were two equally outstanding candidates, so two awards were made – to Tom White of the University of Sydney and to Ilya Shadrivov of the ANU.

On the last day of the congress Dr Paul McManamon, the president-elect of the SPIE, as well as speaking on his own work, presented the OSA/SPIE student prizes for the best student presentations in optics at the congress. The winners were Aidan Brooks of the University of Adelaide and Peter Domachuk of the University of Sydney. Aidan's presentation has been written up and appears in this issue of the Newsletter. In addition two other student presenters received honourable mentions for their presentations. These were Florian Englich of Macquarie University and Trina Ng of the University of Sydney. I would like to congratulate all of these winners on behalf of the AOS.

Our thanks go also to three other AOS members who had a major part in the congress, Ken Baldwin who was the congress chair, Hans Bachor who was the program chair for the congress and to Neil Manson who was the program chair for the AOS sessions. They each have done an excellent job.

The council has had two meetings since the last newsletter. The first was an e-meeting which was held to ratify the decision to make two AOS Postgraduate Student Prizes. The outcome of that meeting is fairly obvious! The second was a face to face meeting at the congress. Most matters were fairly routine, but one that I'd like to bring to the attention of the membership is the future of the ACOFT series of conferences. This successful series of conferences on optical fibre technology is 50% owned by the Photonics CRC through its subsidiary the Photonics Institute. The termination of the CRC means that the Photonics Institute is to be wound up, leaving ACOFT partly an orphan. A proposal is being drafted to suggest that the AOS takes over the 50% of ACOFT with the other 50% ownership remaining with IEAust. If any readers have views on this matter would they please direct them to myself or Dr John Love (see councillor's contact details).

The next optics meeting in Australia will be the BGPP/ACOFT conference in July from the 4th to the 9th. The latter days will be workshops with the main meeting being from the 4th to the 6th. The AOS will hold its AGM at this meeting at 1pm on the 6th of July 2005, The venue being Star City in Sydney.

Murray Hamilton
President, Australian Optical Society
February 2005

Position Vacant
Australian Optical Society Newsletter
Editor

The AOS is seeking an editor for the newsletter. This is a quarterly publication conveying optics news, scientific articles and optics advertising to the Australian Optics community.

The editor will be paid an honorarium of $2000 p.a or $500 per issue.

Applications and enquiries for this position should be addressed to the President of the Society, Dr Murray Hamilton

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murray.hamilton@adelaide.edu.au

Advance Notice
AOS Annual General Meeting 2005

The annual General Meeting of the Australian Optical Society will be held at 1pm on 6th July 2005, Star City, Sydney.

Free to a good home!

3.6 m Jarrell-Ash specrometer? The resolution in the visible is around 0.1 nm. Actual dimensions: 356 cm (L) x 73 cm (W) x 149 cm (H)
For further information
Stephen Collins, Victoria University
Phone: 03 9919 4283Email: stephen.collins@vu.edu.au

Awards for AOS members in 2005

AOS Technical Optics Award 2004: Yabai He, Macquarie University

OSA/SPIE Student prizes 2005: Peter Domachuk, University of Sydney and Aidan Brooks, Adelaide University

Optical Society of America – Meggers Award 2004: Brian Orr, Macquarie University

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WARSASH/AOS STUDENT PRIZE – ANNOUNCEMENT

Warsash Pty Ltd has very generously offered to fund a prize for postgraduate students who are in the AOS. The council of the AOS together with Warsash has instituted the following rules for this prize. Please see the AOS website for details.

Applications will close on the 30th of June each year.

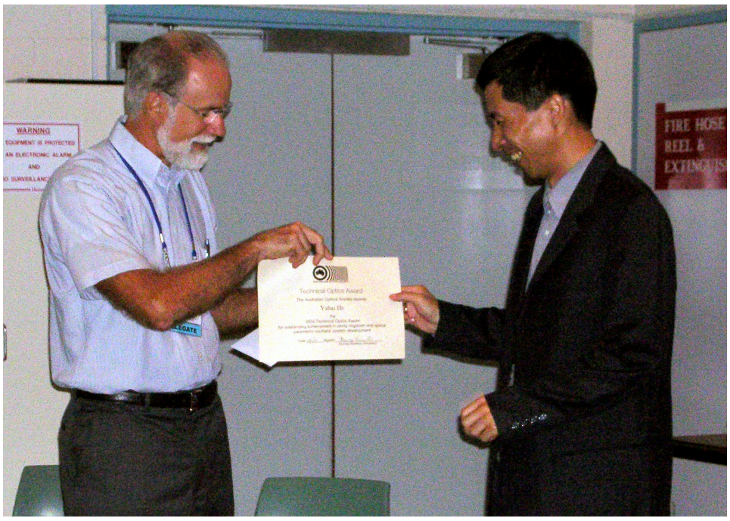
AOS MEDAL

Nominationtions for 2005 have closed (15 Feb 2005).

AOS TECHNICAL OPTICS AWARD

Nominationtions are invited. See AOS website for details. There is no closing date for this award.

Prof. Brian Orr receives the OSA Meggers award from Dr Eric van Stryland (OSA) at AIP 2005



Dr Yabai He receives the AOS Technical Optics Award from Dr Eric van Stryland (OSA) at AIP 2005

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CUDOS, one of eight highly prestigious Centres of Excellence created by the Australian Research Council, is doing research right at the leading edge of photonics. We are developing ways to guide and control photons using optical waveguides – optical fibres, waveguides produced on planar substrates, or in photonic crystals, which are completely new optical materials. We are also investigating nonlinear optical phenomena in these materials.

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- ***Sydney University:***
  Professor Ben Eggleton, egg@physics.usyd.edu.au
- ***Australian National University:***
  Professor Yuri Kivshar, yuri@cyberone.com.au
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- **Networking opportunities with other CUDOS researchers at workshops, collaborative research programs, etc**
- **Excellent job prospects!**

The CUDOS team at a workshop in Canberra– you will be in good company!

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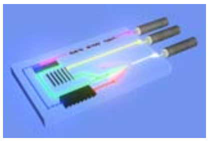
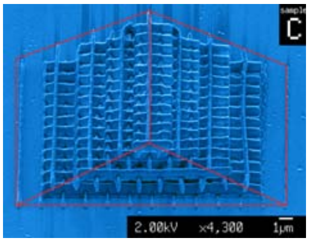
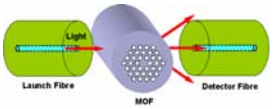
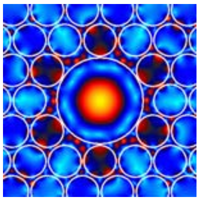


The aim of the **Microphotonics** project is to design, fabricate, characterize and model 3-D polymer-based photonic crystal structures. The demonstration of a photonic crystal superprism is of particular interest because of its startling optical properties.

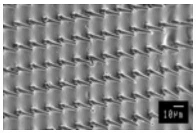


The **Micro-structured Optical Fibre (MOF)** project explores novel MOF designs for use in photonic device applications. MOFS are being explored for device applications and optical interconnects to provide efficient connections from standard single-mode fibers and planar waveguides.

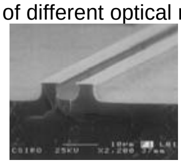


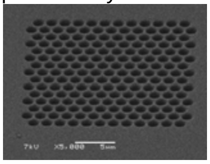


The **Laser Micro-Machining** project develops processes for laser-based micro-structuring of a range of linear, non-linear and high-gain optical materials, to produce photonic structures including waveguides in bulk glasses, 2-D photonic crystals and quasi phase matched crystals.

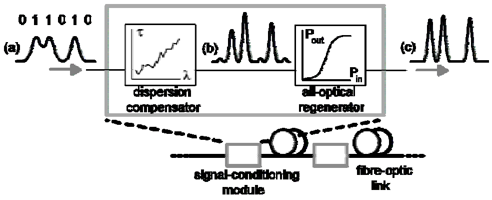


The aim of the **Photonic Integrated Waveguides and Circuits** project is to design, fabricate and characterise planar silicon optical waveguides and 2D photonic crystals in a range of different optical materials.

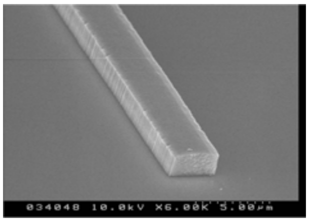




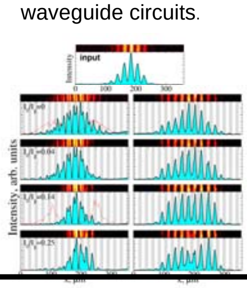
The **Optical devices and Applications** project develops all-optical signal processing functions including regeneration, wavelength conversion and amplification.

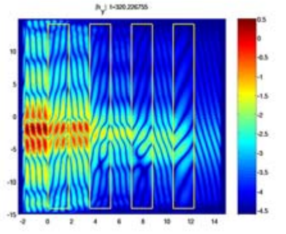


The aim of the **Non Linear Materials** project is to develop high nonlinearity chalcogenide glasses leading to novel nonlinear photonic devices including planar photonic crystals. .

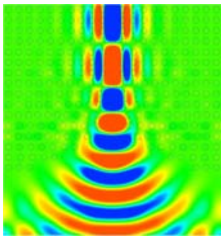


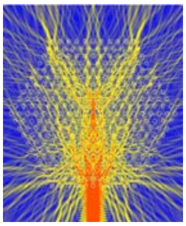
The **Non Linear Photonic Crystals** project studies the generation and propagation of nonlinear localized modes and all-optical switching in periodic photonic structures and waveguide circuits.



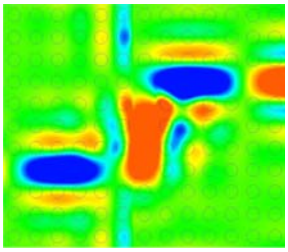


The **Computational Modelling** project provides computational modelling and visualisation techniques through generic modelling tools, new methods for modelling photonic structures and devices, and expertise in visualisation.

