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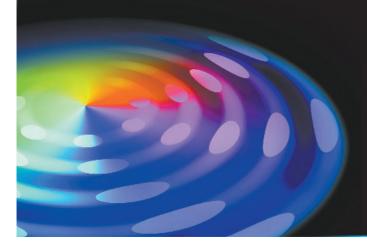
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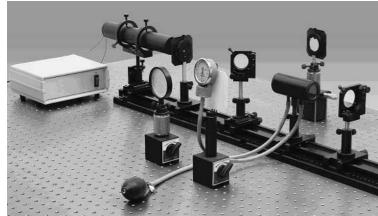
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* Review Article

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

- * Conference Report
- * News Item
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On submission of a scientific or review article you may request that the paper be refereed, and if subsequently accepted it will be identified as a refereed paper in the contents page. The refereeing process will be the same as for any of the regular peer reviewed scientific journals. Please bear in mind that refereeing takes time and the article should therefore be submitted well in advance of the publication date.

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

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Copy for the next issue (Jun 06) should be with the editor no later than 8 June 2006

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SEPTEMBER 2005

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ARTICLES

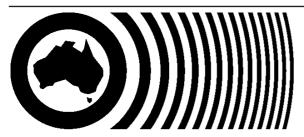
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Cover Picture: A fogbow in Scotland. A fogbow is formed by small water droplets, the same as a rainbow. However the size of the drops is sufficiently small that diffractive spreading of the waves that exit the drops is greater than the spectral dispersion. Thus the rainbow colours are superposed, resulting in white light. Photo by M. Hamilton.



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President's Report

It's been a February spent dealing with the start of the academic year and feeding the government's information addiction (i.e. ARC application). I remember when I was a postgrad, that an application for enough money to buy a CW dye laser system required only two pages. Anyway enough of this forty-years-ago-when-I-was-a-boy stuff.

As noted briefly in the previous AOS News there was a very successful ACOLS 2005 conference held in Rotorua - thanks to the organisers John Harvey and Howard Carmichael and their team. A healthy crop of awards was presented or announced at the conference.

- Prof. Brian Orr of Macquarie University received the AOS Beattie-Steele Medal for 2005
- Aidan Brooks of the University of Adelaide received the AOS Postgraduate Student Award for 2005
- Vijay Sivan of RMIT University was awarded the AOS/ Warsash Student prize for 2005
- Michael Ventura of Swinburne University received the 2006 SPIE Student Prize
- Nathan Langford of the University of Queensland received the 2006 OSA Student Prize And my congratulations go to all of these people on behalf of the Society.

You will see in this issue one of the outcomes of the conference; a business meeting was held to discuss certain aspects of the future of ACOLS *. The first aspect concerned the financial arrangements. This series of conferences has been run as by a committee representing three interest groups; the AOS, the Spectroscopy committee of the Australian Academy of Science and a body called the Australasian Council for Quantum Electronics (ACQE). The funds held by that committee were looked after by the AOS, that part not needed as a float for the next ACOLS being held in a separate account. However the AOS was the guarantor of last resort should an ACOLS fail financially. We have seen in recent years that conferences can make a rather large financial loss, the last ACOFT* losing a sum roughly equal to the entire reserves of the AOS. Thus a good deal of care is needed in running conferences, especially for a small organisation like the AOS. The meeting at Rotorua endorsed the desire of the AOS council to have direct financial control of ACOLS in the future. ACOLS will of course continue and a steering committee that represents the interests of all parties that make up the traditional ACOLS community will continue (although this latter point is not spelled out in the report of that meeting). Details of the setup of this committee have yet to be threshed out, but I envisage it being similar to the new ACOFT steering committee that was set up last year.

Other matters that were dealt with at that meeting concerned the continuation of the ACQE (whose main reason for existence was to bring IQEC to Australia in 1996!, and whose potential disbandment has an obvious effect on the constitution of ACOLS), and the name of the AOS. The latter was sparked by a debate that has been going on in the AOS council about if and how we should attract more members from New Zealand. There will be a discussion about this at the AGM, so if you want to hear my opinion about this (as a New Zealander) be there!

Organisation is well underway for the ACOFT/AOS conference that will be held in July at RMIT. See the announcement that is in this issue (page 24). The AGM will be held at this conference (late afternoon Weds 12th) so please support your society and make it quorate! You will find the notice, agenda and proxy form at the back of this issue. Ann Roberts (Uni of Melbourne) has accepted the job of chairing the program committee for the AOS part of the conference, which begins at lunchtime on the Wednesday and ends on Thursday afternoon.

Don't forget our main AOS conference of the year either! It's part of the AIP Congress to be held in Brisbane in early December.

Murray Hamilton President, Australian Optical Society March 2006.

* ACOLS = Australasian Conference on Optics Lasers and Spectroscopy ACOFT = Australian Conference on Optical Fibre

ACOFT = Australian Conference on Optical Fibre Technology

Position Vacant Australian Optical Society Newsletter

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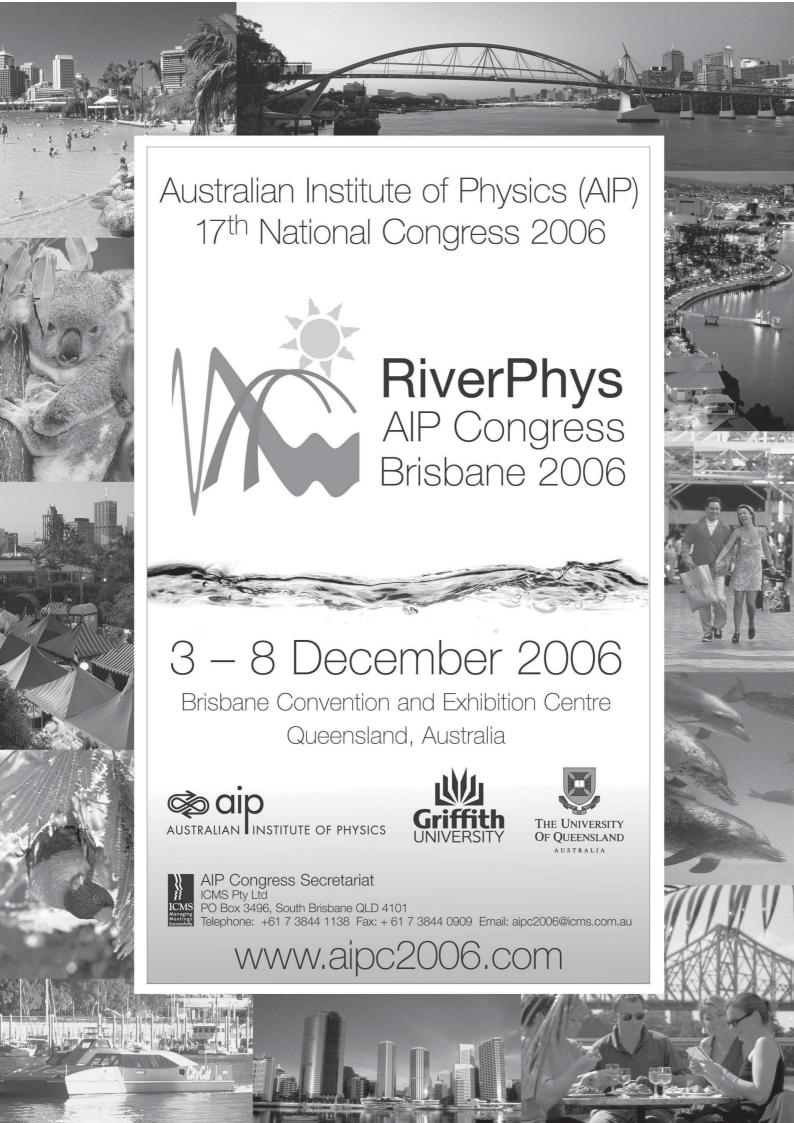
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The editor will be paid an honorarium of \$2000 p.a or \$500 per issue.

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

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Ms Malar R. K., Optics Software Specialist, WaveLab Scientific Pte Ltd.

Ms Malar obtained her Bachelor of Engineering degree in Electrical and Electronics discipline, and a Mster degree in Photonics from Nanyang Technological University of Singapore.

She has received entire training at ZEMAX Development Corporation USA and conducted training courses in Singapore successfully.

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Direct writing of guided wave devices inside bulk glass using femtosecond lasers.

Martin Ams, Graham D. Marshall, David Spence, Judith M. Dawes, James A. Piper and Michael J. Withford.

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Abstract: We review femtosecond laser-direct write inscription of guided wave structures in bulk glass and discuss our recent demonstrations of a range of 2- and 3-D photonic devices using this technique.

Femtosecond laser – direct writing of waveguides and devices:

In 1996 it was first shown by Davis et al [1] that tightly focused output beams from femtosecond pulsed laser could modify the optical properties of a silica glass. In particular, femtosecond laser irradiation was reported to induce refractive index changes between 0.01 and 0.035 in pure and Ge-doped silica. Even in this seminal work the authors were quick to recognize the possibilities for using laser direct write methods for inscribing 3D lightwave circuits in bulk glass. In the last 5 years the number of research groups working in this field has risen significantly, coinciding with the ready, commercial availability of femtosecond lasers. These groups currently span the US (eg. MIT, CREOL, LLNL, Harvard), the UK (eg. ORC; Southhampton University, Aston University), Germany (Freidrich Schiller University, Max-Planck Institute, LZH), France (CEDEX), Italy, Spain, Canada, Lithuania, Korea, Japan, Singapore, China and, most recently, Australia. The body of effort in this field reflects the high stakes involved.

The original paper by Davis et al [1] identified that femtosecond laser radiation induced Si E' and Ge E' defects when irradiating pure silica or Ge doped silica respectively. They also proposed that multiphoton absorption of the infra red output (~ 1.5 eV) of the laser source induced these high energy (~5 eV) structural changes. Si E' formation is also associated with the refractive index changes produced when UV laser writing fibre Bragg gratings within the core of photosensitive optic fibre and is an obvious candidate explaining the refractive index changes photoinduced in silica by femtosecond lasers. However, fs laser photoinduced refractive index changes in borosilicate persist even after elevated temperatures erased Si E' colour centers. By comparison, UV laser written fibre Bragg gratings are erased at elevated temperatures. This behaviour has led to an alternate proposal that heating, melting and resolidification induces densification of the glass [2].

Ultrafast laser direct writing of guided wave devices in glasses presents an attractive alternative to conventional thermal and field assisted ion exchange methods. A wide variety of femtosecond laser written passive photonic devices have already been demonstrated in silica and silicate glasses. Examples include x-couplers [3], directional couplers [4], 3D splitters [5], 3D optical interconnects [6], 3D coupled waveguide arrays [7], gratings [8] and Mach Zehnder interferometers. Waveguides and measurements of gain have also been reported by writing inside rare earth doped glasses. Most recently, a C-band waveguide amplifier was reported with peak gain of 9.2 dB at 1535nm and gain spanning 1530 to 1580nm [9]. Simple photonic devices such as 2D splitters have also been written in nonlinear glasses such as

chalcogenide [10] and novel tubular waveguides in a polymer [11].

Parallel vs. perpendicular writing:

Parallel beam delivery, where the waveguide is written along the same axis as the beam propagation direction, has been shown to produce highly symmetric waveguides, however, it is limiting as a fabrication method because the maximum waveguide length is fixed to the working distance of the focusing objective. This can range from a few mm's to a few µm's for the typical objective magnifications used, namely 20 to 100x. By comparison, perpendicular writing methods, as shown in Figure 1, are well suited to writing long (and complex guided wave structures), however, this method requires that the depth of field is of similar dimensions to the focal spot diameter. This is readily achieved using high magnification and high numerical aperture objectives (typically 100x). The downside to these objectives is again their short working distances (100's µm at best) that limit the writing process to a relatively shallow portion of the glass substrates thus limiting the opportunities for 3-D writing.

Beam shaping using diffractive elements

A standard 20x microscope objective is well suited to 3-D direct writing in bulk glass because it produces a focal spot size smaller than a typical waveguide diameter and has a relatively long working distance (2-4 mm). However, the depth of field of a 20x objective is significantly longer than the focal spot diameter as shown in Figure 2a. This manifests in waveguides with highly elliptical cross sections and consequently, large propagation losses. In order to counter this effect we have employed beam shaping methods using diffractive elements. Fig. 2c shows a simulation of a diffractive element, in this case a 500 µm slit, placed in the beam path as shown in Fig. 1. This simulation assumes the beam has a Gaussian profile and evolves via paraxial theory.

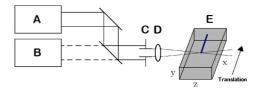


Figure 1: Schematic of the perpendicular writing method used to inscribe waveguides in bulk glass. The components are A: 150fs Ti:Sapphire laser, B: in-line camera, C: variable slit for beam shaping, D: 20x objective lens and E: a bulk glass sample.

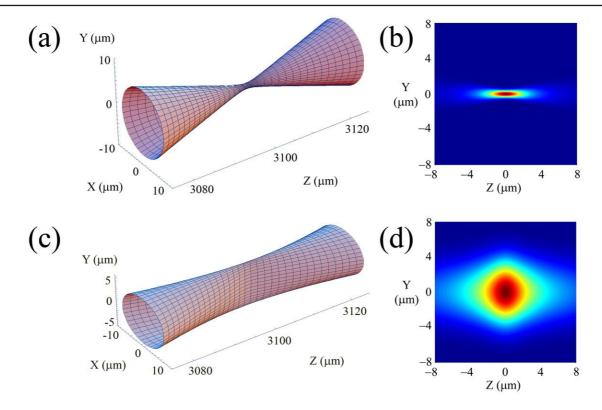


Figure 2: Beam evolution (a) and energy distribution in the YZ focal plane (b) when using a standard spherical focusing geometry. Beam evolution (c) and energy distribution in the YZ focal plane (d) when beam shaping using a slit.

