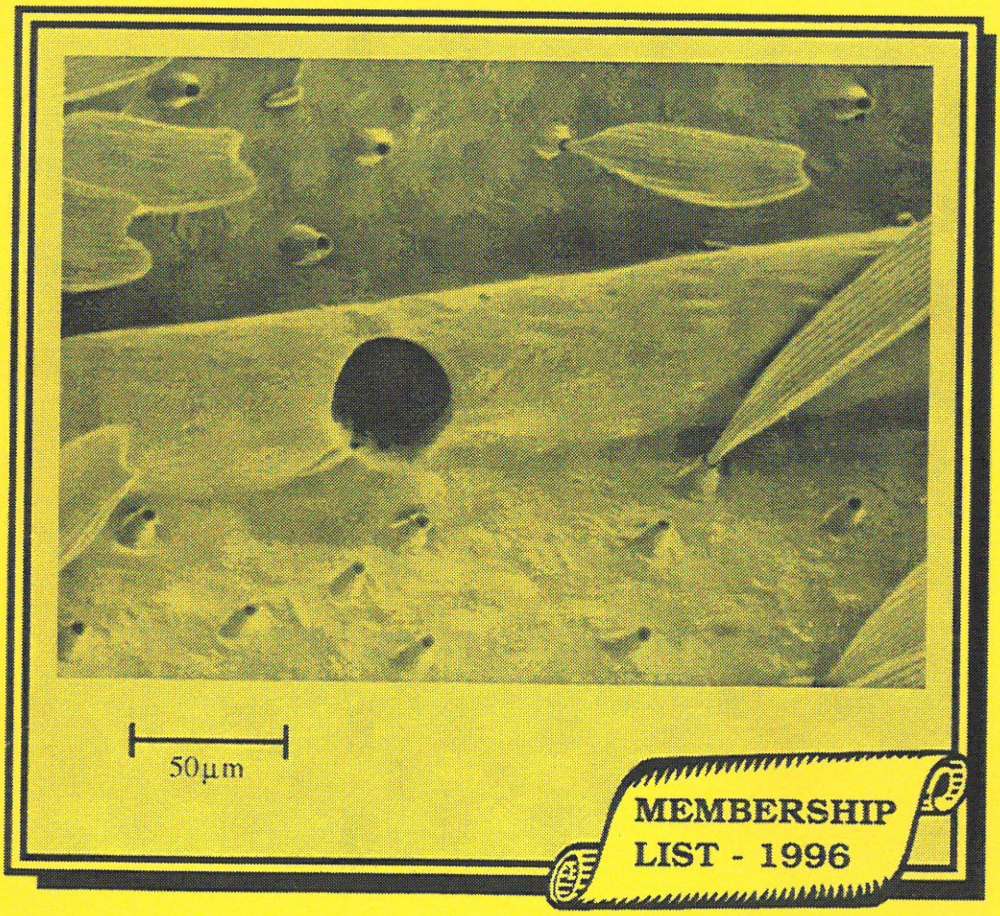
Australian Optical Society

# NEWS

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**COVER**:
A 40 μm hole in a moth wing made by high speed laser micro-machining (see article p21). The high absorption of organic materials in the UV region results in clean ablation by a predominantly photochemical process. The molecular bonds are broken and the material is ablated, as opposed to melted, resulting in a minimal heat effected zone.

**SUBMISSION OF COPY:**
Contributions on any topic of interest to the Australian optics community are solicited, and should be sent to the Editor or one of the Associate Editors. Use of electronic mail is encouraged, or else submission of hard copy together with an ASCII text file on floppy disk.

Accepted word processor formats include Microsoft Word (for Windows and Mac), WordPerfect and Latex. Where possible, diagrams should be contained within the document or sent as separate encapsulated postscript files. Figures on A4 paper will also be accepted.