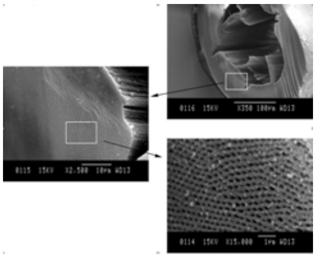




The **Photonic Circuits** project aims to find the best way to achieve tight guidance of light in optical circuits and to optimize photonic circuit features for Fresnel losses, radiation losses and impedance mismatches.



The aim of the **Radiation Dynamics** project is to explore radiation dynamics in microstructured photonic crystal materials. We aim to identify bandgap structures and use quantitative structural information to predict their optical properties.



2005 Australian Museum Eureka Prizes

REWARDING OUTSTANDING AUSTRALIAN SCIENCE

The **2005 Australian Museum Eureka Prizes** are now open with a record 10 prizes to reward outstanding Australian research. The prizes cover many areas of science including new awards for leadership in science, bioinformatics research and research which minimises the use of animals or animal products. They are also the largest national award scheme for research into critical environmental and sustainability issues facing Australia.

- **$10,000 Australian Catholic University Eureka Prize for Research in Ethics –** for research that contributes to the understanding and development of ethical standards.
- **$10,000 Australian Skeptics Eureka Prize for Critical Thinking -** for work that promotes rational thinking in the community and amongst young people.
- **$10,000 Botanic Gardens Trust Eureka Prize for Biodiversity Research** – for research that contributes to the conservation of Australia's biodiversity.
- **$10,000 British Council Eureka Prize for Inspiring Science** - for research, inventiveness, innovation or creativeness that has raised the profile of science, technology or engineering.
- **$10,000 Land & Water Australia Eureka Prize for Water Research** - for research that contributes to the protection and sustainable use of Australia's water resources.
- **$10,000 NSW Ministry for Science and Medical Research Eureka Prize for Bioinformatics Research** – for novel applications of bioinformatics tools.
- **$10,000 Royal Societies of Australia Eureka Prize for Interdisciplinary Scientific Research** - for collaborative research involving scientists from two or more disciplines.
- **$10,000 Sherman Eureka Prize for Environmental Research** – for research that leads to the resolution of an environmental problem or an improvement in our natural environment.
- **$10,000 University of New South Wales Eureka Prize for Scientific Research** - for research undertaken by a young scientist that is deemed to be under-appreciated by the Australian public.
- **$10,000 Voiceless Eureka Prize for Research which Replaces the Use of Animals or Animal Products** - for work that has, or has the potential to reduce the use of animals in laboratory-based research.

Be part of Australia's largest single event that rewards outstanding scientific research and enter yourself, your team or your colleagues for an Australian Museum Eureka Prize.

For full details and entry forms go to the Australian Museum website www.amonline.net.au/eureka **Entries close Friday May 13.**

Bragg Gratings, Poling and Photosensitivity/ 30th Australian Conference on Optical Fibre Technology BGPP/ACOFT 2005

4-9 July 2005, Star City, Sydney

http://www.bgppacoft2005.com/

Nonlinear light propagation in periodic structures – experiment and theory

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Home Page: http://wwwrsphysse.anu.edu.au/nonlinear/

Abstract: We discuss novel concepts for active control of light by light itself in optically-induced photonic structures in highly nonlinear materials. We predict theoretically and demonstrate experimentally the key aspects of light propagation in these structures, such as beam shaping and interactions. The outcome of this fundamental research may open-up new directions for technological advances in the photonics industry, with applications in all-optical switching and information storage.

Introduction

Nonlinear propagation of light in periodic media has long been a focus of strong interest [1]. Intensity-dependent modification of the optical refractive index through the medium nonlinearity can strongly affect the process of wave scattering from photonic structures with a periodic modulation of the refractive index, such as fiber Bragg gratings and photonic crystals. For example, nonlinearity can suppress the spreading of optical beams and pulses due to diffraction and dispersion, and allow for wave transmission though the periodic structure under the conditions when linear waves experience resonant reflection. These effects may have future applications in the development of new generation of all-optical switching and processing devices. Moreover, the study of such fundamental phenomena can have implications beyond the field of optics, since similar effects can occur in a large variety of different physical systems where the wave dynamics is defined by the interplay between intrinsic nonlinearity and scattering from the periodic potential, including excitations in biological molecules, electrons in solid-state matter, and ultra-cold atoms in optical lattices.

Optically-induced lattices

Many of the predicted effects in nonlinear periodic systems, however, remained largely unexploited due to difficulties in realization of suitable materials with periodicity on a wavelength level together with strong nonlinearity, accessible at low laser powers. Fabrication of periodic structures at optical wavelengths with micro- and nano-processing equipment is time and cost ineffective. Strong nonlinearities are also not readily available and to access the nonlinear effects, high power pulsed lasers are required.

Fast and efficient creation of photonic structures can be realized with holographic techniques. Interference patterns created by writing laser beams have been used to fabricate a permanent photonic structure in photopolymerizable materials [2]. In nonlinear crystals, there exists a remarkable possibility to induce a *reversible change* of the refractive index, such that the lattice configuration can be dynamically adjusted by modifying the holographic pattern.

To realize this idea we implemented an experimental set-up [Fig. 1(top)] to induce a periodic modulation in the refractive index – an *optical lattice* in a photorefractive (PR) crystal, which intrinsically has high optical nonlinearity due to the strong electro-optic effect. The optical lattice is induced by interference of several broad laser beams [Fig. 1(a)], propagating along the PR crystal [3]. The realized physical system is similar to an array of coupled waveguides [4] with the advantage that the periodicity can be changed by varying the angle between the interfering beams, and the refractive index modulation can be controlled by the external electric field applied to the PR crystal. Additionally, the dimensionality of the system can be extended from one [Fig. 1(b)] to two transverse dimensions [Fig. 1(c)] [5]. **This technique allows us to generate highly nonlinear, reconfigurable periodic structures, laying the test-bed for experimental demonstration of novel nonlinear phenomena and providing knowledge for future photonic crystal applications utilizing all-optical schemes for light control and switching.**

Linear and nonlinear wave propagation in optically-induced lattices

In order to form the basis of future application of nonlinear periodic structures, first one needs to characterize how the propagation of light beams is influenced by the periodicity. This includes a study of the (i) linear properties – formation of band-gap structure, transmission of linear waves, and their dispersion relations; (ii) nonlinear properties - formation of localized waves or solitons, their mobility and steering behaviour; and (iii) study of nonlinear beam interaction for optical switching and steering. By using optically-induced periodic lattices, we aim to investigate these effects, linking them to the specific needs for optical switching and control.

Linear propagation of beams

The key features of optical beam propagation and scattering in a lattice can be captured with the help of Floquet-Bloch theory, which states that any input beam can be decomposed into a sum of Bloch waves [6]. These waves are found as eigenmodes of the periodic structure, which shape remains constant during propagation similar to conventional guided modes. Dispersion dependencies for Bloch waves relating their normalized transverse (K_b) and longitudinal (β) wave-numbers form distinctive band regions [Fig. 2(a)] where propagation of optical waves across the lattice is allowed. The bands are separated by gaps for certain longitudinal wave-vectors corresponding to Bragg reflection resonances, where optical components can not propagate across the structure [marked BR gap in Fig. 2(a)]. Additionally, there is a semi-infinite gap due to the effect of total internal reflection (TIR gap).

To explore the band-gap structure experimentally as well as to test the dispersion properties of the propagating waves, first we investigate the linear diffraction of a narrow low-intensity laser beam propagating in a one-dimensional optical lattice. In the experimental arrangement we use a green laser beam (532nm) from a cw $Nd:YVO_4$ laser, focused onto the input face of the crystal by a lens, where the output face is

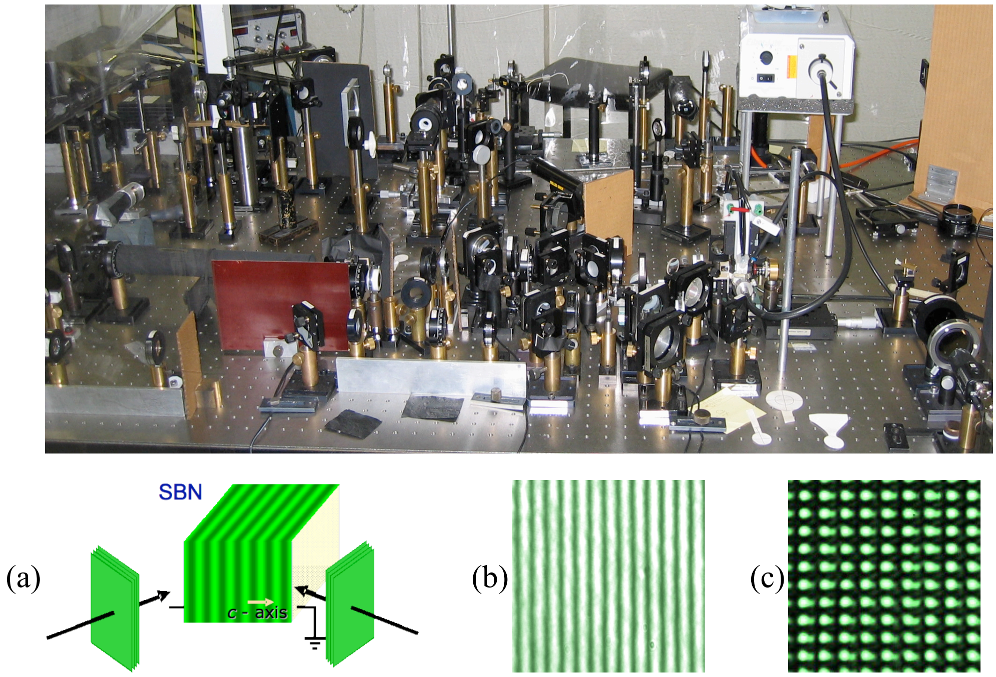

Figure 1: Experimental setup for inducing photonic lattices. Below: (a) Scheme for one-dimensional lattice generation in a photorefractive crystal by using interference of two laser beams, and light intensity patterns formed by a (b) one- and (c) two-dimensional optical lattices on the crystal output face.