The numerical aperture is 0.46, the slit width $500 \, \mu m$ and the refractive index of the target glass of 1.54. The corresponding energy distribution plots near the focal point are shown in Figures 2(b) and 2(d).

Figures 3(a) shows side and end view, phase contrast micrographs, of a waveguide written in phosphate glass at a pulse energy of 0.24 μ J, a translation speed of 40 μ m/s and without using beam shaping methods. In this case the waveguide exhibits an elliptical shaped core of aspect ratio 4:1 and has significant propagation losses. By comparison, Figure 3(b) shows micrographs for a symmetric waveguide written in phosphate glass using the beam shaping methodology. The incident pulse energy was 1.5 μ J, the translation speed 40 μ m/s and the slit width 500 μ m. The propagation loss of these waveguides was measured as 0.39 dB/cm at 1550 nm. The refractive index change induced in the glass was estimated from fitting simulate mode profiles to the measured near field profile as $\Delta n = 3.5 \times 10^{-3}$.

Passive Devices:

Parametric studies have helped identify optimal device designs and achieve excellent control over their optical properties. Of key importance in the design of splitter devices, are factors such as waveguide overlap and interaction region become very important. Controlling these during device fabrication presents a challenge to the experimental physicist given that the position tolerances involved in these designs are very tight. To that end, we employ nanometre resolution brushless translation stages that can operate in 3-dimensions. Furthermore we control the laser exposure and power programmatically to automate all aspects of device fabrication; a process that can take between minutes and hours depending on the study.

Examples of a series of 1x2 splitters, fabricated in silica glass, are shown in Figure 4. Figure 5(a) shows a phase contrast micrograph of a 2-dimensional 1x4 splitter fabricated using the femtosecond laser in silica. The output arms have an angular separation of 2° from each other. Figure 5(b) shows both the experimental (measured using a CCD camera) and theoretical (RSOFT simulations) output intensity profile of this device. In this case $\sim 90\%$ of the power is shared between the 2 central output ports and 10% shared between the 2 outer ports. Equal power sharing between all 4 output ports can be readily achieved by nesting a sequential series of planar 1x2 splitters, however, the 3-dimensional capability of this fabrication process enables power sharing with non-planar variants of the 1x4 splitter, as shown in the measured output intensity profile in Figure 6.

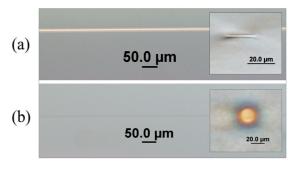


Figure 3: Phase contrast microscope images of waveguides fabricated in phosphate glass using a) a standard spherical focusing geometry and b) the slit beam shaping technique.



Figure 4: Phase contrast micrograph of a series of 1x2 splitters femtosecond laser inscribed in silica. Arrays such as these are used to characterise losses and identify optimal designs.

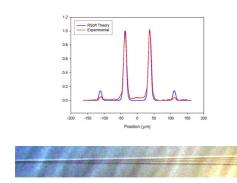


Figure 5: Phase contrast image, and experimental and theoretical analysis of the output intensity profile of a planar 1x4 splitter.

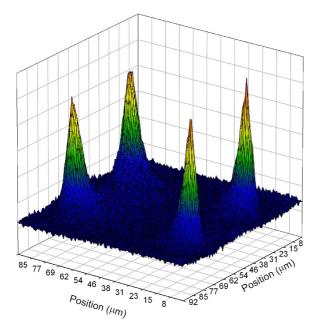


Figure 6: Output intensity profile measured for a 3-dimensional 1x4 splitter.

The ability to use this style of waveguide to manipulate light can be taken to high level of sophistication by employing evanescent coupling. In this process waveguides are written close enough to each other for the guided mode to couple into a neighbouring structure. We have fabricated evanescent splitters and modelling their behaviour using a beam propagation code confirms our experimental results. An example of an evanescent coupler and its output near field optical profile is shown in Figure (7). The splitter efficiently shares the input signal between the output arms of the device and is considerably smaller than an equivalent optical fibre based device.

Active Devices:

To date we have demonstrated waveguides can be written in a range of glass materials such as silica, borosilcate and (doped and un-doped) phosphate glasses. We are currently building on this platform by fabricating low-loss optical waveguides in Er:Yb doped phosphate glass. Preliminary analysis has shown several dB of internal gain in a 55 mm long active waveguide. Modelling and the evidence of ASE selfabsorption point to shorter waveguides producing optimal gain for the same levels of active dopant. The optical pump source for these devices is combined with the signal in an external wavelength division multiplexer such that it co- or counter propagates with the optical signal. The use of this and other types of active glass offers the prospect of being able to manufacture a range of miniature active waveguide devices. Using the femtosecond direct write technique in active glasses one can envisage a new range optical waveguide devices such as 'no loss' splitters and monolithic laser devices that utilise external or internal mirrors. Again, work such as this open large realms of experimental parameters which we continue to investigate using a range of different active glass dopant levels and device lengths.



Figure 7: Phase contrast image of a evanescently coupled 50:50 splitter. Note that the central input waveguide terminates after an interaction length of 4mm. The near field profiles at the output ports are shown in the inset.



Figure 8: Image of the 55mm long length of Er: Yb doped phosphate glass, with embedded waveguides, coupled to optic fibre probes at its input and output faces.

Conclusion:

Femtosecond laser direct writing of guided wave structures opens new opportunities for fabricating photonic devices in a range of glass hosts. In this paper we showed that long working distance objectives can inscribe highly symmetric, low loss waveguides using perpendicular writing configurations. As a result, prospects exist for writing guided wave devices over 100's of planes spanning several millimetres of glass. We also demonstrated that 3-dimensional devices can be fabricated with this technique. Finally, preliminary results of our experiments leading towards compact waveguide amplifers was presented.

References:

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Business Meeting on the Future of ACOLS

At a business meeting of the ACOLS conference held in Rotorua on Tuesday 6th December, the following paper was discussed. The resolutions listed below were passed unanimously.

The recommendations were then referred to a meeting of the AOS Council which was held on Wednesday 7th December. At that meeting it was resolved to;

- Present this document to the AOS membership via the AOS News
- Email this document to all registrants for both the present and the previous (Melbourne 2003) ACOLS meetings
- 3. Email this document to all New Zealand researchers in the ACOLS topic areas
- 4. Carry out the consultations contained in recommendation 2
- Present recommendations 1 and 3 in this document to the AOS AGM which will be held in Melbourne at the ACOFT/AOS meeting July 13th for adoption as AOS Council action items.

This article is the first step in this process. Comments on the recommendations should be sent to the Secretary of the AOS:

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for collation prior to discussion at the AGM.

A Short History of ACOLS

The ACOLS conference series started in 1987 at the Gold Coast where it was entitled the Australian Conference on Lasers and Spectroscopy, incorporating the 5th Australian Laser Conference and the 15th Australian Spectroscopy Conference. Subsequently, "Optics" replaced "on" and the Australian Optical Society (AOS) became a major player in the series. At the 1998 ACOLS conference in Christchurch, the name of ACOLS was again changed to begin with "Australasian", to demonstrate the important participation of New Zealanders at the conference.

In 1991 the ACOLS conference series was formalised in an agreement between the AOS, the Australian Academy of Science (AAS) Spectroscopy Committee, and the Australasian Quantum Electronics Council (ACQE). The ACQE represents the laser interests in ACOLS and was established in part to support the successful bid for IQEC '96 in Sydney. The AAS Spectroscopy Committee also selects and funds the Frew Fellow, who is one of the three main ACOLS plenary speakers (plus nominally one in optics and one in lasers). These three bodies are each represented by two nominees on the ACOLS Liaison Committee (which includes the previous ACOLS Chair), whose constitution (attached) entrusts oversight of ACOLS to this Committee.

The Financial Role of the AOS

Under the constitution, the AOS is the custodian of the ACOLS conference funds, and receives interest as specified under the constitution. The interest is designed to reward the risk arising from the AOS acting as the guarantor of last resort for the ACOLS conference. The balance of the ACOLS fund is currently \$63,560.

However, the AOS does not receive any surplus from the conference, although it shoulders all the risk. Furthermore, there is little opportunity for the AOS to hold stand alone conferences in order to boost its own reserves, since colocation with the AIP and ACOLS has occurred in alternate years in the recent past. In addition, arrangements to provide a discounted rate for AOS members at ACOLS conferences has to be negotiated with each individual conference committee. Thus non-AOS members registering at ACOLS do not necessarily become AOS members, as they did previously at stand-alone AOS conferences, thereby boosting the AOS membership.

The AOS therefore has a key interest in the financial wellbeing of the ACOLS conference series, and has been playing an increasingly important controlling role in a *de facto* fashion in recent years, since many members of the ACOLS Liaison Committee are AOS members (beyond the two statutory AOS members). The AOS would prefer to have this financial role formally recognised, and become the body financially responsible for ACOLS conferences. It is envisaged that the AOS would also give occasional favourable consideration to providing ACOLS account funds to underwrite more specialised conferences in the area of optics or lasers or spectroscopy (e.g., an Australian Spectroscopy Conference independent of the regular ACOLS series).

Recommendation 1: The AOS takes on financial responsibility for the ACOLS conference, and the ACOLS trust funds become part of the AOS reserves while remaining in the ACOLS account. Proposals can then be put to the AOS to use the ACOLS account funds to underwrite conferences in the area of optics or lasers or spectroscopy.

ACOLS Liaison Committee Programme Oversight

The non-financial oversight role of the ACOLS Liaison Committee then needs to be considered. At present, the three bodies representing Optics (AOS), Lasers (ACQE) and Spectroscopy (AAS Spectroscopy Committee) in theory oversee the programme balance for the conference.

However, the ACQE has recently handed over its responsibility for selecting an Australian representative on the International Council for Quantum Electronics to the AOS. This leaves the ACQE, who are very often AOS members, with very little formal role except on the ACOLS Liaison Committee. This raises the question as to whether the ACQE should disband, and if so, whether the ACOLS Liaison Committee then has any significant role in ACOLS, since its AAS Spectroscopy Committee members are also often members of the AOS.

If the AOS were to assume the full role of the ACOLS Liaison Committee, the selection of the Frew Fellow as an ACOLS plenary speaker would continue to be the responsibility of the AAS Spectroscopy Committee. Indeed, the Frew Fellowship is running short of money, and one solution might be to assist this through contributions from the ACOLS conference account.

Recommendation 2: The AOS communicates with the ACQE and the AAS Spectroscopy Committee concerning the handing over of all responsibilities from the ACOLS Liaison Committee. The Frew Fellow would continue to be selected by the AAS Spectroscopy Committee, with supplementation of funds from the ACOLS account if appropriate.

New Zealand Participation

Already ACOLS has an Australasian name, and significant trans-Tasman participation. The AOS, if it is takes on complete responsibility for ACOLS, may therefore wish to offer New Zealanders greater participation in the AOS. This would provide New Zealand members with a wider representative role *via* the AOS as the body which promotes optics for the region. Increased participation could (in part) take the form of a designated position for at least one New Zealand member on the AOS Council. If this trans-Tasman representative role develops further, the AOS may wish to become the Australasian Optical Society. If so, it could also take on the role of the New Zealand Institute of Physics in nominating the New Zealand member on the ICQE (who shares a vote with the Australian member, now nominated by the AOS).

Recommendation 3: The AOS considers undertaking a constitutional change to alter its name to the Australasian Optical Society and to offer wider representation for the New Zealand optics community.

AOS Council December, 2005

ACOLS LIAISON COMMITTEE CONSTITUTION

1. PREAMBLE

The Australian Conference on Optics, Lasers and Spectroscopy (ACOLS) is a composite meeting incorporating the Australian Optical Society Conference, the National Laser Conference and the Australian Spectroscopy Conference. Each of these conferences has its own history and traditions in its own right, but ACOLS is held approximately every two years as a joint meeting for these related and overlapping areas. To facilitate the organisation of each ACOLS has seen the ACOLS Liaison Committee established (hereafter referred to as the Committee). The Committee is to be seen separately from the ACOLS Local Organising Committee which is formed for each ACOLS and charged with the responsibility of running that particular conference.

2. MEMBERSHIP

The Committee will have a membership of;

- * Two persons nominated by the Australian Optical Society
- * Two persons nominated by the Australasian Council on Quantum Electronics
- * Two persons nominated by the National Committee for Spectroscopy
- * The chairperson of the Local Organising Committee of the preceding ACOLS

Each body will review its nominated members at the time of each ACOLS and the membership of the incoming Committee will be announced by the end of the Conference. The incoming Committee shall elect one of its members as Chairperson. The Chairperson's term of office will expire with the holding of the subsequent Conference. An outgoing Chairperson will not be eligible for immediate reelection.

3. DUTIES

- (a) The Committee will;
- * On the advice of the ACOLS Business Meeting, decide on the approximate timing, venue and Chairperson of the Local Organising Committee for the subsequent Conference.
- * Approve the budget and budget variations of the subsequent Conference.

- * Make the experience and expertise of its members freely available to the Local Organising Committee especially with regard to management strategies and programme.
- * Be responsible for the monies held from previous Conferences
- (b) The Committee Chairperson will;
 - * Coordinate the activities of the Committee.
- * Act as the contact for the ACOLS Organisations between Conferences

4. FINANCIAL

The Committee will be responsible for monies held between Conferences as a result of previous surpluses and from other sources. These funds will be used;

- * As a source of float money for the Conference. The Local Organising Committee shall request an appropriate sum for pre-Conference expenditure (estimated to be about \$5,000). The Local Committee shall budget to repay this sum to the ACOLS Liaison Committee fund after the conference.
- * As a contingency against the Conference expenditure exceeding its income.
- * With the agreement of at least six members of the Committee, as a source of float money to other conferences organised either solely by one of the member bodies or by two of the member bodies jointly where other sources of float money are not available. This money shall be repaid after the conference.