**EDITOR**
Duncan Butler
CSIRO Applied Physics
PO Box 218
Lindfield NSW 2070
Tel: (02) 9413 7302
Fax: (02) 9413 7200
Email :
duncanb@swifty.dap.csiro.au

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**DECEMBER 1996** **VOLUME 10 NUMBER 4**

# AOS NEWS

## ARTICLES



## DEPARTMENTS

*A.O.S. News* **is the official news magazine of the Australian Optical Society. The views expressed in A.O.S. News do not necessarily represent the policies of the Australian Optical Society.**



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**AOS COUNCIL (1996/7)**

**PRESIDENT**- *Brian Orr*
School of Chemistry
Macquarie University
Sydney NSW 2109
Tel: (02) 9850 8289
Fax: (02) 9850 8313
Email : brian.orr@mq.edu.auCSIRO

**VICE-PRESIDENT** - *Halina Rubinsztein-Dunlop*
Department of Physics
University of Queensland, QLD 4069
Fax: (07) 365 1242
Email : halina@kelvin.physics.uq.oz.au

**SECRETARY** - *Clyde Mitchell*
CSIRO Division of Materials Science and Technology
Private Bag 33,
Clayton South MDC, Vic. 3169
Tel: (03) 9542 2942
Fax: (03) 9544 1128
Email: mitchell@mst.csiro.au

**TREASURER** - *Esa Jaatinen*
CSIRO Division of Applied Physics
PO Box 218, Lindfield NSW 2070
Tel: (61 2) 9413 7269
Fax: (61 2) 9413 7200
Email : esaj@dap.csiro.au

**PAST PRESIDENT** - *Chris Walsh*
Division of Applied Physics
PO Box 218, Lindfield NSW 2070
Tel: (02) 9413 7156
Fax: (02) 9413 7200
Email : cjw@dap.csiro.au

**COUNCILLORS**

*Jesper Munch*
Dept Physics and Maths
University of Adelaide
GPO Box 498
Adelaide SA 5001
Tel: (08) 303 4749
Fax: (08) 232 6541

*Ken Baldwin*
Laser Physics Centre
Research School of Physical Sciences and Engineering,
Australian National University
Canberra ACT 0200
Tel: (06) 249 4702
Fax: (06) 249 0029
Email: kgb111@rsphy1.anu.edu.au

*Kieran Larkin*
Department of Physical Optics
School of Physics
University of Sydney
NSW 2006
Tel: (02) 9351 3941
Fax: (02) 9351 0923
Email: larkin@physics.usyd.edu.au

*Chris Chantler*
School of Physics
University of Melbourne
Parkville VIC 3052
Tel: (03) 9344 5437
Fax: (03) 9347 4783
Email:
chantler@physics.unimelb.edu.au

*Ann Roberts*
School of Physics
University of Melbourne
Parkville VIC 3052
Tel: (03) 9344 5038
Fax: (03) 9347 4783
Email: annr@muon.ph.unimelb.edu.au

*Peter Farrell*
Optical Technology ResearchLaboratory
Department of Applied Physics
Victoria University
PO Box 14428, MCMC Melbourne
Tel: (03) 9688 4282
Fax: (03) 9688 4698
Email: peterf@dingo.vut.edu.au

*Lew Whitbourn*
CSIRO DMST Optical Systems Engineering
Private Bag 33, Rosebank MDC,
Clayton VIC 3169
Tel: (03) 9542 2948
Fax: (03) 9544 1128
Email: lbw@dap.csiro.au

## CORPORATE MEMBERS

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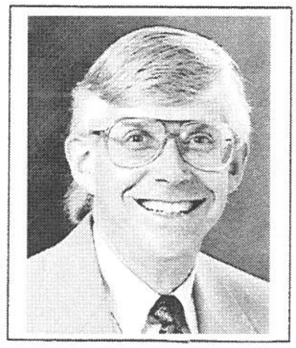
Optical Society of America
SPIE - The International Society for Optical Engineering

# President's Report

*by Brian Orr*

There is something special about optics. That is clear, for instance, from the Society's 1994 report on "Optics: Highlight of the Future," which established the credentials of optics as an enabling science and a technological growth area, supported by a strong local research base and economic potential for Australia. But it is special in another sense that applies on a much wider front than just that of AOS members.



What I mean is that just about everybody has a sense of the way that optics works. In contrast to most branches of modern science and technology, it can be said that the average person "understands" optics. Their understanding may be quite elementary by the standards of our profession, but the elements of light propagation, optical components (e.g., spectacle lenses, solar collectors), natural optical phenomena (e.g., rainbows, sunsets), vision and imaging (e.g., photography, colour), and advanced optical technology (e.g., laser-based barcode scanners, optical fibre communications) are a part of everyday experience.

Is it a coincidence that we acknowledge that we understand something by saying: "I see"?