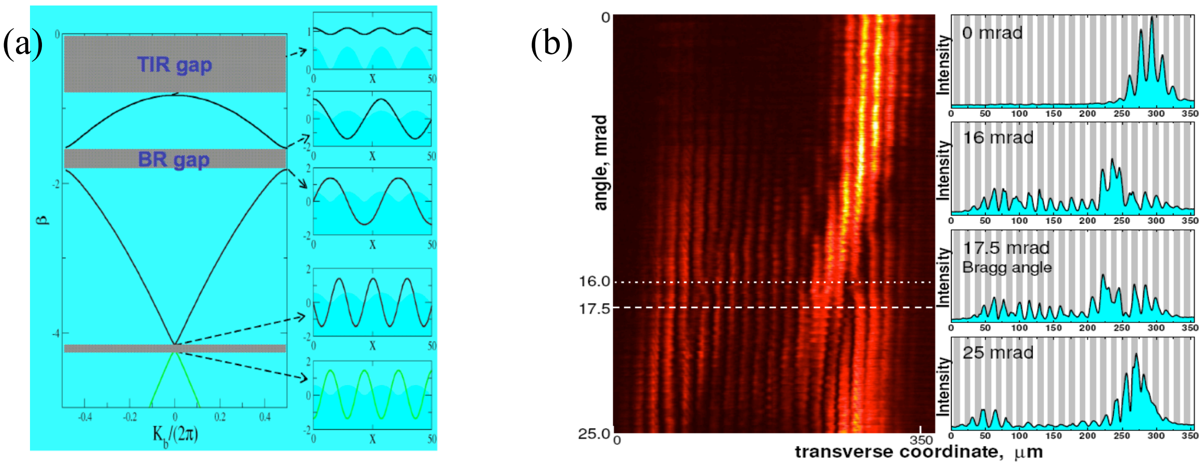

Figure 2: (a) Schematic of the induced band-gap structure with the corresponding Bloch waves. (b) Experimentally observed beam scattering by an optically-induced lattice of a period 14μm for low laser powers. Left: output intensity vs. the tilt angle; right: beam profiles at different angles, shading marks the positions of the lattice minima. After Ref. [7].

imaged by a microscope objective onto a CCD camera and recorded on a computer. As seen in Fig. 2(b), at smaller angles between the beam and the lattice, Bloch waves belonging to the first band are predominantly excited. When the tilt approaches the Bragg angle, we observe simultaneous excitation of Bloch waves belonging to the lower edge of the first band and the upper edge of the second band [7]. These Bloch waves become spatially separated at the output, as they propagate through the structure at different angles defined by the normal directions to the corresponding dispersion curves.

Nonlinear beam propagation

Next step, after measuring the linear properties of the induced structure, is to study the nonlinear self action of different types of Bloch states. Nonlinearity is intrinsic to PR crystals and can be observed already at micro-Watt laser powers. Therefore, by properly exciting the corresponding spectral band and increasing the laser power at the output of the crystal we can easily observe the nonlinear self action. Self-focusing nonlinearity effectively increases the longitudinal wavenumber (β), and can shift it inside the gap where the beam becomes transversely localized and diffraction is suppressed - a *lattice soliton* forms.

At collinear propagation of the beam relative to the lattice, Bloch waves belonging to the top of the first spectral band are excited, and at threshold input intensities soliton formation associated with the semi-infinite total-internal reflection gap is observed (Fig. 3). These solitons exist in two different forms [left and right plots in Fig. 3(b)] centred at the lattice minima or maxima depending on the lattice shift with respect to the input beam [4,8].

The Bragg-reflection gap appears due to mutual scattering of counter-propagating waves. At high intensities they can trap together and form a *gap soliton*. Gap solitons have many distinctive properties comparing to the solitons in the total internal reflection gap [9] due to the fundamentally different physical origins of the corresponding gaps. Controlled excitation of such solitons can be achieved by combining two input beams inclined at the Bragg angles, which interference pattern matches the Bloch-wave symmetry at the top of the second band, where intensity maxima are positioned between the regions of high refractive index in the lattice. Using this approach, we have generated slow and immobile spatial gap solitons (Fig. 4) [10] and observed a number of novel effects in their dynamics. Immobile gap solitons propagate in the structure with zero transverse velocity [10,11], when exact balance between the input waves propagating in opposite directions [to the left and to the right in Fig. 4(a)] is achieved. However, this balance can be removed when the lattice is tilted, resulting in anomalous steering in the opposite direction [10].

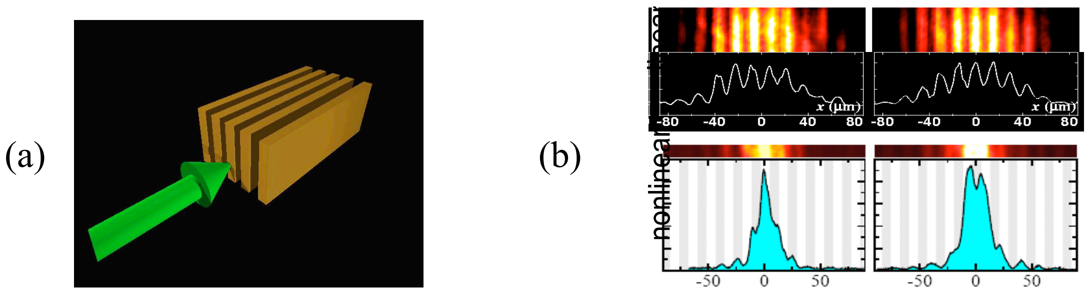

Figure 3: (a) Excitation scheme for localized states in the total internal reflection gap. (b) Profiles of solitons for different lattice shifts (bottom), at the crystal output for intensity levels when diffraction was suppressed due to self-focusing. At lower intensities the output profiles are much broader due to diffraction (top). After Ref. [8].

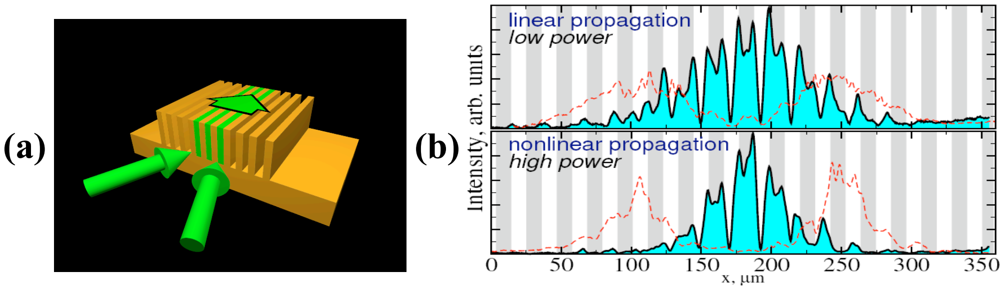

Figure 4: (a) Two beam experimental scheme for excitation of spatial gap solitons. (b) Gap soliton formation. After Ref. [10]

Soliton steering

The beams steering due to tilting of the lattice is proportional to the difference of the diffraction coefficients inside the structure and in free-space. Because Bloch-wave diffraction strongly depends on the refractive index contrast, this refraction could be efficiently controlled if the lattice depth is dynamically modified. For Bloch waves from the top of the first band, diffraction coefficient is smaller than in free space, and therefore they always experience positive refraction, propagating in the direction of the lattice tilt, see Figs. 5(a), (b,c-left). In a sharp contrast, diffraction of second-band Bloch waves is enhanced in shallow lattices, resulting in the effect of *negative refraction*, see Figs. 5(a), (b,c-right). Remarkably, as the lattice is made deeper, second-band negative refraction can be eliminated. This behaviour is confirmed experimentally [12], when the lattice dept is controlled by varying the applied voltage on the crystal. In Fig. 5(d) it is clearly seen that with increasing of the voltage the output shift is greatly reduced. This shift is generally preserved at higher intensities, when beams are localized in the form of solitons. The shift for gap solitons at the output can be several times larger than the lattice shift, and this can be potentially exploited for the purpose of optically-controlled beam steering.

Soliton interactions

The *nonlinear interaction* of optical beams is the key factor for realizing schemes for all-optical control and switching. In periodic structures there is a remarkable possibility to utilize beams associated with different bands, which distinctive properties define the unconventional character of their interactions. We performed both theoretical [13,14] and experimental studies of multi-gap interactions, and identified a number of fundamental effects which can also occur in other physical contexts. We developed an experimental scheme for phase-insensitive interaction of two components by making them mutually incoherent in order to avoid intensity beating [Fig. 5(a)]. One component corresponds to the first band and the other one to the second band (formed by interference of two beams under Bragg angle). This experiment showed that solitons belonging to different bands can mutually trap each other [Fig. 5(b)], which provides a generalization of the idea for soliton trapping in periodic structures [15]. Mobility properties of such multi-gap solitons are expected to be highly unusual and are currently being investigated.

Effects of higher dimensionality

The advantage of using optical lattices to induce periodic structure in the refractive index is that they can be easily extended to two transverse dimensions, thus testing nonlinear effects in periodic structures of higher dimensionality, similar to photonic crystals.

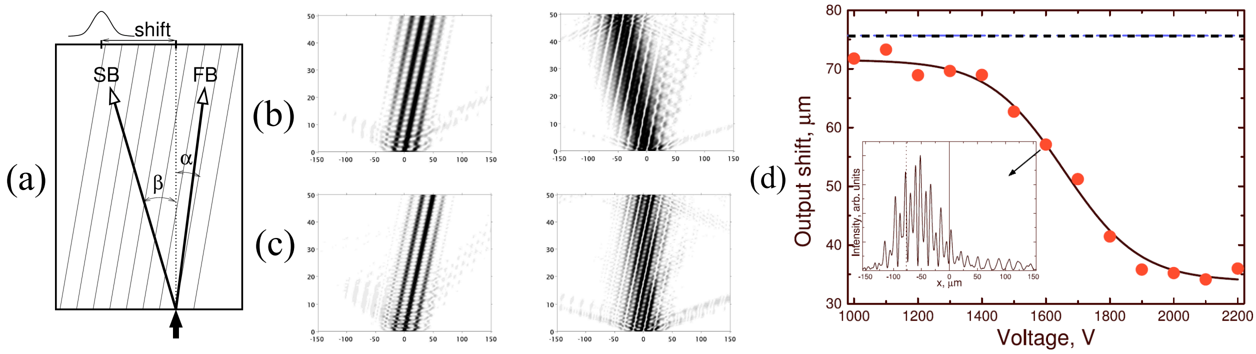

Figure 5: Soliton steering properties. (a) Scheme for beam deflection, demonstrating negative (second band) and positive (first band) refraction for Bloch waves. (b,c) Numerical results for refraction of beams associated with the first (left) and second (right) bands in (b) shallow and (c) deeper lattices. (d) Measured output position of a beam corresponding to the second band as a function of the applied voltage. Lattice period is 18µm, and its initial tilt is 3.1mrad (21% of the Bragg angle). Inset shows characteristic profile for a voltage of 1.6kV. Dashed line corresponds to the shift at a Bragg angle. After Ref. [12].