Notes:

- (a) Where ACOLS money is employed as float money, the conference organisers will insure the pre-conference expenditure against loss due to the conference not being held for reasons beyond control of the organisers.
- (b) It is not the intention that the ACOLS funds be increased beyond an amount considered reasonable to supply float money and act as contingency. This amount is currently considered to be about \$30,000. Funds held exceeding this amount can be supplied in the form of a Grant to the Local Organising Committee. The Committee will determine the amount of the Grant taking into account all necessary factors. If the amount of the funds falls substantially below the above amount, the Committee may request the Local Organising Committee to budget for a surplus of Conference income over expenditure by an amount necessary to help restore the funds to the appropriate level.
- (c) The ACOLS funds will be held in trust by the Australian Optical Society. Disbursement of money from the fund will require the signing authority of one member of the Committee and the Treasurer of the AOS. The AOS will take financial liability for the Conference (but not conference involving two or fewer of the member bodies). As a fee for the service, the Committee will remit annually (January 30, commencing in 1993) to the AOS either the interest earned by the funds in the previous calendar year or \$1,000, whichever is the lesser amount.
- (d) All amounts of money specified in this document are expressed in 1991 dollars and will be inflated by the CPI increase of each calendar year subsequently.
- (e) In the event of the winding up of the ACOLS series, the funds held by the Committee will be divided equally amongst the three member bodies after all outstanding payments have been made
- (f) It was resolved by the ACOLS Liaison Committee in December 2003 that the standard amount of Conference float funds should be increased from \$5,000 to \$10,000.

(This is the currently valid constitution, Ed.)



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Optics, Lasers and Spectroscopy: Resonance at Work

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Resonances in molecules, optical cavities and sensitive instruments enable much innovative research on spectroscopic sensing, on high-performance sources of tunable coherent light, and on fundamental studies of molecular processes. The paper includes biographical information on W.H. (Beattie) Steel (1920–2004), Charles Fabry (1867–1945) and Alfred Perot (1863–1925).

INTRODUCTION – A TRIBUTE TO BEATTIE STEEL

The longstanding Australasian Conference on Optics, Lasers and Spectroscopy (ACOLS) series covers the three concurrent themes of this article, which was presented as a Keynote Talk at the recent ACOLS 2005 meeting (Rotorua, NZ, December 2005). The talk was associated with my being awarded The 2005 Australian Optical Society W.H. (Beattie) Steel Medal - the most senior award of the Australian Optical Society (AOS). This Medal is designated for "an outstanding contribution or contributions to the field of optics in Australia by a member of the AOS" and for "a nominee at an advanced stage of his or her professional career and with a strong and sustained record of authority, enterprise and innovation in the field of optics in Australia".

The above qualities applied extraordinarily aptly to Dr Beattie Steel (see Fig. 1), whose death in mid-June 2004 prompted the AOS to add his name to what was previously "The AOS Medal". Reminiscences of his influence and authority were inescapable in the context of my ACOLS 2005 Keynote Talk and of this article. Beattie reputedly acquired his almost-lifelong nickname when, as a student at Geelong College, he played the role of Beatrice in Shakespeare's *Much* Ado About Nothing [1]. He was world-famous in optics, with a reputation established during his term of more than thirty years as a CSIRO physicist via his research in areas such as image diffraction theory, coherence, Fourier optics and advanced design, fabrication and testing of optical instruments, as well as his classic monograph, Interferometry [2]. In 1985, Sir Alan Walsh (the inventor of Atomic Absorption Spectroscopy) paid the following warm tribute in his Foreword to Beattie Steel's Festschrift [3]:

"All Beattie's work is characterized by elegance of design and he always appears to arrange his experiments so that they are aesthetically pleasing. ... I have seen him derive the same sort of pleasure from an experiment to generate holographs that he gets from good wines."

In 1985 the Optical Society of America (OSA) awarded Beattie Steel its prestigious C.E.K. Mees Medal, which recognises a person "who exemplifies the fact that optics transcends all boundaries – interdisciplinary and international alike". From 1972 until 1975, he was President of the International Commission for Optics (ICO). He was a strong advocate for optics in Australia [4] and was the prime mover behind establishing the AOS, serving as its Foundation President (1983–1984) [5]. Among his personal interests, Beattie was a francophile with a passion for French food, wine and culture (no doubt stemming from his doctoral studies in Paris [6]), a keen yachtsman, gardener and bushwalker, as well as an enthusiastic train traveller.

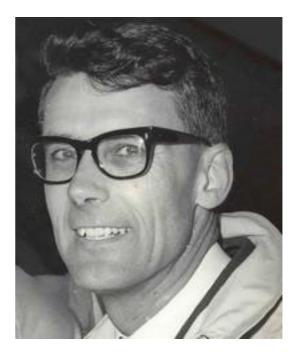


FIG. 1: Dr W.H. (Beattie) Steel (1920–2004) – "a leading light in the world of optics" [1].

This article, which serves as a further tribute to Beattie Steel, considers several aspects of optics, lasers and spectroscopy in which resonant interactions are essential. Such phenomena are evident in interferometry [1], in interactions between light and optical cavities (including lasers themselves), in spectroscopy of many atomic or molecular optical processes (*e.g.*, absorption, scattering, nonlinear optics, etc.) and in instrumentation for assorted approaches to optical sensing. In particular, within the above unified context, we focus on several aspects of our current research that put resonances to work, both in the molecules studied and in the optical instruments used to detect processes of interest:

- Novel forms of rapidly swept cavity ringdown (CRD) spectroscopy, enabling efficient, precise molecular sensing of gases, both in the laboratory and for applications in industry, medicine, agriculture and the environment;
- High-performance narrowband pulsed optical parametric oscillators (OPOs), controlled by injection seeding and with optical-heterodyne (OH) pulse-by-pulse diagnostics that enable new forms of precision laser spectroscopy;

Fundamental spectroscopic studies of collisioninduced molecular energy transfer by infraredultraviolet or Raman-ultraviolet double resonance.

FABRY-PEROT OPTICAL RESONATORS

Reminiscing about Beattie Steel, I am reminded of Fabry-Perot resonant optical cavities or Etalons. The elegant simplicity of this arrangement of two highly reflective parallel surfaces is ubiquitous, both in nature (e.g., thin films such as oil slicks; iridescence in some animals and minerals although many such phenomena entail multi-dimensional optical structures such as gratings or photonic crystals [7,8]) and in interferometric instruments that grace many optical laboratories. I discussed this general subject with Beattie during his post-CSIRO years, when he was an Honorary Professorial Fellow in Physics at Macquarie University and regularly joined in lively tea-room conversations. On several occasions Beattie was able at an instant to answer questions on optical science of which I was uncertain. A direct link arose from the fact that Beattie had conducted the research for his Docteur ès Sciences Physiques degree at Paris's celebrated Institut d'Optique, of which Charles Fabry (1867-1945) had been the first director. However, Fabry was actually from Marseilles, in the south of France, where he spent most of his career. So, too, did Alfred Perot (1863-1925) who provided the instrument-design expertise to complement Fabry's theoretical talents [9-11]. Collaboration between Fabry and Perot was extensive, including their famous 1897 paper on the optical resonator that now bears their names [12] and subsequent elaboration of its applications to spectroscopy [13].

The spelling of Perot's name is a question that interested Beattie Steel [14]: is it "Perot" or "Pérot"? The former, accentfree spelling is indeed correct, but the misspelt, accented version persists to this day in the scientific literature, including an otherwise-excellent biographical paper [11] and in the ultimate double demerit "Fabry-Pérot etalon" (where the accent migrates from a word where it belongs to one where it does not!). Beattie preferred "Perot", on the basis of his own enquiries at the University of Marseilles [14], as is confirmed by Perot's birth certificate and other official documents [10]. He hypothesised that frequent misspelling as "Pérot" had its origins in Parisian journals such as Comptes Rendues, the savant editors of which might have over-zealously purported to know better than authors from the south of France. However, this hypothesis is not borne out if one examines original French papers (e.g., refs [12], [13] and [15]), in which Perot's name is rarely misspelt. Rather, it appears that the error became entrenched on the other side of the Atlantic, where Perot's name was persistently misspelt in American digests of his papers during the period 1900–1905 [15].

Pedantry aside, the Fabry-Perot resonator is central to much of the research that we consider in this article, not only in the optical cavities that are vital to virtually all lasers but also in various optical and spectroscopic measurements of relevance here. An iconic representation of some of our research techniques is shown in Fig. 2 [16], where laser light (propagating from the upper right) is coherently converted to one or more new wavelengths (e.g., signal and idler outputs of a quasi-phase-matched nonlinear-optical parametric generator) that are used to monitor molecules contained in a high-finesse Fabry-Perot cavity; the resulting cavity ringdown comprises a temporal decay (upper left) that can be

transformed to generate an absorption spectrum (lower right) with high sensitivity.

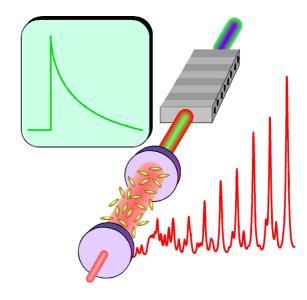


FIG. 2: A representation of some of the ingredients of our research techniques: tunable laser radiation, coherent nonlinear-optical wavelength conversion, light-molecule interactions in a high-finesse optical cavity, ringdown decay of light converted to spectroscopic information [16].

RAPIDLY SWEPT CAVITY RINGDOWN SPECTROSCOPY

Particularly sensitive forms of laser spectroscopy can be achieved by placing an absorbing medium of interest inside a Fabry-Perot optical cavity, external to the cavity of the laser itself. This advantage was recognised at an early stage by Kastler [17]. Various forms of cavity-enhanced laser spectroscopy have subsequently evolved [18-23] and have yielded remarkably fine noise-equivalent detection sensitivities (e.g., ~10⁻¹⁴ cm⁻¹ Hz^{-1/2} from the NICE-OHMS technique [18,24]). All such techniques gain from the fact that light resonating in an optical cavity with high finesse Fhas its effective pathlength enhanced by a factor of $(2 F / \pi)$, relative to single-pass propagation. In particular, cavity ringdown (CRD) spectroscopy relies on the fact that light resonating inside a high-finesse Fabry-Perot optical cavity takes a finite (and measurable) time to decay out of that cavity, typically exponentially with a characteristic constant τ known as the ringdown time.

The CRD principle was first applied [25] as a means of characterising high-reflectivity, low-loss mirrors. Its implementation for spectroscopy by means of pulsed lasers was reported in 1988 [26] and, less than a decade ago, with continuous-wave (cw) lasers by several groups [27-29]. In CRD spectroscopy we measure the ringdown decay time τ of radiation inside the cavity, rather than transmitted optical power or energy as in conventional absorption spectroscopy; this approach is insensitive to amplitude and/or frequency fluctuations of the tunable coherent light. Spectroscopic information is derived from the linear contribution of optical absorption by intracavity sample gas to the total intracavity loss $\Sigma_{\rm loss}$ (along with other contributions from scattering, mirror transmission, etc.). The corresponding first-order rate constant τ^{-1} equals ($\Sigma_{\rm loss}$. FSR), the product of $\Sigma_{\rm loss}$ and the

cavity's free spectral range (FSR = c / 2L, where 2L is the round-trip optical pathlength and c the speed of light in the Fabry-Perot cavity). Intracavity optical absorption therefore contributes linearly to τ^{-1} , from which an absolute absorption coefficient can be derived. A CRD absorption spectrum is typically derived by measuring and plotting τ^{-1} as a function of laser frequency or wavelength.

CRD spectroscopy is now a mature technique, with many excellent reviews (e.g., refs [19] - [23]). We at Macquarie University have performed CRD-spectroscopic experiments with pulsed OPOs [16,30,31], but our main interest has been in novel forms of cw-CRD spectroscopy [31-34]. In pulsed CRD spectroscopy, the build-up and decay of the CRD signal is initiated naturally by the rise and fall of the light pulse. By contrast, it is necessary in cw-CRD spectroscopy to couple light into the cavity and then interrupt the interaction between the cw light and the ringdown cavity, usually by means of an active optical switch or modulator [27-29]. It is advantageous in many sensing applications of cw-CRD spectroscopy to use tunable diode lasers, notably those designed for optical telecommunications, together with associated fibre-optical components. For example, diode lasers operating in the wavelength range of 1.4–1.65 µm cover overtone absorption features of numerous molecules (e.g., CO, CO,, CO, H,O, NH, and various hydrocarbons) that are relevant to gassensing applications in industry, medicine, security, the community, and the environment.