I was impressed by this "public domain" attribute of optics recently when I was asked to help a young girl in our neighbourhood to think up a primary school science project that would demonstrate some of the properties of light. It was obvious from the outset that optics was a subject that she and her parents could discuss at a primitive scientific level with "the professor from across the road". I doubt that I should have found the same amount of common ground if the subject had been other areas of my professional expertise, such as physical chemistry or quantum mechanics! (Incidentally, my young friend chose to construct a pinhole camera as a simple demonstration of light propagation and imaging.)

The point that I am trying to make is that we as opticists have a special advantage in communicating our branch of science to the general public. Obviously, the scientific frontiers that challenge our research, both in terms of understanding and technological mastery, are as remote from the public domain as for any other branch of modern science. However, we have something positive to build on at an elementary level. Moreover, we are not confronted by negative community attitudes to things like "chemicals" or "nuclear energy", as is the case in neighbouring areas of physical science. Indeed, optics can be a useful vehicle for popularising wider aspects of physics, applied mathematics and engineering in schools and universities.

Opportunities may soon arise to press such advantages. For instance, as this issue of *AOS News* goes to press, the Federation of Scientific & Technological Societies (FASTS) is preparing to stage its annual Council Meeting in Canberra on 21 November, preceded the day before by a FASTS National Forum on "Valuing Education: The Case for Mathematics and Science". At the FASTS Council there will be a discussion session to choose "Ten Top Policies" as priority matters for FASTS to pursue over the next twelve months. I expect that science education at all levels will be a prominent issue in this context and hope that the topical attractions of optics will not be overlooked.

(I imagine that the next issue of *AOS News* will contain some reports of the strategies to be adopted by FASTS and its affiliated societies. In the meantime, you may be interested to monitor FASTS policies and activities *via* their Web site: http://bimbo.pharmacol.su.oz.au/fasts/fastshome.html.)

By the way, affiliation with FASTS is just one of the many benefits that AOS membership provides. At this time of year, when our annual subscriptions fall due, it pays to take stock of such benefits: *AOS News* itself; discounted registration at stand-alone AOS conferences (next to be held in Adelaide on December 10 Ð 12 1997); information about combined meetings, such as the ACOLS conference series; a voice, through the AOS Council, in the local development of optics; discounted membership arrangements with other scientific/professional bodies such as the Optical Society of America, SPIE, and the Australian Institute of Physics. In case you need more convincing that AOS has much to offer, why not visit our Web site: http://www.dap.csiro.au/OPTECH/Optics-Radiometry/aoshome.htm?

Enough of the sales pitch! The main theme of my message on this occasion is that we should be working together to promote optics as an attractive vehicle in scientific education (primary, secondary, tertiary, community). I should be very pleased to receive your comments Ð supportive or critical Ð and suggestions as to how we can take productive steps in this regard. (My email address is: brian.orr@mq.edu.au.)

Do you see the point on which I am focusing?

# AOS MEDAL

AUSTRALIAN OPTICAL SOCIETY

The Australian Optical Society is seeking nominations for the third award of this medal, which is for an outstanding contribution or contributions to the field of optics in Australia by a member of the Australian Optical Society.

The inaugural winner of this Medal, in 1995, was the late Bill James of James Optics, Melbourne, cited for his numerous contributions to the design, production and testing of aspheric and other high precision optics. The second medal was presented in July of this year to Dr Parameswaran Hariharan, Visiting Professor at the University of Sydney and Honorary Fellow at CSIRO Division of Applied Physics, for his extensive achievements in interferometry, holography, and other areas of optics.

This Medal is the most prestigious award of the Australian Optical Society. It would normally be presented only to 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.

Nominations for the 1997 AOS Medal Winner should include brief personal details and a curriculum vitae emphasising the main contributions made by the nominee to Australian optics. Two letters of recommendation should also be provided. Nominations may be made either by or on behalf of any eligible candidate. The selection panel reserves the option to seek additional information about candidates for the award.

It is hoped that the person selected to receive the medal will be able to do so at the Australian Optical Society Conference to be held in Adelaide in December 1997.

**The closing date for nominations is 31 January 1997.** Nominations should be sent to the Secretary:

Dr Clyde Mitchell
CSIRO DMST
Private Bag 33
Clayton South
Victoria 3169

Fax: (03) 9544-1128
E-mail: mitchell@mst.csiro.au

## Editorial

Lasers feature strongly in the articles that appear in this the final issue of the *AOS News* for 1996. Halina Rubensztein-Dunlop describes the work that her team have been performing on laser diagnostics for aerospace vehicles, while our second feature, from Elizabeth Illy and colleagues, concerns the use of ultra-violet lasers in micro-machining. Many thanks to the authors for their time and effort.