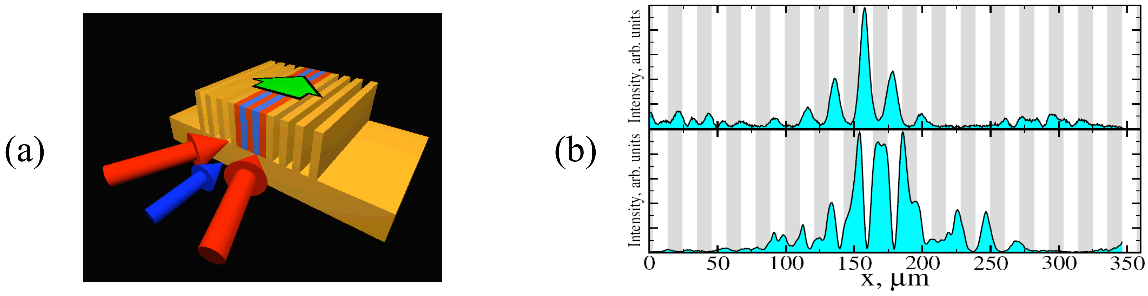

Figure 6: (a) Experimental scheme for investigation of nonlinear interaction of beams corresponding to different bands. (b) Experimentally observed multi-gap soliton consisting of mutually trapped components localized in total internal reflection (top) and Bragg-reflection (bottom) gaps. After Ref. [15].

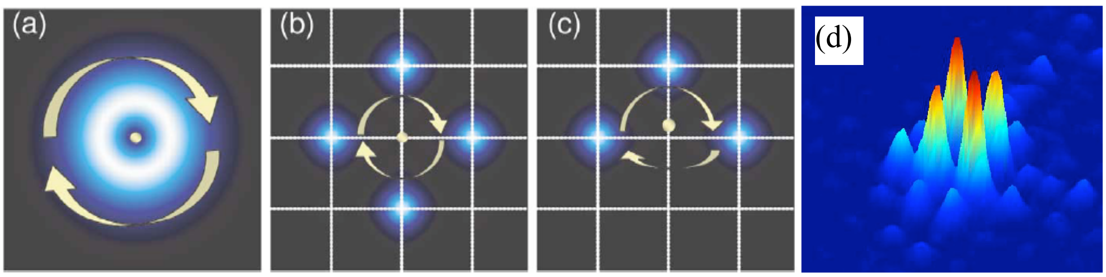

Fig. 7: Schematics of the light intensity distribution in an optical vortex soliton (a) in a bulk nonlinear medium, (b) in a two-dimensional "square" photonic lattice. Arrows show the directions of the energy flow. (c) Non-trivial asymmetric vortex predicted to exist in the spectral gaps. (d) Characteristic four-peak intensity distribution of the discrete soliton in the total internal reflection gap, observed in our experiments. After Refs. [18,20].

Two-dimensional optically induced lattices enabled us to study propagation and localization of beams with complex topological structure, such as optical vortices. Optical vortices are beams of light carrying a phase singularity, with associated circular energy flow around the vortex core. The intensity of light at the vortex core is always zero, and in nonlinear media vortices can be spatially localized as vortex solitons [Fig. 7(a)]. Remarkably, vortex solitons can exist in the lattice [16,17], where their intensity profile is strongly modulated [18,19], but a directional flow of energy is preserved [Fig. 7(b)]. We demonstrated the experimental generation of a *discrete vortex soliton* in a photorefractive crystal [Fig. 7(d)] [18]. Unlike the vortex propagating in a bulk self-focusing medium, where it quickly disintegrates, the discrete vortex is stabilized by the lattice. More recently, we discovered that lattices may support a novel class of asymmetric vortex solitons [20] with no counterparts in homogeneous media [Fig. 7(c)]. Experimental observation of the broad class of asymmetric vortices in photonic lattices is underway.

Anomalous diffraction

The strength of diffraction experienced by Bloch waves is proportional to the curvature of their dispersion curves. At the lower band edges, the curvature is negative [see Fig. 2(a)], and Bloch waves experience anomalous diffraction. This is a unique feature of periodic lattices, since in free space the diffraction coefficient is always positive. Most remarkably, the effect of nonlinearity on anomalously diffracting beams can be reversed. In the case of self-focusing response of the material this leads to beam defocusing at higher laser powers [21]. This behaviour was recently used to demonstrate generation of dark solitons in self-focusing nonlinearity [11]. In the case of self-defocusing nonlinear response of the medium such anomalous diffraction will lead to localization of the beam corresponding to the bottom of the first band with the increase of nonlinearity and the formation of staggered-type bright soliton [22,23].

Conclusions and future directions

Optically-induced lattices provide an ideal test-bed for demonstration of novel nonlinear phenomena in periodic structures, due to their dynamical tunability and strong nonlinear properties at moderate laser powers. Using their advantages, we were able to observe experimentally the formation of optical localized structures, belonging to different spectral gaps, thus studying the basic building blocks for future all-optical switching techniques. We demonstrated their interaction and steering properties, which are the key issues for the new type of light controlling devices based on periodic light structures, including photonic crystals. We believe that the observed effects can be easily transferred to structures fabricated on an optical chip, e.g. $LiNbO_3$ waveguide arrays (see Fig. 8), and open up the way for realization of novel high-bandwidth optical devices, the future of the optical computing and communications.

There are many other novel research directions which we are actively pursuing, including beam switching in superlattices [23], quasi-periodic structures, and lattices with longitudinal modulation of the refractive index closely resembling photonic crystals. All such structures can be readily fabricated or induced with the holographic technique

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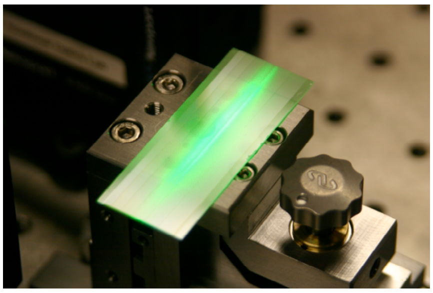

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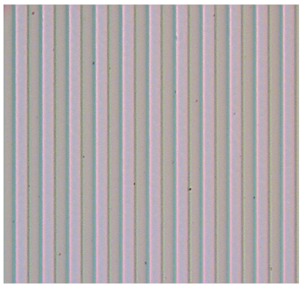

Figure 8: Fabricated waveguide arrays in $LiNbO_3$ hold promises to apply the obtained results for high-bandwidth optical devices. (a) Light coupled into the array. (b) Microscope image of an array with a period 10μm. Samples fabricated by A. Mitchell and H. Mendis at RMIT.

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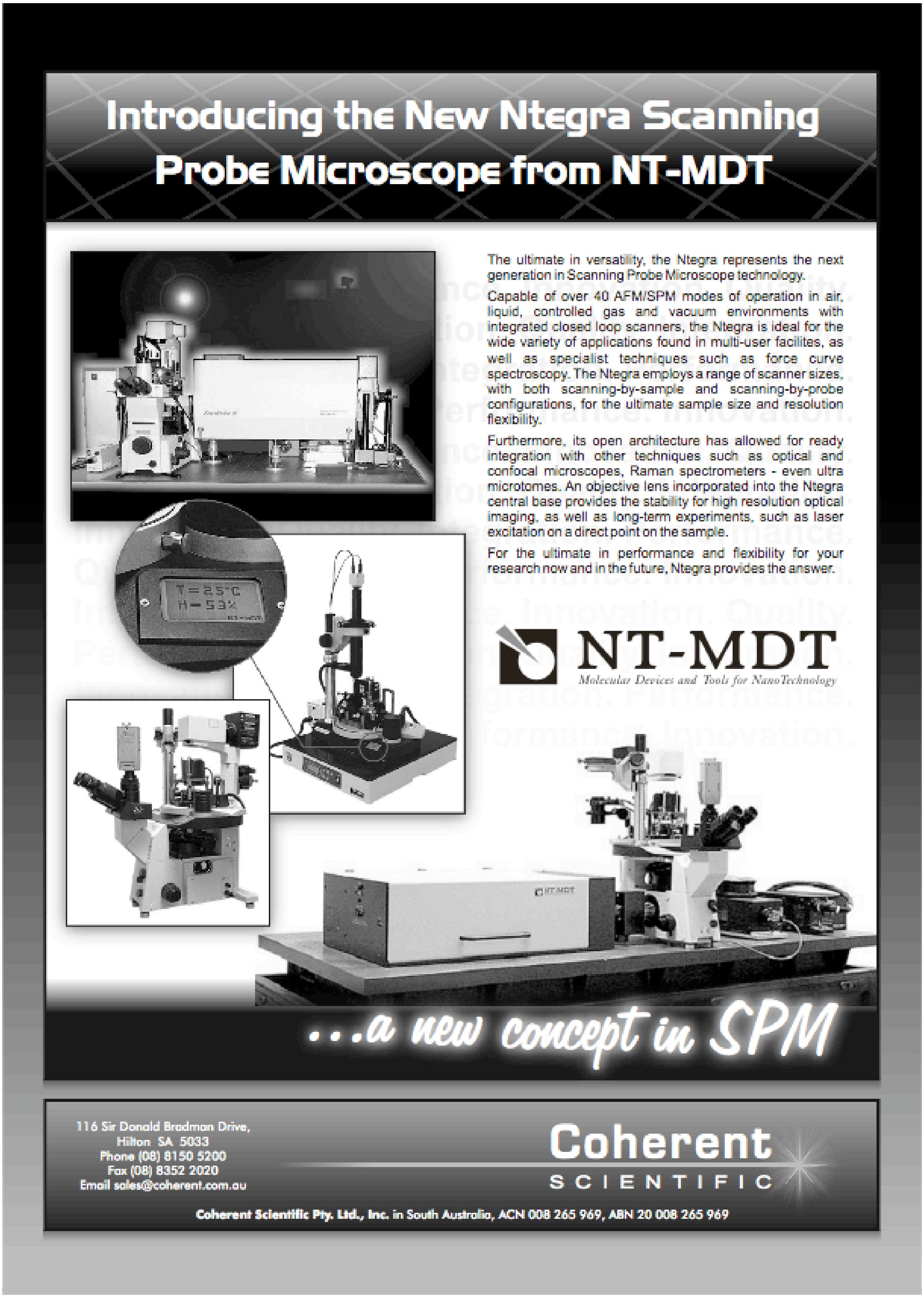
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Coherent blue laser beam production in a rubidium vapour cell