Our distinctive approach to cw-CRD spectroscopy, depicted in Fig. 3, entails rapidly moving the cw radiation and the optical cavity in and out of resonance with each other, by sweeping either the cavity length (and hence the grid of longitudinal-mode resonance frequencies separated by its FSR) [31,32] or the laser frequency (traversing a broad spectroscopic tuning range in a short time) [33]. Both of these rapidly-swept forms of CRD spectroscopy are intrinsically simple and avoid the need for active optical switching and cavity resonance control. In both cases, we use two alternative modes of operation: either forwardpropagating detection of light directly transmitted by the cavity or backward-propagating optical-heterodyne (OH) detection of light actively reflected from the cavity. Corresponding transmitted and reflected CRD signal waveforms (see inset in Fig. 3) display oscillations that arise from interference between incident and intracavity light. Our swept-frequency (SF) cw-CRD technique contrasts with other CRD methods, in which spectra are recorded relatively slowly by step-scanning the laser frequency or wavelength and measuring τ at each step. The wide-ranging continuous frequency sweep and high data-acquisition rate of our SF cw-CRD approach [33] make it suitable for rapid spectroscopic

The layout of a fibre-coupled rapidly swept cw-CRD spectrometer is illustrated in Fig. 4. The coherent light source is a cw tunable diode laser, either set at a fixed (or slowly varying) frequency in the swept-cavity case or rapidly swept in the SF case. The Fabry-Perot ringdown cavity comprises two mirrors with a piezoelectric translator (PZT) for fine control of their separation (and hence the grid of cavity resonance frequencies), which can be *either* rapidly swept *or* varied stepwise in the SF case. The backward-propagating OH-detected CRD signal retro-reflected from the ringdown cavity returns *via* the same optical fibre and is separated from incident laser light by an optical circulator and monitored by photodetector PD₁. The ringdown cavity and associated components (enclosed by a dashed line in Fig. 4) can be widely

separated from the transmitter/receiver unit (in the top half of Fig. 4) and linked by optical fibre; a single-ended configuration of this type is favourable for quasi-remote and distributed-sensor applications. The second photodetector PD₂ records the corresponding directly transmitted CRD signal in the forward-propagating direction.

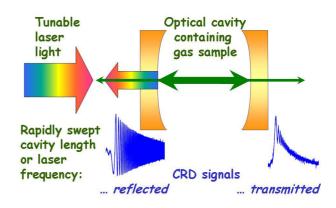


FIG. 3: Rapidly-swept cavity ringdown (CRD) spectroscopy based on build-up and decay of cw radiation in a Fabry-Perot cavity, with *either* transmitted *or* reflected CRD detection options

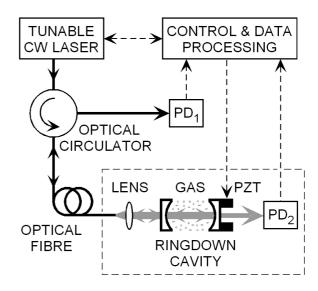


FIG. 4: Schematic layout of a fibre-coupled cw-CRD spectrometer, based on *either* rapidly-swept cavity length *or* a swept-frequency tunable laser [32,33].

Our rapidly-swept cw-CRD techniques, based on the characteristic decay of light from a high-finesse optical cavity, enable us to record weak absorption spectra of gases with high resolution and high analytical sensitivity [31-33]; our current research efforts focus on realising enhanced CRD detection sensitivity (e.g., approaching $\sim 10^{-10}$ cm⁻¹ Hz^{-1/2}) without sacrificing simple instrument design. In recent work

[34], we have extended cw-CRD spectroscopy from its conventional optical-absorption mode of operation into the regime of coherent Raman spectroscopy. The ringdown decay rates of interest are dependent on pump laser irradiance and are associated with stimulated Raman gain. Remarkably, such Raman-CRD resonances yield ringdown times τ that are longer than in the off-resonance case, rather than shorter (as is usual for absorption and other optical loss processes).

INJECTION-SEEDED OPTICAL PARAMETRIC OSCILLATORS

Optical parametric oscillator (OPO) and amplifier (OPA) devices are well established as nonlinear-optical sources of tunable coherent light, with spectroscopic applications such as sensing of chemical processes, in industrial or environmental diagnostics, and in basic optical physics [16,30,35-40]. OPOs are similar to, but distinct from, lasers. They typically comprise a non-centrosymmetric solid-state medium with nonlinear-optical susceptibility $\chi^{(2)}$ inside a resonant optical cavity; an incident coherent pump wave (P) then generates signal (S) and idler (I) coherent output waves. These output wavelengths can be varied over a wide tuning range in various ways, some of them not readily applicable to tunable lasers. The three optical frequencies ω_i (j = P,S,I) obey energy conservation, $\omega_p = \omega_s + \omega_t$, while peak output depends on momentum conservation of corresponding wave vectors k_i (j = P,S,I). In birefringently phase-matched OPOs, the phase mismatch $\Delta k = k_p - k_s - k_I$ is minimised to optimise OPO conversion efficiency and thereby control the output signal and idler wavelengths; this is achieved by adjusting the angle and/or temperature of the birefringent nonlinearoptical crystal [41]. A more recently implemented alternative is to use quasi phase-matched (QPM) media, notably periodically poled (PP) materials such as PPLN (LiNbO₂) [42] or PPKTP (KTiOPO₄). Many of the nonlinear-optical design characteristics of OPO media are accessible through the readily available SNLO software, developed by Smith [43].

The output radiation from a simple free-running OPO (with no wavelength-selective elements) typically has a broad optical bandwidth (~5 cm⁻¹ or more). Such an OPO represents one extreme of operational simplicity, yielding broadband output radiation suitable for low-resolution or multiplex spectroscopy. Additional OPO wavelength-control measures are usually necessary for narrowband applications such as high-resolution spectroscopy. Intracavity wavelengthselective elements (e.g., filters, Ètalons, prisms, or gratings) provide the traditional way to attain narrowband OPO operation. This approach was used in early ns-pulsed LiNbO₃ OPO designs [36] that were continuously tunable in the near infrared (IR) with an optical bandwidth of \sim 0.1 cm⁻¹ (\sim 3 GHz). However, these were often difficult to operate and damageprone (with intracavity losses from gratings and Etalons causing the operating threshold to approach the damage threshold of materials such as LiNbO₃). More recent advanced ns-pulsed OPO cavity designs have yielded continuous narrowband tunability on a single-longitudinal-mode (SLM) basis, as is needed for high-resolution spectroscopy [16,30,37,39,40]. More specialised cavity designs are generally needed for cw and ultrafast tunable OPOs [39].

Our OPO-based research at Macquarie University has favoured an alternative approach to narrowband OPO wavelength control, namely, injection seeding by a low-power tunable coherent source [16,30,44-50]. In this approach, pulsed OPO construction is simplified by putting the wavelength-control function into a module that is effectively

separate from the optical generation and amplification functions. A favorable feature of injection seeding is that only one of the two OPO output wavelengths must be accessible to a source of tunable seed radiation.

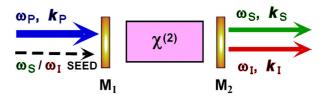


FIG. 5: Wavelength control of a narrowband pulsed OPO by injection seeding with narrowband cw radiation at ω_S or ω_I from a low-power external tunable laser. The pump, signal and idler waves are defined by frequencies and wave vectors (ω_P, k_P) , (ω_S, k_S) and (ω_I, k_I) , respectively.

The layout of a typical injection-seeded pulsed OPO (in this case, based on PPLN pumped by a Nd:YAG laser at 1.064 μm and seeded at a signal wavelength of ~1.55 μm [16,30,46,47]) is depicted schematically in Fig. 5. Continuously tunable SLM operation is achieved by an "intensity dip" method [46], in which the OPO ring cavity is locked by PZT to resonance with cw seed light by monitoring that seed light reflected off the active OPO cavity between successive pump pulses. Use of a SLM pump laser yields pulsed SLM signal and idler outputs. It is also possible for an active OPO cavity pumped by a multimode (broadband) pulsed laser to yield narrowband output at the resonated seed wavelength (e.g., signal) with the pump's multimode quality transferred to the other output wave (e.g., idler) [47]. A similar approach has been adopted in our ongoing collaboration with Dr Ken Baldwin et al. at ANU [48,49], using PPKTP pumped at 532 nm by a long-pulse SLM Nd:YAG laser and seeded at a signal wavelength of ~800-900 nm. We have used an acousto-optic modulator (AOM) at ~700 MHz to generate cw AOM-shifted seed light that can form optical-heterodyne beats against each OPO output pulse; with this OH technique we are able to monitor instantaneous-frequency and opticalbandwidth characteristics of each OPO signal pulse in real time, thereby optimising SLM operation and spectroscopic performance [48].

Another innovative form of injection-seeded pulsed OPO is depicted in Fig. 7 [50]. It incorporates a photorefractive crystal (e.g., Rh-doped BaTiO₃) in which cw injection-seeding radiation at ~840 nm writes a wavelength-selective phaseconjugate Bragg grating. When the PPKTP crystal in the resulting OPO cavity is pumped at 532 nm by a SLM Nd:YAG laser, it generates SLM output light with no need for active control of cavity length. This new approach effectively the pathlength-dependent eigenfrequencies of the optical cavity and constrains the cavity to be resonant at the seed wavelength. To do this, we replace a regular cavity reflector by a photorefractive element that operates as a phase-conjugate reflector, with its wavelengthselectivity controlled self-adaptively by the same light that is used to injection-seed the OPO process. This results in adjustment-free operational simplicity and continuous SLM tunability.

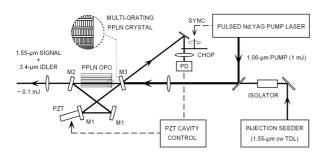


FIG. 6: Modular layout of a narrowband, tunable pulsed OPO system, pumped at 1.064 μm by a SLM Nd:YAG laser. The actively controlled PPLN OPO ring cavity is injection-seeded at its signal wavelength of ~1.55 μm by a cw tunable diode laser. The output of the multiple-grating PPLN crystal (see inset) can be coarsely tuned by vertical positioning and/or temperature variation [16,30,46,47].

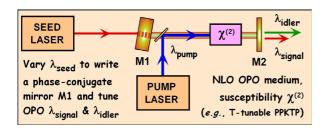


FIG. 7: Narrowband, nanosecond-pulsed OPO tuned by injection seeding with a self-adaptive phase-conjugate cavity mirror (M1) comprising a photorefractive crystal [50].

ATOMIC AND MOLECULAR SPECTROSCOPY

Spectroscopic measurements of processes in gas-phase atoms and molecules have been a major driving force behind development of optical cavity-based techniques such as those outlined above. It suffices here to mention two such areas of application on which we focus at Macquarie University.

Time-resolved infrared-ultraviolet double resonance (IR-UV DR) spectroscopy, detected by laser-induced fluorescence (LIF), has long been pivotal in our investigations of the structure, energetics and collision-induced energy transfer in small polyatomic molecules [51-57]. Our early work of this type concentrated on perturbed rovibrational states of deuterated formaldehyde (D₂CO and HDCO), excited by a pulsed CO₂ laser and probed by a pulsed dye laser [51]. Subsequently, our interest shifted to acetylene (C₂H₂) and its isotopic modifications [52-54], including Raman-UV double-resonance experiments [52] and studies of the C₂H₂-Ar van der Waals complex [54].

Figure 8 depicts the IR-UV DR excitation scheme used in our recent extensive investigations of C_2H_2 , rovibrationally excited into its 11 600-cm⁻¹ v_{CC} + $3v_{CH}$ manifold [55,56] or its 12 700-cm⁻¹ $4v_{CH}$ manifold [57]. This scheme employs narrowband IR laser pulses (from a Raman-shifted, Nd:YAG-pumped tunable dye laser) to selectively excite rovibrational transitions $(V, J, K) \leftarrow (V'' = 0, J'', K'')$ within the electronic ground state \tilde{X} of C_2H_2 . This excitation is probed by UV laser pulses (from a frequency-doubled, excimer-pumped dye laser, suitably tuned and timed) to excite rovibronic transitions

 $(V',J',K') \leftarrow (V, J, K)$ in the $\tilde{A} - \tilde{X}$ absorption system,

detected by UV LIF from the \tilde{A} electronically excited manifold. The manifold of intermediate states (V, J, K) monitored by UV LIF may be *either* directly prepared by the IR PUMP pulse itself *or* subsequently populated by collision-induced rotational energy transfer and/or state-to-state vibrational energy transfer.

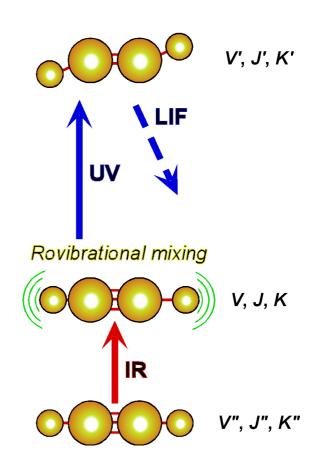


FIG. 8: Excitation scheme for time-resolved, LIF-detected IR-UV double resonance spectroscopy of collision-induced energy transfer within a high-energy rovibrational manifold (V, J, K) of acetylene molecules (C, H_2) [55-57].

It is a challenge to characterise collision-induced stateto-state energy transfer within a highly excited, congested rovibrational manifold, even for a small linear, centrosymmetric molecule such as C₂H₂ in the gas phase. We need to consider the effect of intramolecular perturbations that give rise to a variety of anharmonic, l-resonance and Coriolis couplings, complicating intramolecular dynamics and yielding unexpected forms of collision-induced rovibrational energy transfer [56,57]. We have implemented three complementary forms of IR-UV DR experiment (IR-scanned, UV-scanned, and kinetic) to investigate collision-induced rovibrational satellites, comprising both regular even- ΔJ features and unexpected odd- ΔJ features, and to reveal unusual collision-induced quasi-continuous background effects that accompany regular even- ΔJ rovibrational energy transfer and that account for much of the observed collisioninduced odd- ΔJ satellite structure. We now have a large body of IR-UV DR kinetic results that can be simulated by a phenomenological master-equation model.

Apart from fundamental spectroscopic studies of atomic and molecular processes, it is customary for us to measure spectra (e.g., CRD, photoacoustic absorption, coherent Raman and two-photon excitation) to verify the performance characteristics of optical instruments (e.g., tunable narrowband OPO/OPA systems [16,30,31,37,44-47]) that we have developed. In this context, we have recently demonstrated a new technique, CHAPS (Coherent Heterodyne-Assisted Pulsed Spectroscopy) [49], for highresolution spectroscopy. This approach employs OH detection [48] to monitor the instantaneous frequency of individual optical pulses, together with a frequency-binning method to generate high-precision spectra. We find that active tuning of the light source is not necessary if the inherent frequency jitter of the source spans the spectral region of interest, as has been confirmed by sub-Doppler two-photon excitation of the 8S-6S transition in atomic cesium vapour [49]. CHAPS can be applied in real time by using output from our longpulse, injection-seeded OPO/OPA system, which is confirm to be operating very close to the Fourier-transform limit.

CONCLUSION – RESONANCES EVERYWHERE!

The investigations reviewed above rely on a variety of resonant interactions, both in the atoms and molecules studied and in the optical instrumentation used to detect physical processes of interest. Another underlying form of resonance is less tangible: it concerns the extensive cooperation within and between research groups that has made such outcomes possible. Moreover, this sustains the AOS and conferences such as ACOLS. Such inter-personal resonances are not to be taken for granted, as they depend on a wide range of scientific interests, linkages and communications, a willingness to share ideas and concepts that motivate or inspire us, as well as harmonious group interactions. For those who recall the state of optics in pre-AOS Auustralia and compare it with the status quo, the AOS's role as a resonant mechanism should be evident - yet another tribute to Beattie Steel's vision.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge valuable contributions of research students and colleagues (many of whom are named in refs [16], [30], [32], [34], [44], [45], [48], [54] and [57]) who deserve to share the credit for the 2005 AOS Beattie Steel Medal. Particular mention should be made of my ultradependable research partner, Dr Yabai He, whose special ways with optics, lasers and spectroscopy were rewarded recently when he received the 2004 AOS Technical Optics Award; Yabai is a stimulating colleague and makes all sorts of challenging ideas and experiments happen! Macquarie University's Centre for Lasers and Applications has served as a highly favorable environment for our research. I am grateful to other colleagues who have provided encouragement and/or background information that assisted me in preparing this article: Ken Baldwin, Peter Browne, Judith Dawes, Murray Hamilton, Parameswaran Hariharan, Ross McPhedran, Jim Piper and Barry Sanders. My recent research has been funded by the Australian Research Council and Macquarie University.

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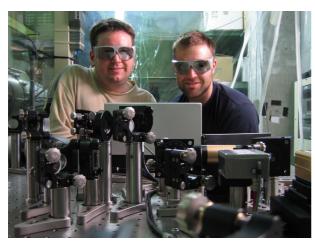
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New laser makes waves in Japan

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Laser developers Damien Mudge (left) and David Hosken Photo courtesy of Jesper Munch

The University of Adelaide's Discipline of Physics is making its mark on the world stage by designing, building and exporting a high-tech laser to Japan. After several years of development, students and staff have this month installed a super-stable laser on the Japanese TAMA-300 Gravitational Wave Interferometer, located at the National Astronomical Observatory on the western outskirts of Tokyo. The laser is a 10 watt, single frequency, single mode, ultra-stable laser developed at the University of Adelaide, with a purely South Australian heritage linking it back to a pulsed laser range finder originally developed by

the DSTO. "The collaboration with Japan was developed through workshops with the Australian Consortium for Interferometric Gravitational Astronomy, of which the University is a founding member along with Australian National University and the University of Western Australia," said Professor Jesper Munch, Professor of Physics in the School of Chemistry and Physics. "Our laser was chosen because of its superior performance and design, and will replace a laser manufactured by a large Japanese company." Professor Munch said the scientific collaboration is expected to continue once the laser is incorporated into the interferometer. "At that time the laser will have to work continuously, 24 hours per day, seven days a week, often completely unattended. "It is required to emit 10 watts continuously, and be locked to the interferometer to result in an ultra-stable laser beam with extremely tight specifications for amplitude and frequency noise. "Our laser is one of a very few in the world that can comfortably meet these requirements." The development and fabrication was carried out in the Physics Department, primarily by PhD student, David Hosken, and post-doctoral research fellow, Dr Damien Mudge. They received expert technical assistance from technical officers, Blair Middlemiss, Trevor Waterhouse, Neville Wild and Bob Nation, and guidance from Dr Peter Veitch and Professor Munch. "The complex hardware and electronic control system were all designed and built in the Physics Department, which for the past 15 years has established itself as a leader in laser and photonics research, including worldwide recognition as a leader in stable lasers for remote sensing," Professor Munch said.



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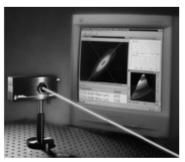
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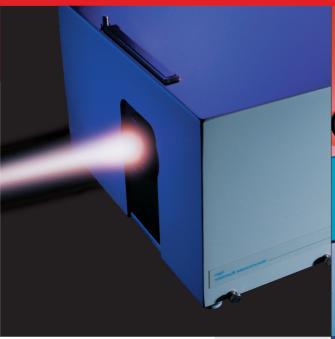




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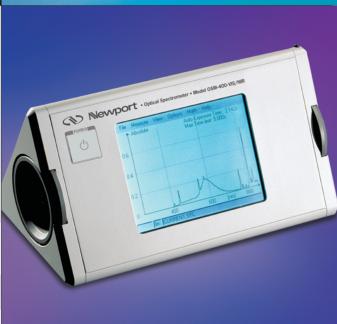
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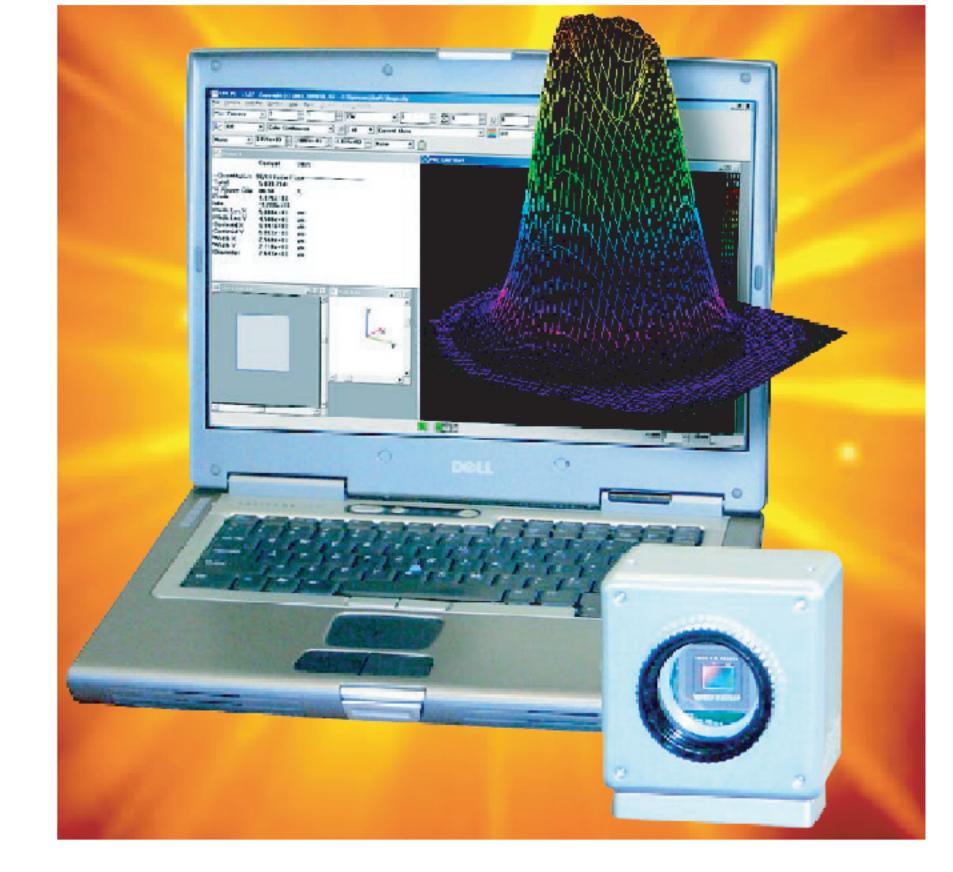
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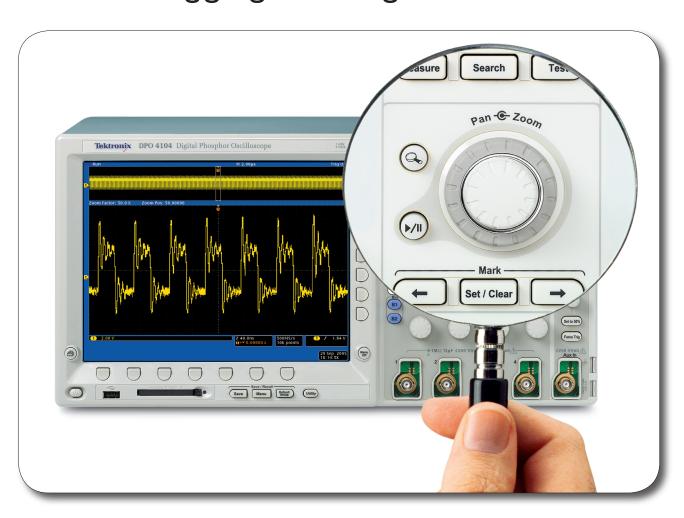


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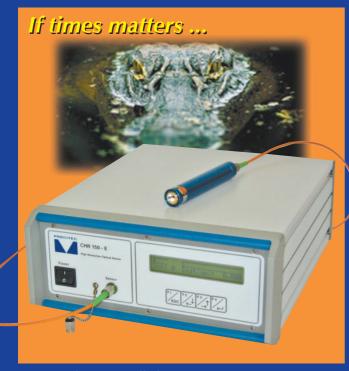
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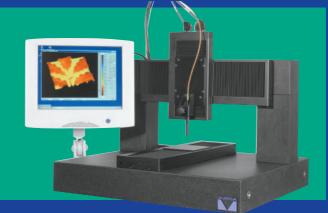
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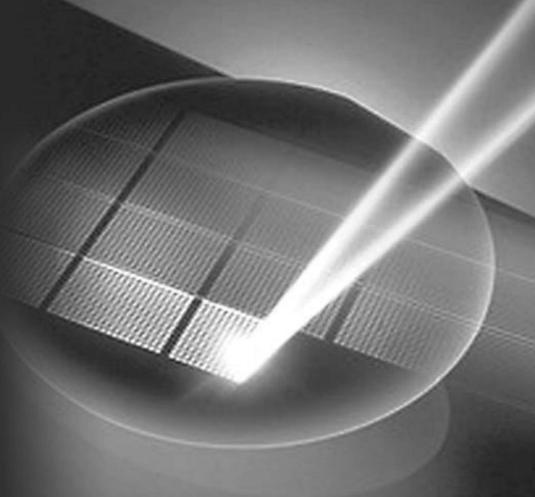
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Bose-Einstein condensation of metastable He achieved at ANU

R. G. Dall, K. G. H. Baldwin and A. G. Truscott ACQAO, Research School of Physical Sciences and Engineering, agt116@rsphysse.anu.edu.au

In December 2005, we achieved a Bose-Einstein condensate of metastable helium atoms (He* in the 2³S₁ state at ~20eV) for the first time. This is the fourth BEC using excited state atoms after Paris and Orsay in France (2001), and Amsterdam in the Netherlands (January, 2005).

We load around ~5 x 10^8 He* atoms into a high vacuum magneto-optic trap (MOT) from a low velocity intense atomic beam (LVIS). We first spatially compress the MOT, and further cool to around 200 μ K with a 3-D Doppler molasses. The magnetic trap is then energised with a bias field of 20 Gauss yielding very weak trapping frequencies, typically $f_r = 84$ Hz and $f_a = 75$ Hz, which minimises heating of the atomic cloud. At transfer we have around 3 x 10^8 atoms at a temperature of 600 μ K. Immediately after transfer we apply a 1-D Doppler cooling beam along the bias field of the magnetic trap, cooling the atoms down to ~150 μ K. The bias field of the trap is then reduced, increasing confinement and raising the temperature. A second Doppler cooling stage again achieves a temperature of ~150 μ K. We then evaporatively cool the atoms in six seconds, reaching the transition temperature of ~1 μ K with around one million atoms.

We plan to exploit the ability to detect single He* atoms (due to their high ~20eV internal energy) to undertake experiments studying the quantum statistical properties of the He* BEC, in analogy with similar experiments in quantum optics. In particular we aim to answer one of the questions established as one of the key goals of the Centre: how does a BEC develop phase?

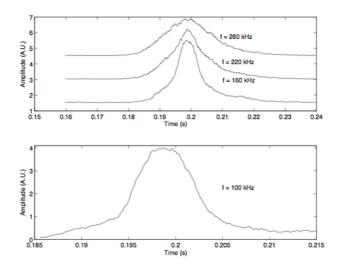


Figure 1: Time of flight traces taken from an electron multiplier located directly under our magnetic trap, for runs of the experiment with different final evaporation frequencies. As the cloud is cooled, a bimodal distribution is seen indicating the presence of a BEC.

Nonlinear photonic crystals in Chalcogenide: towards the all-optical logic chip

C. Grillet¹, D. Freeman², C. Smith¹, B. Luther-Davies², S. Madden², E. C. Magi¹, R. McPhedran¹, D. J. Moss¹, M. J. Steel,* M. Byrne³, A. Asatryan³, L. Botten³ and B.J. Eggleton¹

abstract

All optical switching devices based on nonlinear effects, where light switches light, are enjoying renewed interest. The dream of ultra compact all-optical devices operating at very low power and integrated on a chip is entering the realm of reality thanks to the advent of photonic crystal. In this paper, we show that marrying photonic crystal and a new class of highly nonlinear material, Chalcogenide glasses, is a very promising way to achieve an all-optical chip. We describe the fabrication and the characterization techniques we have developed for manufacturing and investigating two-dimensional Chalcogenide photonic crystal devices and present the first promising experimental results that should open the way to all-optical logic chip.