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Introduction

A blue laser beam at 420 nm has been produced via coherent two-step excitation using 780 and 776 nm lasers and a rubidium vapour cell, as recently described by Ref. [1]. The process demonstrates efficient frequency up-conversion, producing $40\,\mu$W of blue output with pump beam powers of 15 mW each, orders-of-magnitude greater efficiency than traditional up-conversion using nonlinear crystals. The process has been explored as a function of pump laser frequencies, and the blue coherence has been investigated through double-slit interference. In addition to the details of the experimental investigation, a semiclassical model of the system is presented. The model shows that coherent excitation of two transitions induces a transparency on the 420 nm transition, which permits gain without inversion.

Setup

In our experiments, two co-propagating infrared laser beams at 780 nm and 776 nm are directed through a Rb vapour cell with natural isotopic abundance of ^{85}Rb and ^{87}Rb (Fig. 1). The power in each beam was 15 mW, focused to a beam waist of approximately 0.4 mm ($1/e^2$ diameter). The cell was heated to 280°C. The infrared lasers were independently tunable. Strong blue fluorescence was observed, and a coherent beam at 420 nm (measured with a 15 cm monochromator) propagating in the forward direction, i.e. co-propagating with the infrared lasers.

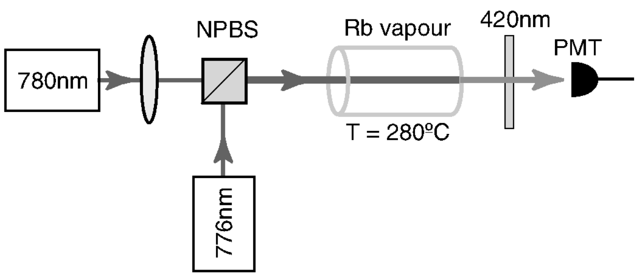

Figure 1: Experimental configuration.

Fluorescence from the Rb system is understood by considering the simplified level-scheme for Rb shown in figure 2. The two pump lasers are tuned to the $5S_{1/2} - 5P_{3/2}$ ($|1\rangle - |2\rangle$) transition at 780 nm, and to the $5P_{3/2} - 5D_{5/2}$ ($|2\rangle - |3\rangle$) at 776 nm. When the frequency sum for the two lasers matches the two-photon resonance, a large population is created in excited state $|3\rangle$, and a large coherence $|\rho_{13}|$ between the ground and excited states. The long-lived $5D_{3/2}$ state

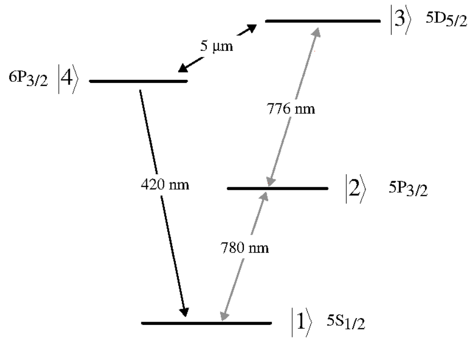

Figure 2: Rubidium energy levels.

($\tau_3 = 240$ ns) can decay via spontaneous emission to the $6P_{3/2}$ ($|3\rangle \rightarrow |4\rangle$), which then decays back to the ground state $|1\rangle$ emitting 420 nm fluorescence.

Numerous novel effects have been seen with this system, including enhanced index of refraction, slow light, Electromagnetically Induced Transparency (EIT), and counterintuitive results such as Lasing Without Inversion (LWI) [2]. Ref. [1] first observed production of a coherent collimated blue beam, with power up to 12μW. We confirm their results and demonstrate the spatial and temporal coherence, and have achieved more than three times their output power.

Experimental results

The previous maximum output of 12μW was found for a detuning of the 780 nm laser of 120 MHz above resonance [1]. We have also found significant (2μW) output at this detuning, but we find dramatically greater output power (40μW) for a detuning of the 780 nm laser by about 1 GHz above resonance.

The output was also measured as a function of the 776 nm laser frequency (Fig. 3). These traces only show the 420 nm beam output for a detuning range of less than a few hundred megahertz. The structure in this tuning range, as well as structure over a larger range including the region of maximum output power, has not been explained to date. Previous studies have measured the spectral width of the blue beam to be ≤ 2 MHz, but measurements of the degree of coherence have otherwise not been made. We have shown that the beam has a strong degree of coherence, by producing a Young's double slit pattern (Fig. 4). The image was taken with slits of width 0.04 mm and separation 0.25 mm. The high fringe contrast demonstrates strong coherence. Future experiments will measure the coherence in detail using Wigner phase-space tomography.

Theoretical modelling

We have modelled the system with a standard semi-classical treatment, using the density matrix ρ to describe the macroscopic atomic populations and coherences. The time evolution of the density matrix is given by:

$$\frac{\partial \rho}{\partial t} = -\frac{i}{\hbar}[H, \rho] \quad (1)$$

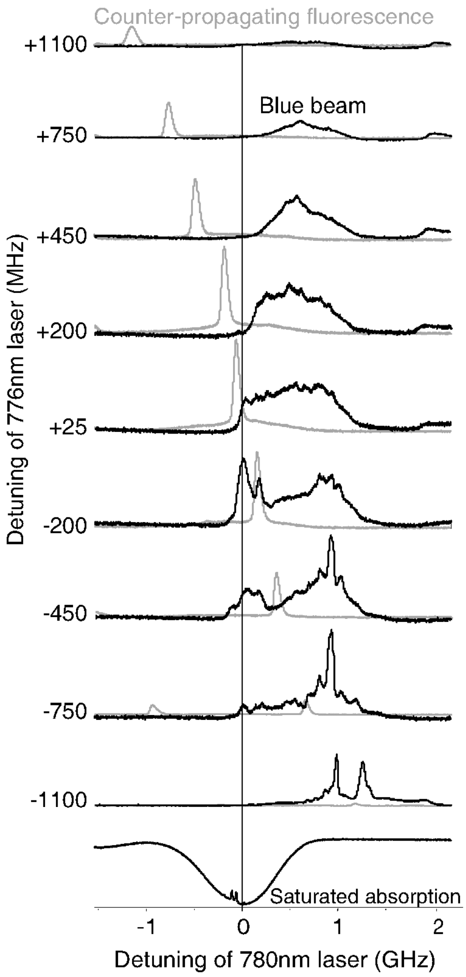

Figure 3: 420 nm output power as a function of the 780 nm laser frequency, for various detunings of the 776 nm laser. The saturated absorption curve provides a frequency reference for the 780 nm laser. The 780 and 776 nm laser beams were also counter-propagated through a separate vapour cell; the fluorescence peak occurs when the combined detuning is zero.

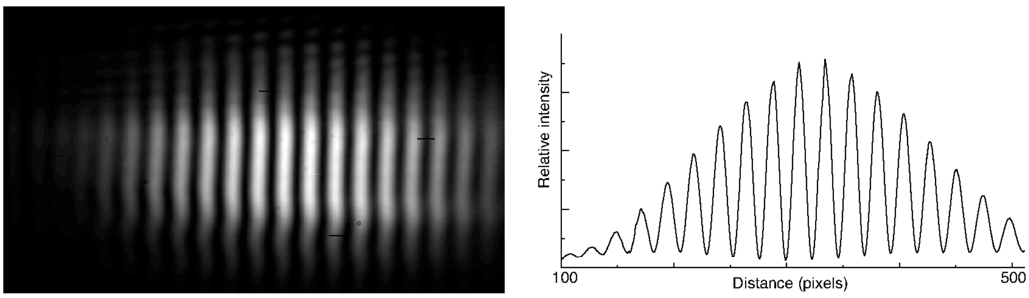

Figure 4: Intensity image of double-slit interference of the blue light, with slits of 0.04 mm width and 0.25 mm separation. A single line profile across the fringes is also shown. No attempt has been made to subtract background.

The Hamiltonian in the interaction picture describing the four levels and coupling light fields is, in the rotating wave approximation,

$$H = \frac{\hbar}{2}\begin{pmatrix} 0 & \Omega_{21} & 0 & \Omega_{41} \\ \Omega_{21} & 2\Delta_{21} & \Omega_{32} & 0 \\ 0 & \Omega_{32} & 2(\Delta_{21}+\Delta_{32}) & \Omega_{34} \\ \Omega_{41} & 0 & \Omega_{34} & 0 \end{pmatrix} \quad (2)$$

where the Ω_{ij} are the Rabi frequencies and Δ_{ij} are the relative detunings. The Rabi frequencies Ω_{34} and Ω_{41} are for the spontaneously generated 5 μm and 420 nm fields. Decay terms are added phenomenologically [3]. For the diagonal elements the equations are:

$$\frac{\partial \rho_{ii}}{\partial t} = -\frac{i}{\hbar}[H,\rho]_{ii} - \sum_j \Gamma_{ij}\rho_{ii} + \sum_k \Gamma_{ki}\rho_{kk} \tag{3}$$

in which Γ_{ij} is the decay rate from $|i\rangle$ to $|j\rangle$. For the the off-diagonal terms the equations are:

$$\frac{\partial \rho_{ij}}{\partial t} = -\frac{i}{\hbar}[H,\rho]_{ij} - \frac{1}{2}\sum_k \left(\Gamma_{ik} + \Gamma_{jk}\right)\rho_{ij}. \tag{4}$$

This system of coupled first order differential equations can be solved by the method of eigenvector expansion, showing that a unique steady state exists. The fields were modelled through Maxwell's equation:

$$\frac{\partial}{\partial t}\mathcal{E} = \frac{\omega}{2\varepsilon_0 c}\mathrm{Im}\mathcal{P} \tag{5}$$

where $\mathcal{E}$ and $\mathcal{P}$ are the slowly varying amplitudes for the electric field and polarisation, respectively. The steady state solution was used to solve Maxwell's equations for the evolution of the fields as they propagate through the cell. A weak seed field on the 5 μm transition was included, physically equivalent to some initial spontaneous emission.