Context and motivation

If we think back the last 60 years, there were two really revolutionary technologies that came to fruition and changed our daily lives. The first was electronic chips where the related technology was following Moore's law, i.e. doubling of the performance every 18 months by reduction of the elementary electronic component (electronic transistor) size. The second technology was photonics where you could transfer huge amounts of information over optical fibers using laser source with very little energy. But those two technologies existed in two different worlds. Schematically, the first was used to process the information, the second to carry the information. The problem is that the transmission of information between electronic components within the chip or between chips is not carried out using light pipe but via metallic wires (interconnection). The increasing density of metallic interconnections implies more heat, more crosstalk, simply more degradation of the performance; and the faster (the higher frequency or the higher bandwidth) you want your electronic system to operate, the more manifest those limitations appear. The next revolution is when we are going to bring the light right into the microprocessor not only as a communication pipe but also to use the signal processing capability of light to increase the capacity of communications networks and computing facilities.

Why use optics and nonlinear optics?

The goal for today's computing and communications networks is to deliver more data faster, so the ability to process information at the speed of light—the fastest possible speed known today at 300 million meters per second—clearly has its advantages. Optical data streams can intersect without mutual interference (no cross-talk). Optical interconnects offer low-loss transmission and contrary to electronics, the density of optical interconnection is not affected by the bandwidth of the data carried by each connection. Another key advantage of optics is that optical data processing can perform several operations simultaneously (in parallel) in a more natural way than electronics. This is due to the fact that when more processors are used in electronics, there is more time lost in communications between the processors limiting the computational speed. Another option not available in electronic systems is that free space light beams may also be used for interconnections, opening the possibility of exploiting the third direction to create a dense three dimensional network of interconnections. For all these reasons, it is now time to

bring optical technologies, initially developed for the telecom, closer to and around the microprocessor. At issue is the replacement of electrons by photons, of electronic transistors by photonic switches in which switching involves the interaction of beams of light through nonlinear material. A class of nonlinear phenomena is associated with coupling light into and out of cavities that contain 'Kerr' nonlinear material in which the refractive index is intensity-dependant.

$$n_{eff} = n_0 + n_2 I \qquad (1)$$

where n_0 is the linear refractive index, n_2 is the nonlinear Kerr coefficient and I is the electric field intensity in the cavity. It is easy to see that such a device, whose behavior depends on the intensity of a control signal, or even the information signal itself, may serve as an all-optical logic gate or a 'photonic transistor' (Fig. 1). As the resonant frequency of the cavity is determined by the refractive index of the material within the cavity, the optical energy magnified inside the cavity, when tuned near resonance, can alter the refractive index enough to shift the resonant frequency. Because the cavity is now more nearly resonant, even more power is built up in the cavity, which accelerates the shift of the resonance. This feedback phenomenon leads to bistable behavior of the transmitted power with respect to the incident power that can be exploited for logic operations.



Figure 1. Schematic description of an all-optical switch, 'photonic transistor'[1] (A) In the off-state, the input signal, does not penetrate the gate; (B) in the on-state, a control signal opens the gate by means of nonlinear interaction and allows the input signal to be transmitted. Note that the control signal can be the input signal itself.

All-optical switches based on optical bistability were predicted in the early 1980s [2]. The experimental demonstrations involved optical materials with relatively weak nonlinearities and important linear and nonlinear absorption losses, so optical powers needed to obtain switching were prohibitively large making those switches no more than laboratory curiosities. Up till now the main technical difficulty for implementation into a viable device

remains 'the creation of large high-density arrays of fast optical gates that operate at sufficiently low switching energies and dissipate manageable power'.

A new era for all-optical logic?

The aim of our work is central to this ambitious goal. We aim to develop a novel compact all-optical photonic crystal switch based in a two dimensional photonic crystal made of a highly nonlinear material, chalcogenide glass.

The key to all-optical processing is the ability to enhance nonlinear effects. Two approaches have been followed: one thrust is towards the development of new materials with higher nonlinear refractive index. The second thrust is based on developing optical configurations in which nonlinear effects in a weakly nonlinear material are enhanced by reducing the mode size and increasing the intensity of the light wave. 2D photonic crystal membranes are expected to play a key role in this context.

Photonic crystals were proposed in 1987 [3, 4]. The concept of photonic-band gap structures, i.e., photonic crystal (PhC), was introduced as a formalism to describe the localization of light and the inhibition of spontaneous radiation in these structured materials. A PhC is a class of artificially created material in which the index of refraction varies periodically; in this respect, PCs can be considered the photonic analogues of semiconductors. When carefully designed, a complete photonic band gap appears—a frequency range where the light is precluded from propagating. This concept led to an entirely new branch of photonics that is producing a wealth of science and applications: the fabrication of PhCs, PhCs for integrated optics, and PhCs for fundamental physics (the Purcell effect; quantum optics, single photon sources), novel phenomena (negative refraction, superprisms, and nonlinear optics). A promising class of PhC is the so-called 2D PhC slab. It consists of a 2D PhC structure (providing lateral confinement), for instance air holes etched through a slab waveguide made of a high index material (vertical confinement) (Fig. 2).

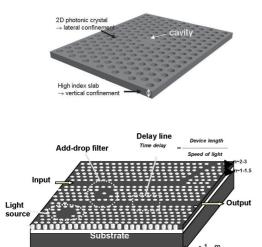


Figure 2. (a) A 2D photonic crystal cavity defect [5]. (b) An example of a 2D photonic crystal slab circuitry

It has been shown that ultra small and high quality factor Q (the ability to trap the light) can be created by introducing a carefully designed defect in the PhC lattice (Fig. 2) [5]. Following those advances, there have been predictions of the possibility of light switching light using nonlinear compact PhC microcavities (microns in size!) operating at power levels of only a few mW [6, 7]. Most experimental works that followed these predictions have been on PhCs made from

conventional optical materials; a highlight of 2005 was the experimental demonstration in silicon PhCs of all-optical switching with < 10 fJ pulse energies, and response times of < 100 ps [8]. On the other hand, little has been done on the study of highly nonlinear material in PhC geometry. If we could develop all-optical logic gates presented by the combination of PhCs and a highly nonlinear material, it could open the prospect of integrated photonic devices with design flexibility for fundamentally new optical processing functionalities, including an all-optical switch array, in a considerably smaller package than that allowed by any other approach. There exists a class of material, chalcogenide glasses, which have generated great excitement recently because of their attractive properties. Chalcogenide glasses are infrared transmitting materials containing the chalcogen elements S, Se or Te, compounded with network forming elements such as As, Si and Ge. Glasses can be formed over a wide range of compositions. The refractive index of chalcogenide is high, typically between 2.4 and 3.0 allowing 2D PhC slab to be created. Absorption losses are low over a wide wavelength range (near- to mid-infrared). Chalcogenide glasses possess a relatively large third-order optical nonlinearity (100-1000 times that of silica), and low twophoton absorption. Figures of merit (FOM = $n_x/\beta\lambda$, in which β is the two-photon absorption coefficient) higher than 12 have been achieved in As₂S₃ in the telecommunication wavelength. In addition to reducing the switching power requirements, the pure Kerr-like nonlinearities offer the potential for near instantaneous response times (<100 fs) and are only limited by the resonator Q-factor. This compares favorably to carrier-based nonlinear effects, as exploited in silicon [1,8] or III-V-based devices [9], which rely on dissipation to occur after switching, limiting the response time to tens of picoseconds.

Combining chalcogenide glasses and 2D PC ability to confine light at the wavelength scale and to enhance light nonlinear material interaction are expected to be essential ingredients for all-optical ultra-fast switching at low powers. Two types of 2-D PhC membranes displaying high-Q resonances either by direct coupling to Bragg resonances of PhC membrane ("Fano" resonances) or to resonances associated with defects in the membrane structure are investigated. Typically the first approach could be applied for chip to chip interconnections logic gates using free space beams whereas the second approach could be used as a logic gate within an integrated photonic chip (intra chip logic gate). In section 2, we will describe the fabrication methods of 2D PhC devices in chalcogenide using FIB. Section 3 investigates microcavities (0D or 1D defect) in a 2D PC membrane, probed via an evanescent coupling technique. Bulk photonic-crystal films, using fano probe techniques, are investigated in section 4 to possibly produce bistability. We conclude in section 5.

Fabrication of planar photonic crystals in a chalcogenide glass using a focused ion beam

To date, most 2D PhC structures in other materials have been fabricated using electron-beam or photolithography combined with dry etching. Whilst these processes are well developed for silicon, this is not the case for most other high index optical materials. FIB milling provides a simple single-step approach that allows rapid prototyping of PhC devices in new materials. Full details of the fabrication process are briefly reviewed here and will be published elsewhere, see [10] for an earlier approach. A chalcogenide film of thickness 300nm, composed of AMTIR-1 glass ($Ge_{33}As_{12}Se_{55}$ - refractive index ~2.7 @ 1.55 µm) was deposited by ultrafast pulsed laser deposition

on a 50nm thick silicon nitride ($\mathrm{Si_3N_4}$) membrane supported on a silicon substrate. The $\mathrm{Si_3N_4}$ membrane was fabricated by wet etching the backside of a nitrided Si wafer. The $\mathrm{Si_3N_4}$ initially 100nm thick was then accurately thinned to 50nm using Reactive Ion Etching. This resulted in a free-standing chalcogenide film on a thin (50nm) silicon nitride support film with an open aperture of approximately 130 μ m.

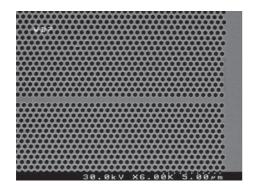


Figure 3. PhC waveguide imaged at 0∞

Subsequently a thin Au coating was applied to both sides and a Ga+ FIB was used to mill cylindrical holes into the film from the back side (through the nitride). Consequently the beam first had to penetrate the relatively robust nitride layer before milling the softer glass, which greatly reduced the sculpting of the upper glass surface by the low intensity beam pedestal and resulted in nearly vertical sidewalls. The triangular lattice consisted of 550nm spaced holes of radius ~200nm (0.36×period). High-resolution scanned electron micrographs of a typical structure are shown in Fig. 3, taken at normal incidence imaged from the glass side. Finally, the Au was wet etched and stripped for testing. The sidewall roughness can be very low in these structures, estimated to be <3 nm in our previous work [10]. The nearly cylindrical holes had sharp edges where they met the surface of the membrane. Figure 3 shows a PhC membrane waveguide consisting of a "W1" defect comprising a missing row of holes along the Γ -K direction.

Chalcogenide planar photonic crystal microcavities

The most natural scheme for engineering optical bistability exploits strong local field effects in microcavities suffering low losses (high Q cavities). It is well known those cavities can exhibit optical bistability at incident powers that scale as the inverse square of the cavity's quality factor 1/Q². It is also well known that the minimum peak δn/n needed to operate the device has to be greater than the inverse of the cavity's quality factor 1/Q. A common characteristic with glasses is that they possess an upper bound index change achievable on of few 10-4. It implies a fundamental requirement on the minimum's Q-factor. We have to work with a resonance Q-factor greater than 10,000 to observe a nonlinear switching of the response. Using PC microcavities offer the advantage to strongly localize the mode in a small volume while limiting radiation losses trough a careful design (Fig. 2).

Accessing PC waveguides (typically a W1 see Fig. 3) and high-Q PC cavities remains an issue. One approach to access this nonlinear cavity involves coupling this cavity to a 1D waveguide, PC waveguide or fiber (Fig. 4). The challenge is to couple sufficient light into the cavity to induce the bistable behavior. An optically impedance matched approach combined with accurate positioning to couple to the ultra-small mode volume of the PhC is required. To this end, we use a novel low-loss fiber taper to couple to the PhC waveguide via evanescent coupling (Fig. 4).

Figure 4 shows the principle of the coupling scheme along with the actual experimental setup. Evanescent coupling of silica nano-wires to PhC waveguides has been shown to be capable of very high coupling efficiencies. Since the nanowire mode field must extend evanescently for some length outside the silica core, typical nanowire diameters need to be submicron. The fiber tapers are manufactured using a procedure developed previously and applied to both standard SMF and microstructured optical fibre (MOF). Taper waist lengths are typically a few mm, with outside diameters down to 800nm being achieved. The fiber taper is aligned above and parallel to the PhC waveguide using an automated nanopositioning facility. Both vertical and lateral positioning is imaged with two microscopes onto CCD cameras. Light is launched into the Single Mode Fiber using a source consisting of four edgeemitting laser diodes covering the 1250-1700 nm bandwidth. In the taper region, light is adiabatically converted into the fundamental air-guided mode, allowing its evanescent tail to interact with the PCWG. The output end of the fiber is

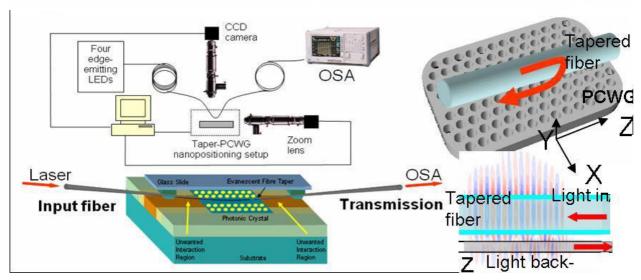


Figure 4. Schematic of the coupling scheme between the tapered fiber and the PC waveguide along with the actual experimental setup

connected to an optical spectrum analyser where the transmission spectrum through the nanotaper is measured. Since typical taper waist lengths are at least a few mm (limited on the short side by the requirement of having adiabatic transition regions) whereas PhC membrane lengths are at most a few hundred microns, there is the possibility of evanescent coupling to the surrounding substrate region. For this reason we introduced a curvature in the taper waist, limiting the interaction region to the PhC itself.