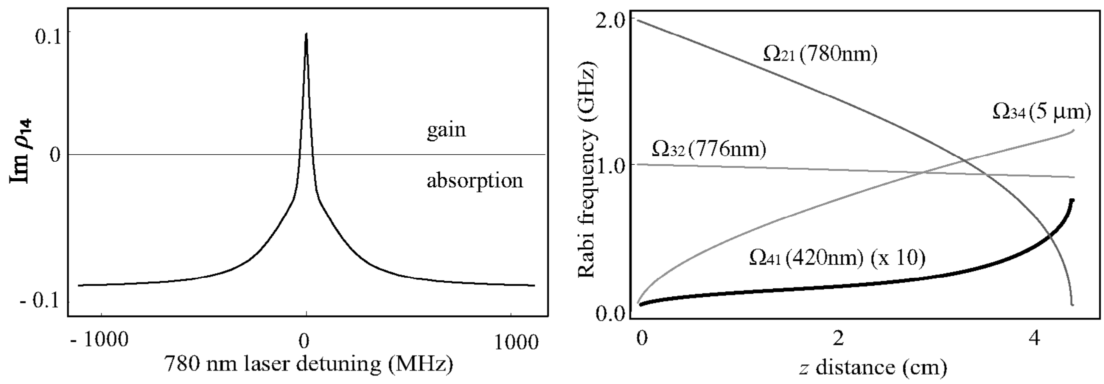

Figure 5: On-resonance simulation results showing gain in the 420 nm transition, and the different field strengths along the cell, in terms of their Rabi frequencies.

Figure 5 shows results from the simulation. The imaginary part of ρ_{14} (proportional to gain or absorption of the 420 nm light) becomes positive when the two infrared lasers are on resonance. The four field strengths are shown in terms of their Rabi frequencies, as a function of propagation distance through the cell.

Our results demonstrate efficient frequency up-conversion using low-power laser beams in a vapour cell. The model qualitatively predicts the behaviour of the system, and in particular inversionless gain at the appropriate laser detunings. We are now extending the model to include hyperfine structure and the atomic velocity distribution, such that quantitative predictions of output power can be made.

This work was supported by the Australian Government International Science Linkages programme and by the Australian Research Council.

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Off-Axis Wavefront Sensors in High Power Gravitational Wave Interferometers

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1. Introduction

Betting on science – it's a relatively new phenomenon; but in August last year online betting agency Ladbrokes offered odds of 500 to 1 that there would be a successful detection of gravitational waves by 2010. Gravitational waves are ripples in space and time predicted by Einstein's theory of General Relativity and observation of them will provide an entirely new way of looking at the universe (so far all of our observation of the universe comes from electromagnetic radiation and cosmic rays). A huge worldwide collaborative effort is under way to build detectors capable of seeing these ripples. It is a testament to the innovation, dedication and skill displayed by scientists working on these detectors that when betting closed at Ladbrokes at the end of the month the odds had shortened to 2 to 1.

The proposal for detecting gravitational waves is to use Michelson interferometers with baselines of over a kilometer to measure the tiny strain on space-time due to a passing gravitational wave [1-6]. The sensitivity of current interferometers is now sufficiently high that a gravitational wave from a not too distant object is likely to be detectable in the next few years. But in order to form an image of the universe using this technology, the sensitivity must increased in order to increase the volume of space from which events can be detected. A range of proposed improvements will give the next generation of GWIs an increase in amplitude sensitivity of at least 10 times [7-8]. This will increase the volume of space searched and the rate of detectable events by 1000 times. Details of these improvements can be found at www.ligo.caltech.edu and they cover such as seismic isolation, laser noise and increased stored optical power.

ACIGA[1] has been contributing to the improvements in the worldwide GWI community. One of the areas of interest is the high laser beam power required and its adverse side-effects. The installation of these improvements is not without engineering problems. Of concern to us, at the University of Adelaide, is the increase in stored optical power. The increased optical power will increase thermal lensing, caused by absorption in the interferometer optics, from being a minor inconvenience to a critical problem in the system. An active compensation system to reduce thermal lensing has been proposed. Our contribution to this system is the development of a wavefront sensor tailored to the specific requirements of this compensation system.

2. The Thermal Problem

Next generation GWIs will have large stored optical power, as shown in figure 1. The Fabry-Perot arm cavities are kept at resonance using a Pound-Drever-Hall servo system, where RF phase modulation sidebands must be resonant in the power recycling cavity.

It has long been recognized that absorption of optical power in the cavity mirrors would give rise to thermally induced refractive index distributions (RIDs), or thermal lensing. Computer simulations of the mode matching between the laser beam and cavity, in the presence of this thermal lensing, have been performed by Ryan Lawrence and David Ottaway [10]. They predicted that as input power was increased, the mode matching of the laser to the cavity decreased. This was particularly pronounced in the RF sidebands. In fact, when the input power reached the nominal operating level, the RF sidebands were completely rejected by the power recycling cavity. Consequently, the arm cavity would no longer be locked resulting in total instrument failure.

It is necessary to reduce the thermal lensing to prevent instrument failure from occurring. This will be accomplished by employing an active thermal compensation system, consisting of a wavefront sensor and a thermal actuation system, such as a heating ring around the cavity mirror, or a scanned CO2 laser to heat colder parts of the cavity mirror. Thermal actuation systems are being developed at UWA and MIT. We are developing a wavefront sensor.

The wavefront sensor and actuation system from UWA will be tested at the joint ACIGA/LIGO High Optical Power Test Faciltiy (HOPTF) near Gingin, WA. This facility will investigate wavefront distortion and other parametric effects, in Fabry-Perot cavities with high stored power, their measurement and compensation.

3. Wavefront sensors for GWIs

There are two basic requirements for the wavefront sensor. The results of Lawrence and Ottaway imply a maximum level of distortion of less than $\lambda/200$. Any compensation system must be capable of reducing the distortion to this level and the wavefront sensor should have even better sensitivity. Additionally, the sensor cannot use any new optics on the optical axis of the GWI because these would introduce more noise. This means the sensor must probe the cavity mirror at an angle to the axis, i.e. it must be off-axis.

There are a number of options to consider including interferometry, Hartmann or Shack-Hartmann sensors. We chose a Hartmann sensor because it is more accurate than a Shack-Hartmann [11] and is less sensitive to alignment than interferometry.

4. Implications of an Off-Axis sensor

The wavefront distortion accumulated by propagation through cylindrical RID at an angle is not the same as that accumulated on-axis. There isn't a one to one correspondence between them; no simple transformation or rotation can operate on the off-axis wavefront to produce the on-axis wavefront. How then, do we reconstruct the distortion seen by the laser beam of the interferometer from our off-axis data?

[1] Australian Consortium for Interferometric Gravitational Wave Astronomy

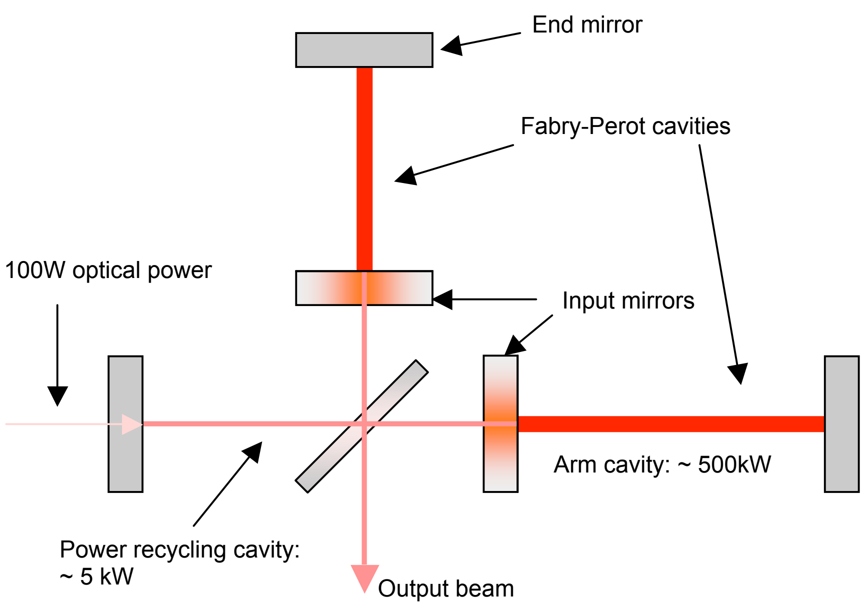

Figure 1. Power recycled Michelson interferometer. Illustrates multiple high power resonant optical cavities. Note the thermal blooming (or lensing) in the input mirrors due to absorption of stored optical power in the mirror substrates.

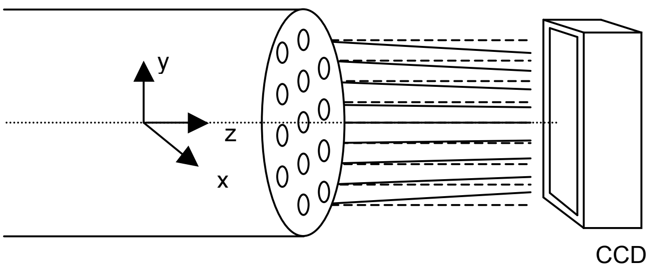

Figure 2. Hartmann sensor. An array of apertures is illuminated by a large diameter laser beam. The resulting rays propagate normal to the wavefront onto a CCD. Dotted lines indicate original ray directions prior to wavefront distortion being added to the laser beam.