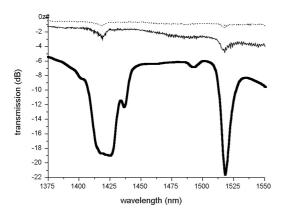


Figure 5. Transmission spectra of tapered nanowire, in closed proximity to chalcogenide glass photonic crystal waveguide, showing resonant coupling. Dotted line is for large (>1.5 µm) fibre-waveguide separation. Thin black curve is for a 1 µm separation. Thick Black curve is for direct contact. Transmission spectra have been normalized to the transmission through the taper in absence of the PCWG.

Efficient coupling occurs when a mode in the PCWG is phasematched with a fiber taper mode. The momentum matching between modes of dissimilar waveguides is made possible by the inherent strong dispersion of PhCs. As shown in Fig. 4 we have used this technique to demonstrate for the first time a high efficiency coupling (near unity coupling) from the taper to a chalcogenide PCGW [11]. Figure 5 shows the transmission spectrum through the nanowire, with the PC waveguide placed at different separations from the PC waveguide, from >1.5°m (dotted curve) to direct contact (thick black curve). By subtracting the overall off resonance losses (estimated at around 6 dB), we can estimate that the strong narrow resonance near 1520nm is > 18 dB in depth, and reflects the resonant coupling to the fundamental guided mode of the PCWG. The ability to couple the light into a chalcogenide PC structure represents a significant step in the drive towards Kerr nonlinearity based all-optical switching in PhC nanocavities.

Bulk PhC membranes for nonlinear application: using Fano resonances.

The second architecture we employ as a potential candidate for nonlinear switching is a bulk Chalcogenide PC, i.e a 2D PC without any defects. As mentioned in section 1 this approach could be applied for chip to chip interconnections logic gates using free space beams exploiting the Fano resonances of a 2D PC. Fano resonances are a universal phenomenon arising from coupling between a discrete state and a continuum of states. In our case, it corresponds to a coupling from a free space beam (normal incidence) to photonic states of the 2D PC. When the incident beam excites

a guided resonance of the slab (when they are phase-matched), the leaking waves interfere with the transmitted and reflected beams. This can form very sharp asymmetric spectral features swinging from nearly total reflection to total transmission (Fig. 6) that can be exploited to demonstrate optical bistability. The calculations for Fig. 6 have been computed using a new semi-analytic theory developed at the UTS node of CUDOS. This technique characterises the PhC slab as a generalisation of a Fabry-Perot interferometer, with the propagation and interface reflection properties expressed in terms of the Bloch modes of the bulk crystal.

We have experimentally observed these "Fano" resonances in a chalcogenide glass PhC membrane [12]. In that particular case the structure under test consisted of a free-standing membrane of chalcogenide glass perforated with a triangular lattice of air holes. The transmission spectrum at normal incidence for a beam linearly polarised along the i-M direction is shown in Fig. 7 (logarithmic scale), where we observe strong resonances with transmission suppressed by as much as 42 dB. We are currently working towards engineering very sharp resonances which, combined with the large intrinsic nonlinearity of the Chalcogenide glasses, should allow the demonstration of optical bistability in a PhC mirror.

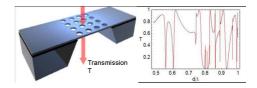


Figure 6. Transmission spectrum for a single layer, photonic crystal slab computed using the multipole Bloch mode method. The slab has a normalised thickness h/d = 0.375 with a square array of holes of normalised radius a/d = 0.3 formed in chalcogenide glass.

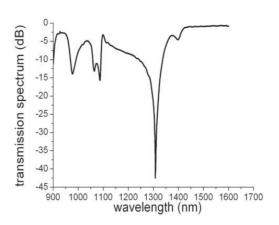


Figure 7. Experimental optical transmission spectrum for a triangular PC Chalcogenide slab on a logarithmic scale Conclusion

We have highlighted Chalcogenide glasses as a particularly promising material for all optical switching. We have demonstrated the use of a focused ion beam to create PhCs devices in chalcogenide glass membranes. This process is capable of rapid prototyping of an almost unlimited range of complex patterns under computer control, allowing rapid optimisation of the structure to obtain particular optical functionality.

2D resonators with high quality factor Q are a first step towards performing optical and logical functions with a very small input power. We have described the two scenarios we are exploring to obtain a bistable response.

We have described our innovative optical platform that uses fibre taper to couple light to and from the PhC and we report the first demonstration of efficient coupling to PhCs made from highly nonlinear glass using this technique that should represent a significant step in the drive towards Kerr nonlinearity based all-optical switching in PhC nanocavities. "Fano" resonances in the optical transmission spectra of a 2D planar chalcogenide

PhC membrane have been demonstrated. The combination of strong resonances with the large intrinsic nonlinearity of the chalcogenide glass opens the door to future all-optical switching applications.

But the ultimate vision of an all-optical logic chip is yet to occur. Advances in the development of novel components for optical interconnection, storage (slow light structure or optical buffer), coding at the chip level are still required. But the main difficulty will remain our ability to cascade several optical functions to make photonic integration a reality. Eventually, the miniaturisation enabled by 2-D PhC slab and our ability to produce those structures by planar microfabrication point towards the good direction. This opens the prospect of integrated photonic devices of flexible design for fundamentally new optical processing functionalities, including an all-optical switch array, in a considerably smaller package than is possible using any other approach.

Acknowledgment

This work was produced with the assistance of the Australian Research Council (ARC). CUDOS (the Centre for Ultrahighbandwidth Devices for Optical Systems) is an ARC Centre of Excellence. We thank Andrei Rode for depositing the film, Maryla Krolikowska for preparation of the membranes, and ANU Electon Microscope Unit for use of the FIB.

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AOS Conference Calendar

AOS conferences in 2006:

ACOFT/AOS 2006, RMIT, 10 – 13 July 2006 (3-days ACOFT + 1.5 day AOS with half day joint sessions.) AIP Congress, Brisbane, 3 – 8 December 2006

AOS conferences in 2007

ACOFT/COIN 2007, Melbourne, probably in July. (Not an AOS conference, but AOS AGM will likely be held there!)

AOS conferences in 2008
ICO Congress 2008 colocated with AOS conference, Sydney, July 2008
ACOFT/OECC 2008, Sydney, July 2008

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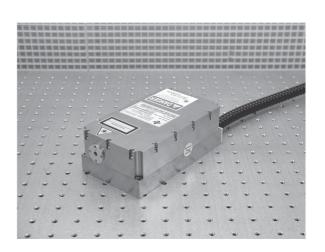


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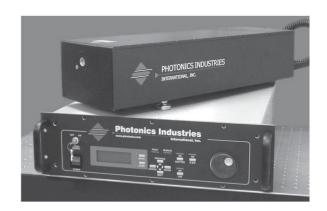


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ICO: bringing together the world of optics

The new ICO president outlines his plans.



Ari T Friberg, ICO president (term 2005-2008) and professor at the Royal Institute of Technology (KTH), Stockholm, Sweden,

take over the presidency of the International Commission for Optics (ICO) from René Dändliker. During his three-year tenure of leadership, and that of Art Guenther before him, ICO revised its structure and operations, putting it in a truly unique position to address global challenges. With their remarkable progress and growth, optics and photonics are now more exciting and promising than ever, and it is important that not only the technologically advanced but also the world's developing regions will be able to share in the profits. The ICO will live up to its motto: the place where the world of optics meets.

The introduction of International Society (IS) Members has put the ICO in direct contact with optical sciences and engineering organizations worldwide. Currently the ICO has six IS Members (OSA, SPIE, IEEE/LEOS, EOS, OWLS and LAM Network), but others could be envisioned, for example geographically covering Latin America. Optics has its roots deeply in physics, and since last year was the United Nations' World Year of Physics 2005 we all can be proud of the great contributions of optics to the development of physics.

The ICO is an Affiliated Commission of the International Union of Pure and Applied Physics (IUPAP). However, optics is progressing as its own branch of science. Indeed, in October 2005 the ICO became an International Scientific Associate of ICSU, the International Council for Science. While retaining its status in IUPAP, the election of the ICO directly in ICSU will greatly enhance the global significance and recognition of optics as a discipline, which will have a positive impact on optics education and industries. To make the best possible use of this new affiliation I invite the whole optics community to contribute with new initiatives.

These are all tremendous developments. However, the uniquely distinguishing strength of the ICO is its Territorial Members, giving ICO a highly valued communication channel to the optical communities and policy-makers throughout the globe. At the ICO-20 Congress in Changchun, China, in August 2005, Greece and Moldova were admitted as new ICO Members, while Ecuador became an Associate

It is with humility, but determination, that I Member. Hence, in total, the ICO currently has 47 Territorial Members and three Associate Members. The Territorial Committees are a precious asset so their working relations with the ICO Bureau must be kept fluent and efficient. With these broad territorial connections and worldwide organizational support, the ICO can assume a leading international role in the progress and promotion of optics on all fronts.

To fulfil its charter the ICO has a number of programmes and initiatives. These include a close collaboration with the ICTP in Trieste, for example the annual Winter Colleges on Optics, directed towards developing countries. In recent years the ICO has especially focused on Africa and Latin America. Additionally, the ICO has a Proceedings Donation Programme and it is actively involved in two conference series: Education and Training in Optics and Photonics (ETOP), which is the only series of global meetings dedicated solely to optics education, and Information Photonics (IP). Besides the Triennial Congresses, the ICO organizes annually Regional and Topical Meetings, and it maintains a Travelling Lecturer Programme, aimed at promoting optics in regions where particular support is needed. Traditionally, it has published every three years the so-called ICO book in the series "Trends in Optics" – I plan to attempt to do that again.

Moreover, the ICO awards several prizes (the ICO Prize, the ICO Galileo Galilei Award and the ICO/ICTP Award) to recognize outstanding achievements in optics. A convenient summary of the ICO's programmes and activities is in the triennial document The ICO Green Book, available on the ICO website.

Although the ICO statutes call for at least two members of the Bureau to be from industry, what is conspicuously missing from the current ICO activities is a direct involvement of the optics industries in advising the ICO and in funding joint actions. All suggestions for such new initiatives are most welcome.

In Changchun a new ICO Bureau was also elected by the General Assembly. Some members, having completed one or two three-year terms, left the Bureau. I sincerely thank these members for their dedicated service to the ICO and the global optics community. In particular,

ICO NEWSLETTER January 2006 I want to acknowledge past-president Art Guenther, who is likely to carry on with the ETOP series, and treasurer Glenn Sincerbox for their work and leadership. Equally, I acknowledge Asher Friesem for his Prize Committee work, Giancarlo Righini for chairing the Regional Development Committee, Lingli Wang for her industrial efforts, and Nestor Gaggioli for tirelessly working for South America. At the same time, it is my pleasure to welcome those who were elected, or appointed, as new members of the ICO Bureau for the period 2005-2008. We have an experienced and productive team to further the general ICO objectives. I'm most pleased to report that Pierre Chavel, the real father of many of the main changes within the ICO, has agreed to

continue his involvement in the new Bureau as senior adviser "ad personam". At this time I would like to recognize the efforts and support of all those who in recent years have contributed to the strengthening of the ICO and to the enhancement of its worldwide visibility.

The success of the ICO ultimately depends on its Members' interest in getting involved in the old and new initiatives. The ICO is an inclusive organization. Active participation of all Territorial and Society Members in the ICO programmes is encouraged and solicited, while scientific freedom and respect for cultural differences are emphasized.

For the next three years I look forward to your enthusiastic and unqualified support.

Ari T Friberg, ICO president, at your service

Valentin Vlad wins the ICO Galileo Galilei Award 2005



Valentin Vlad, a professor of physics at the University of Bucharest and chief of the Laboratory for Non-Linear Information Optics at the Institute of Atomic Physics, Bucharest.



The dynamics of soliton waveguides induced with a femtosecond pulsed laser beam (800 nm) with CW green background illumination in lithium niobate crystals.

Galilei Award 2005 for his work in nonlinear optics to enhance the presence of Romanian optics in the global scientific community.

Vlad graduated the Polytechnic Institute of Bucharest, Department of Electronics, in 1966 and obtained the scientific title of Doctor Eng. at the institute in 1972, with a thesis on information processing in holography.

From 1966 to 1975 he was a researcher at the Institute of Atomic Physics Bucharest (IAPB), where he achieved in 1968 the first solid-state laser in Romania (with G Nemes). In 1969-1970 he studied at the University of Paris (with Prof. M Françon) and at CGE-Marcoussis. In 1975 he became chief of the Holography Laboratory at the Department of Lasers, IAPB. In the period 1977-1989, he was a senior researcher at the Central Institute of Physics. During that time, he was also a visiting scientist at the Physical Institute "A F Ioffe" in St Petersburg (with Profs. Yu I Ostrovski and M P Petrov) and at the Technical University Darmstadt (with Prof. T Tschudi). Since 1990, he has been professor at the University of Bucharest, chief of the Nonlinear and Information Optics Laboratory in IAPB-NILPRP, Department of Lasers, and he is co-director of the Romanian Centre of Excellence in Photonics (ROCEP). He has been visiting professor at various centres and universities: Chiba University (Japan, with Prof. J Tsujiuchi) in 1991; Centro de Investigaciones en Óptica (Mexico, with Prof. D Malacara) in 1992; and Universita "La Sapienza" di Roma, Dept. Energetics, with Prof. M Bertolotti and Prof. E Fazio, in 2001 and 2005. He was also invited, as a visiting researcher, to the USAF Laboratory in Hanscom (US) in 1999.

Additionally, he has been active as an external collaborator at Imperial College London's Blackett Laboratory since 1991 (in a project elected a member of Academia Europaea.

Valentin Ionel Vlad has won the ICO Galileo with Prof. I C Dainty and Prof. M Damzen) and at the Max-Planck-Institute for Quantum-Optics in Garching (in a collaboration with Prof. H Walther) since 1994. In 1995, he became associate researcher at ICTP, Trieste (Italy), and in 2003 ICTP senior associate. In 2001–2004, he was a project co-coordinator, with Prof. E Fazio, in the frame of the Italian–Romanian Collaboration Agreement in R&D. He has published more than 150 scientific papers in Romania and abroad, has taken part in more than 200 scientific communications at conferences, and is the author or coauthor of five books and editor of four SPIE "ROMOPTO" proceedings. He holds four patents (one in the US).

Vlad was the president of the Physics Commission of the Romanian Consultative College for R&D in 1991-2002 and has been vice-president of the Grant Commission of the Romanian Academy since 1994. He is also the national representative of the EU Network of Excellence FP6-PHOREMOST-NoE IST-2-511616 (on nanophotonics) and in the EU-FP6 COST P8 Action of the European Union. He is the president of div. optics and quantum electronics of the Romanian Physical Society (also acting as the ICO Territorial Committee). In 1991–1993 he was vice-president of SPIE - Romanian Chapter. He is the editor-in-chief of the journals Romanian Reports in Physics and Proc. Romanian Academy A, and on the editorial board of Journal of Optics A (IOPP). Vlad has received several awards, including the T Vuia Award of the Romanian Academy in 1978. He was elected fellow of the Optical Society of America in 1978, and has been a member of the Romanian Academy (a lifetime position for 281 distinguished intellectuals) since 1991 and a fellow of the Institute of Physics and a chartered physicist, UK, since 1999. In 2005 he was

JANUARY 2006 ICO NEWSLETTER

ICO becomes an ICSU International Scientific Associate

come in October 2005 when ICO was made an International Scientific Associate of the International Council for Science at ICSU's triennial General Meeting. This is a step forward in the recognition of optics as an emerging discipline that, in addition to its roots in physics, develops more and more independence. The main reason for this achievement was Pierre Chavel, who was ICO secretary and is cur-

A long-term ICO action had a positive out- rently senior adviser at the ICO Bureau. ICO participation in ICSU, in addition to giving more visibility to our discipline, will create new opportunities to collaborate with ICSU and its members on the global challenges faced by science and technology for the future of mankind. More detailed information will be included in the next issue of this Newsletter, April 2006. For further information about ICSU see www.icsu.org/.

ETOP conference in Marseille proves a massive success





Norbert Hubin and Daniel Maystre.





Christian Cavailler and M J Soileau.





Alain Aspect and Bob Breault.

Photonics conference takes place every two years. ETOP has previously been held in San Diego (US), Leningrad (Russia), Pecs (Hungary), Delft (the Netherlands), Cancún (Mexico), Singapore, and Tucson (US) in 2003, but the ninth ETOP conference was held last October in Marseille (France). It brought together nearly 150 educators, teachers and researchers from 23 countries, who held discussions during three full days.

Optics and photonics are essential fields for the development of advanced technologies, complex systems and our understanding of the universe. The domain is not only useful for progress in health, telecommunications, transport and astrophysics. As was discussed throughout the ETOP conference, it is also useful for helping developing countries to have access to advanced technologies and to help them progress; it is also important to interest young people in science.

ETOP2005 was a wonderful time to share and exchange ideas. The world economy induces many changes. These changes are continuous and technologies are progressing rapidly. It seems that now we must teach young people to be efficient, and to have not only an entrepreneurial spirit, an open mind, transportable skills, critical thinking and interpersonal skills, but also computer and communication skills. This is a real challenge that educators and teachers concerned with sustainable development are having to face. Optics and photonics have an important place in this development. The International Commission for Optics (ICO), SPIE, the Optical Society of America (OSA), the European Optical Society (EOS), the French Optical Society (SFO) and other societies were very active supporters at the 2005 edition of the ETOP conference.

ETOP was held jointly with the Complex Optical Systems conference and the plenary sessions were shared: eight top-level plenary talks were given by leading experts. A series of four presentations concerned complex systems.

The Education and Training in Optics and Norbert Hubin talked on "The Adaptive Optics Status and Roadmap at EOS". Robin Barnsley showed the development of the ITER project (World Project Control Fusion for Plasma Confinement). Ed Moses talked about the National Ignition Facility (NIF), the world's most complex laser and optics system. Christian Cavailler presented "The Megajoule Laser: An Optical Complex System". Two talks on fundamental considerations were also given: Daniel Maystre lectured on "Metamaterials and Optical Resolution: the End of the Rayleigh Limit?" while Alain Aspect lectured on "From Einstein's Intuitions to Quantum Bits: Amazing Entanglement".

> Two of our well known colleagues also came to share their experience acquired through two extraordinary professional careers: M J Soileau explained "The Genesis of the College of Optics and Photonics at the University of Central Florida" and Bob Breault described "How the Formation of One Company Led to Many Global Optics Clusters".

> Three fruitful workshops were held each evening. The first one on "Attracting Young People in the Field of Optics and Photonics' was chaired by M J Soileau. Indeed, demonstrations of optical experiments are a particularly good way to attract young people thanks to the beauty of optics. These demonstrations must take place during college at the time when young people start thinking about their future. The second workshop was "BMD (Bachelor, Master and Doctorate) in Europe". Participants from Germany (Prof. Jens Bleidner, chair), Italy, France, Spain and Romania compared their systems of higher education. Despite the Bologna process homogenizing the European system of higher education, each country has its specifics. The third workshop and last session, "Requirements of Industry", was chaired by Gilbert Dahan, chairman of the European Society of Optic Systems (SESO), and originated quite fine discussions. For more information see www.etoponline.org.

François Flory, general chair, ETOP 2005

ICO NEWSLETTER JANUARY 2006

Award news from ICO's Singapore Territorial Committee



Presentation of the Humboldt Research Award by Prof. Dr Wolfgang Frühwald (left), president of the Alexander von Humboldt Foundation.

Colin Sheppard, National University of Sing- entific lecture on three-dimensional microapore, was presented with an Alexander von Humboldt Research Award (Forschung-spreis) in Physics at the 33rd Humboldt Foundation Symposium for Research Awardees, Ziegelbau, Bamberg, on 18 March 2005.

The Humboldt Research Award for internationally recognized scientists, the highest award of the Alexander von Humboldt Foundation, honours the academic achievements of the winner's lifetime. Furthermore, winners are invited to carry out research projects of their own choice in Germany in co-operation with colleagues for periods between six months and one year.

The award was the first presented to a researcher based in Singapore. At the symposium, Prof. Sheppard delivered the opening sci-

scopic imaging, in which he compared different optical microscopy techniques. The laudation for Prof. Dr Colin J R Sheppard was: "Professor Sheppard is an optical scientist whose work is internationally recognized for its unusual broadness and depth. He invented two-photon microscopy and published pioneering papers on high resolution confocal microscopy. Especially important in his work is the modelling of light propagation including the vectorial properties of the field and ultrashort pulses. During his stay in Germany Professor Sheppard is going to study polarisation effects in nanooptics."

Prof. Sheppard was ICO vice-president during the term 1999-2002 and has participated in the ICO Travelling Lecturer Programme.

Contacts

International Commission for Optics (http://www.icooptics.org).

Bureau members (2005-2008)

President A T Friberg Past-president R Dändliker Treasurer A Sawchuk Secretary M L Calvo, Departamento de Óptica, Universidad Complutense, 28040 Madrid, Spain. E-mail: mlcalvo@fis.ucm.es.

Associate secretary G von

Vice-presidents, elected

S N Bagayev, A M Guzmán, GF Jin, BY Kim, M Kujawinska, H Lefèvre, J Love, I Yamaguchi

Vice-presidents, appointed

M Gu, G Sincerbox, P Stahl, T Tschudi, A Wagué, A M Weiner

Senior adviser (ad personam) P Chavel

IUPAP Council representative Y Petroff

ICO meetings get April, October deadlines

To improve co-ordination and efficiency, the ICO Bureau has decided that ICO meetings and schools applications are from now on considered only twice a year. The deadlines for the applications are 15 April and 15 October of each year, and the applications must have been received by the ICO at least one year before the event.

The application forms for all categories of ICO meetings (i.e. for ICO congresses and other major events, and for ICO co-sponsored and endorsed meetings) are available for download from the ICO website at www.ico-optics. org/. The forms, which are in Microsoft Word

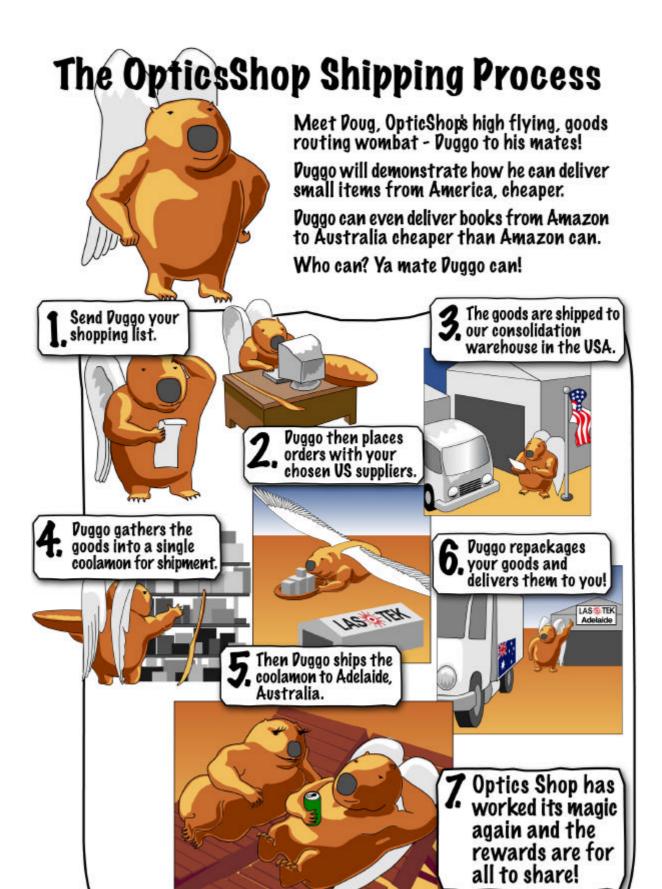
"Information and Guidelines" and "Questionnaire". After studying the Information and Guidelines, the Questionnaire should be filled in and the form returned electronically, as an email attachment, to the ICO associate secretary for processing.

The ICO Bureau takes all decisions about ICO participation in conferences and schools. Please send all ordinary and electronic mails to: Gert von Bally, ICO Associate Secretary (in charge of meetings), University of Münster, Medical Centre, Laboratory of Biophysics, Robert-Koch-Str. 45, D-48129 Münster, Germany. Tel. +49 251 835 6888; fax +49 251 "protected form" format, contain two parts - 835 8536; e-mail lbiophys@uni-muenster.de.

To find out information about forthcoming events with ICO participation, see the events page of the ICO website at www.ico-optics.org/ events.html



JANUARY 2006 ICO NEWSLETTER







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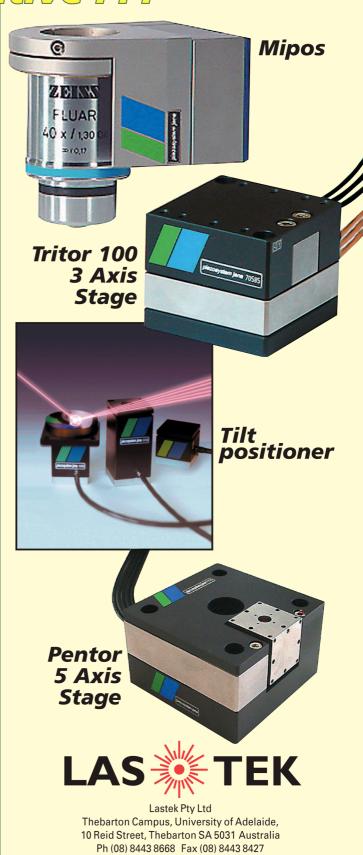
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THE AUSTRALIAN OPTICAL SOCIETY

Notice of Annual General Meeting

The Annual General Meeting of the Australian Optical Society will be held on Wednesday 12th July at 3:30pm* in the Storey Hall on the RMIT premises coinciding with the ACOFT and AOS conferences.

AGENDA for the 2006 AGM

- 1. Apologies
- 2. Agenda
- 3. Minutes of previous meeting
- 4. Business arising
- 5. President's report
- 6. Treasurer's report
- 7. Changes to AOS Constitution
- 8. Election of councillors and office bearers
- 9. Notification of meetings
- 10. Any other business

Members unable to attend this meeting are strongly urged to complete the proxy nomination form below and submit it to the President or Secretary before the meeting. This will ensure that your vote on important matters is counted. The proposed constitutional change will require a vote in favour by 75% of members for it to pass. It is essential therefore that proxy forms are received from those who are not attending.

Australian Optical Society Annual General Meeting 2006 Proxy Nomination Form

by July 1, 2006, OR send to the meeting with your proxy.

*Please note that the exact time of the AGM may vary slightly from the above time as the conference timetable is not completely finalised. Please check the AOS web site for any changes.



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