A Hartmann sensor provides a map of changes in the gradient of a wavefront at a series of discrete points as shown in figure 2. A large diameter collimated laser beam is incident on a plate of regularly spaced apertures, a Hartmann plate, which breaks it into a series of rays. These rays propagate a certain distance, L, at an angle normal to the wavefront and are then incident on a CCD resulting in a pattern of spots. As the wavefront changes, the angle of the rays will shift and the spots will be displaced on the CCD. A first moment calculation performed on each individual spot allows displacements, $\mathbf{d}_i$, to be measured with sub-pixel accuracy. The displacement of the spots is directly proportional to the gradient of the wavefront change:

$$\vec{\nabla}\Phi\left(x_i, y_i\right) = \vec{d}_i \,/\, L$$

where $\Phi(x_i, y_i)$ is the change in the wavefront.

To optimize the sensitivity of the Hartmann sensor for experiments at the HOPTF, we ran a computer simulation using the ZEMAX physical optics package and searched parameter space for different Hartmann sensor configurations. The best configuration was a hexagonal array of 0.2mm diameter holes spaced 0.6mm apart observed at a distance of 60mm. In the simulation we illuminated this with a HeNe beam and produced a reference Hartmann spot pattern on a virtual 12-bit CCD. A second pattern of spots was produced, this time with a simple curved wavefront added to the laser beam (radius of curvature = 1.5km). The displacements of the spots, between the two patterns, were measured yielding the wavefront gradient map, from which the wavefront was calculated. The results, shown in figure 3, demonstrated that, in principle, the Hartmann sensor could detect a wavefront change with a sensitivity of better than $\lambda/1000$.

We attempt a reconstruction of the RID via a modal analysis of the off-axis distortion. Assuming that the RID is axially symmetric, we represent it as a truncated sum of, preferably orthogonal, modes $f_i(r, z)$:

$$n(r,z)=\sum_i a_i f_i(r,z)$$

WD (λ/1000)

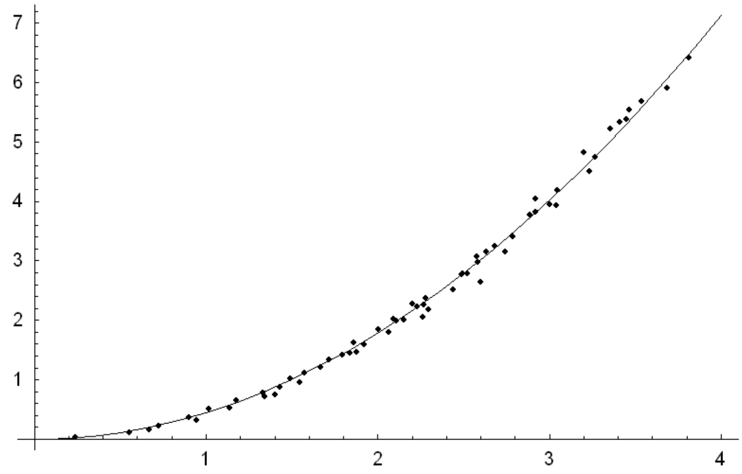

Figure 3. Hartmann sensor ZEMAX simulation results. The data points are the reconstructed wavefront distortion (WD) for each Hartmann spot. The curve is the original wavefront distortion added to the laser beam in the simulation.

The off-axis path integral through each mode is calculated to determine the accumulated distortion from each mode, represented by $g_i(x, y)$:

$$g_i(x,y)=\sqrt{1+\tan^2(\theta)}\int f_i(r(z),z)\,dz \quad \text{where}$$

$$r(z)=\sqrt{(x+\tan(\theta)\,z)^2+y^2}$$

and θ is the angle of the off-axis view to the interferometer optical axis.

A least squares (LSQ) fit of the off-axis data to $g_i(x,y)$ will determine the parameters a_i and hence the structure of the RID. Integration of the RID along the axis gives the on-axis wavefront distortion.

The problem with this technique is finding a set of functions which can easily be integrated and allow a simple LSQ fit in their off-axis form. We have not yet found a complete set of functions which are orthogonal in both forms $f_i(r, z)$ and $g_i(x, y)$. The analysis can be performed efficiently with a small number of non-orthogonal functions, but this is not necessarily accurate enough.

5. Preliminary Experimental Test Results

We have performed a preliminary experimental test of the Hartmann sensor and off-axis analysis to identify any major problems or difficulties. We measured the thermally induced RID in a 65mm diameter cylindrical glass test mass (GTM) using both an off-axis Hartmann sensor and an on-axis interferometer.

The experimental design is shown in figure 4. A 4W 1064nm TEM00 heating laser beam was aligned along the axis of a GTM to produce an axially symmetric RID when required. The glass, BG20 filter from Schott, was selected with the absorption at 1064nm to be such that, when illuminated with 4W of optical power, the thermally induced RID would be approximately the same size as that in a GWI. With the heating beam turned off, the GTM was probed with an on-axis Mach-Zehnder interferometer and an off-axis Hartmann sensor; each sensor recorded a 'cold' or reference pattern. The heating beam was turned on and each sensor recorded a 'hot' or distorted pattern. The difference between the two interferometer patterns measured the on-axis wavefront change. The difference between the two Hartmann patterns measured the off-axis wavefront change.

The off-axis data was analyzed using the method discussed in the previous section. For this test, the fitting functions $f_i(r,z)$ used were a set of radial Gaussian distributions of different widths – clearly not orthogonal, but they did allow for an easy path integral and LSQ fit. The reconstructed RID was integrated to yield equivalent on-axis wavefront distortion.

A fit was performed on the interferometer data and was compared to the analyzed Hartmann data. The difference between these results is shown in figure 5. Within the region of the heating beam, the measurements agreed to an accuracy of λ/25.

Several sources of error have been identified. The off-axis analysis is a source of systematic error because we are fitting to an incomplete set of functions. Random errors are introduced by air currents and seismic vibrations, although these were limited by use of a tent and floating table. A major source of random error was the Electrim CCD camera we were using. We discovered approximately 3 bits of readout noise on the

CCD data. This meant that our 10-bit CCD camera was only giving 7 bits of reliable data.

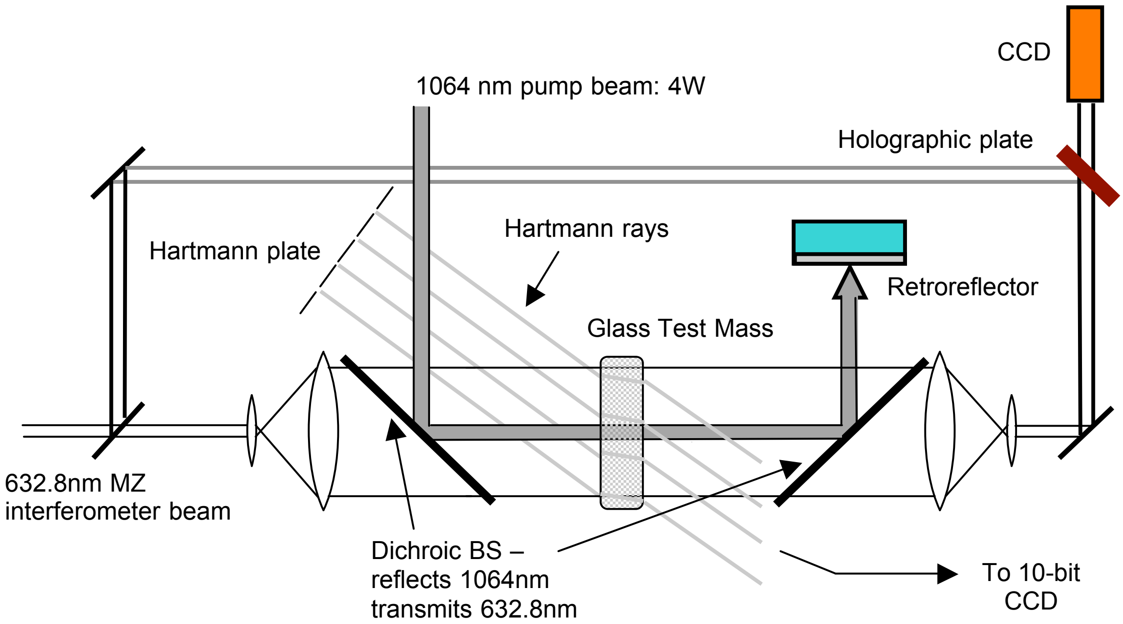

Figure 4. Experimental design (not to scale). A 4W 1064nm laser beam is propagated along the axis of a glass test mass to introduce thermal distortion. The distortion is measured using an off-axis Hartmann sensor and an on-axis Mach-Zehnder interferometer. Stored beam holography is included as part of the interferometer to improve its dynamic range.

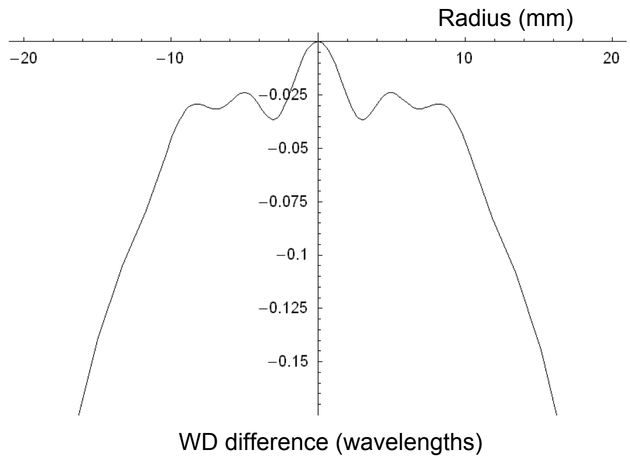

Figure 5. The difference between fit to on-axis interferometric wavefront distortion (WD) and equivalent on-axis WD as calculated by off-axis Hartmann sensor. The heating beam was approximately 8mm in diameter.

	Sensitivity
Experimental Hartmann results	$\lambda/25$
GWI wavefront sensor requirement	$< \lambda/200$
Simulated Hartmann precision	$< \lambda/1000$

Table 1. Summary of sensitivities for Hartmann sensors and as required by GWIs.

6. Conclusion

Table 1 summarizes the current status of the sensor sensitivity. We cannot yet state that an off-axis Hartmann sensor has been shown to be sensitive enough for use in a GWI as we need to improve our sensitivity to less than $\lambda/200$. Modifications are being made which will facilitate this. Our CCD camera is being replaced with a low noise 12-bit CCD and environmental shielding will be improved to minimize the random noise. Additionally, we are attempting to reduce the systematic error by finding some more appropriate functions for use in the off-axis analysis – a more complete set of functions $g_i(x, y)$ will increase the accuracy of the off-axis fit.

Following these improvements, we shall measure the sensitivity of the off-axis Hartmann sensor in the laboratory. The sensor package will then be installed at the HOPTF where it will be tested as part of an active compensation system.

The wavefront sensor will provide a continuous two dimensional map of the distortion (and compensation) in the resonant optical cavity. The level of stored optical power, determined from very low power transmission out of the optical cavity, also indicates the effectiveness of the compensation system. Future active thermal compensation systems will most likely use an off-axis wavefront sensor for gross control and the level of stored optical power for fine control of the thermal actuators.

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Stop Press

ACOLS 2005 has been confirmed for the the week of December 5-9th in Rotorua New Zealand.
The exact dates will depend on the timing of the satellite meeting on Quantum and Atom Optics, which is to be held in Queenstown either before or after ACOLS
Full detail will appear in a later issue.
Mark this week in your calendar!

AUSTRALIAN RESEARCH COUNCIL
CENTRE OF EXCELLENCE FOR
QUANTUM-ATOM OPTICS

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The Australian Research Council Centre of Excellence for Quantum-Atom Optics (ACQAO) is one of Australia's contributions to the rapid development of quantum science that is happening around the world.

The Centre brings together scientists working in three cities, at the Australian National University (ANU) in Canberra, the University of Queensland (UQ) in Brisbane and the Swinburne University of Technology (SUT) in Melbourne, and links them with scientific partners in Europe and New Zealand.

Quantum science will play a major role in future technology and eventually our daily lives.

One area will be optics and wave effects for both light and atoms. Scientifically we are now able to investigate the quantum behaviour of larger objects, involving thousands and even millions of atoms, and see the transition from the microscopic world of a few particles to the macroscopic world of classical effects. Technically we are now able to use the process of entanglement that was just a concept in the 1930s, and employ it in practical applications, such as communication systems.

We now have the technology for cooling atoms to unimaginably low temperatures and for creating Bose-Einstein condensates. Combining these, we are at the threshold of turning fundamental science into practical applications over the next two decades.

The Centre concentrates on fundamental science questions. It combines our well-established track record in quantum optics with our leading groups in atom optics and laser cooling into one team with common goals. We are combining pioneering theoretical work with experimental projects.

The Centre of Excellence is part of the vision of the Australian Research Council to promote excellence in the most successful fields of research and to give them the opportunity to become players in the international arena. The funding and support provided by the Australian Research Council, the three Universities ANU, UQ and SUT and the Queensland and Australian Capital Territory governments will allow us to tackle ambitious Outreach projects, to have an intensive exchange of people, to provide opportunities for young scientists and to build the required research facilities.

In December 2004, the Centre hosted a National Summer School attracting 50 honours students from New Zealand, China, Singapore and from throughout Australia. That same month, 95 participants attended an international workshop on quantum-atom optics at Kioloa, the ANU summer campus. Also as part of our Outreach programme, ACQAO are Corporate Members of the Australian Optical Society.

AUSTRALIAN RESEARCH COUNCIL CENTRE OF EXCELLENCE FOR QUANTUM-ATOM OPTICS

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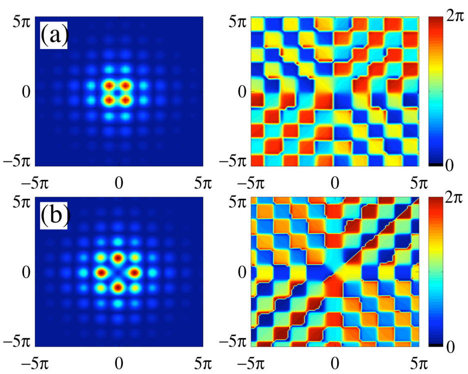
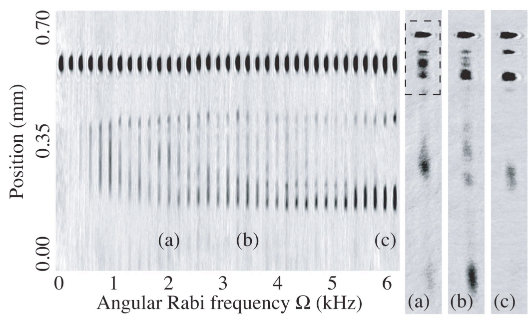
Ultracold atomic gases - Bose-Einstein condensates - loaded into optical lattices formed by standing light waves, behave like an "ideal" solid state system.

The condensate - a giant coherent matter wave - behaves in a periodic potential of an optical lattice like a single electron in a crystalline lattice of a solid. The matter-wave spectrum acquires band-gap structure due to Bragg scattering from the lattice potential, and the diffraction properties of the condensate wavepackets can be modified or even reversed. Interplay between the modified diffraction in the lattice and intrinsic (repulsive) nonlinearity of the condensate due to interatomic interactions can lead to localization of the condensate in the form of atomic solitons. The energies of these localized states lie within spectral gaps, which earns them their name: "gap solitons".

Recently, we discovered that even circular flows of particles with nontrivial phase - condensate vortices - can be localized inside the optical lattice. This result is somewhat surprising because the lattice breaks the rotational invariance of the system. As shown in the figure, the lattice fragments the condensate density according to its symmetry, but the circular flow around the vortex core and the phase ramp (from 0 to 2_) in the central region of the vortex remain intact. Just like atomic solitons with a trivial phase, vortices trapped by the lattice are localized inside the spectral gaps. The study of gap vortices is a step towards our understanding of the relationship between the superfluid and nonlinear properties of the condensates in periodic potentials.

The atom laser is the atomic analog of an optical laser. A Bose-Einstein condensate (BEC) is used as a reservoir of atoms, from which a coherent output coupling mechanism converts atoms from trapped to untrapped states. In this work we investigate the crossover from weak to strong output-coupling in a continuous atom laser based on a radio-frequency (RF) mechanism. Our previous experiments on a pulsed output-coupler suggested that a continuous atom laser would have a stringent limit on peak homogeneous flux. Here we show that peak flux into the magnetic field insensitive state is indeed significantly below that which can be provided by the finite reservoir of BEC atoms that we produce. This 'homogeneous flux' limit is imposed by the interaction between multiple internal Zeeman states of the magnetically confined atoms. Furthermore, we find that a previously predicted effect known as the 'bound state' of an atom laser, effectively shuts off state changing output-coupling and hence the atom laser beam. The figure shows the densities of the condensate and atom laser beam in a series of experiments with a 3 ms continuous atom laser, produced in the F=2 manifold of ^{87}Rb by state changing output coupling to a magnetic field insensitive state. At low output-coupling strength the atom laser beam flux increases gradually and homogeneously until the angular Rabi frequency is approximately 1 kHz. At around this value we observe that the anti-trapped m_F=-2,-1 states begin to play a part in the atom laser dynamics. This leads to increasingly severe fluctuations in the density of the atom laser beam, and a loss of atoms to the anti-trapped states (Fig 1(a),(b)). A further increase in the coupling strength incrementally shuts down the output starting around 4 kHz (Fig 1(c)).





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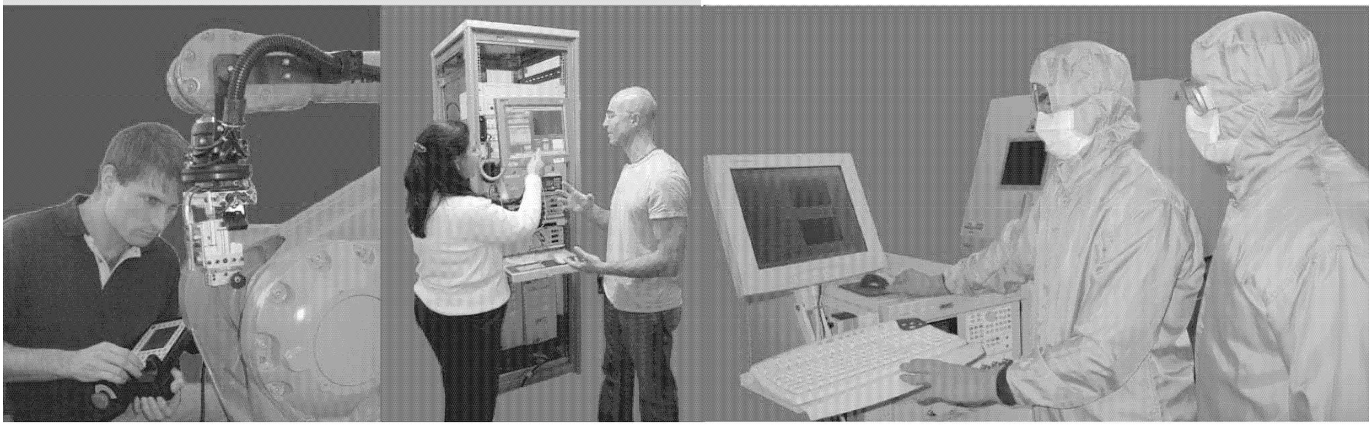

Photonics Manufacturing Technology Access Program

The Photonics Manufacturing Technology Access Program is an AusIndustry funded project with the goal of diffusing state-of-the-art manufacturing techniques to Australian businesses. Regular hands-on workshops in the fields of industrial robotics, wafer processing & lithography, optical sensors, and photonic technology will be held over the next two years in Sydney and Melbourne locations. Valued at over $1500 each, these workshops will be offered to industry on a first come - first served basis. Places are limited - please, book early!

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