A couple of reminders of upcoming deadlines. Nominations for the AOS Medal close on the 31st of January 1997. So if you know of someone that is worthy of this prestigious award (even if it is yourself), then please get an application in.

This time next year we will all be busy preparing for the AOS XI conference to be held in Adelaide. All the information concerning where and when can be found in this issue.

Any views, reviews, announcements or articles you have are welcome submissions to the *AOS News*. Also any feedback on our new web page would be appreciated.

Finally, we would like to wish a very merry Christmas and a happy new year to all members and their families. For those that are travelling, please take extra care on the roads. See you all next year!

Esa Jaatinen

# OPTICS GRAPEVINE

*News from the World of Optics*

## SPIE's 1997 scholarships and grants

SPIE will again award grants to educational institutions and scholarshipsto individual students in 1997. Applications will be accepted through 4 April 1997.

The awards range from $500 to $7000 each. Grants to educational institutions are for academic use, including student travel to SPIE technical programs. Scholarships are for educational purposes, with final selections based on an assessment of the student's potential contributions to the field of optics and optical engineering.

Applications for the awards may be requested from Alson E. Hatheway, Chair, SPIE Scholarship Committee, P.O. Box 10, Bellingham, WA 98227-0010 USA. Fax: 360/647-1445. E-mail: education@spie.org.

Since the Society's inception in 1995 and the establishment of an Educational Fund in 1978, SPIE has contributed cash awards of more than $1,000,000 in scholarships and grants to students and institutions.

## *Members in the News*

Glen Baxter of Macquarie University was one of the winners of the 1996 New Focus Student Essay Competition for his essay entitled, *Teaming Diode Lasers with OPOs for Spectroscopic Sensing*. A copy of Glens prize winning piece can be found in the October 1996 issue of Optics and Photonics News.

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Peter Krug of Sydney University was recently appointed topical editor of Applied Optics. Peter will be looking after the Lasers, Photonics, and Environmental Optical Division of the journal.

### SPIE publishes 1997 edition of Optics Education guide

The latest edition of Optics Education, SPIE's comprehensive directory of international optics programs at universities and colleges, is now available. It contains listings for more than 200 institutions around the world. To receive a free copy, send e-mail to opticsed@spie.org, or fax 360/647-1445. The information will also be available on SPIE Web at

http://www.spie.org/web/education_home.html.

## FASTS on the Web

http://bimbo.pharmacol.su.oz.au/fasts/fastshome.html

Ever turned your office upside down trying to find a reference that has the value of some obscure fundamental constant you just have to have? Well stress no longer, the 1996 Physics Today Buyers Guide has an excellent article by Richard Cohen and Barry Taylor listing the latest values of all the constants that you will need and many more that you have never heard of. So now you too can know the value of the Loschmidt constant to 7 significant figures!

## *World News*

The work of Lew Whitbourn of the CSIRO and his team on their airborne $CO_2$ laser system for mapping mineral deposits, is receiving some international press. Their system is capable of discriminating between silicate and carbonate minerals, the surface distribution of which can indicate hidden bodies of mineral ore. For this to occur the laser must tune between 100 different frequencies in the 9.1 to 11.2 μm wavelength band every 2 mS and provide the necessary power for the measurement. The challenge then was to develope such a source and make it small enough so that it could be carried by an aircraft. What they ended up with was a 700kg system that can fit inside a F-27 Fokker Friendship. To find out more of the details read the article in the World News section of the July 1996 issue of Laser Focus World.

## AOS XI

**Adelaide December 1997**

**Are you going??**

*For Details see page 10*

**Know anyone who has made an outstanding contribution to optics?**

**Perhaps they deserve the AOS Medal.**

*Nominations close 31st of January 1997*

*see page 5 of this issue*

### The Hubble Deep Field Image

The images that are coming from the Hubble Space Telescope following its repair are continuing to astound and impress enthusiasts all over the world. Some of the latest Hubble emissions have been combined to form the Hubble Deep Field Image. This image was formed using 342 separate exposures taken over 10 separate days, and provides researchers with images of never before seen galaxies in various stages of evolution. With more than 1500 galaxies visible, it is hoped that the image can help address fundamental questions about the evolution of galaxies and the age of the universe. The project has an Australian flavour with the involvement of the Anglo-Australian Observatory. [see Optics and Photonics News, May 1996]

## Corporate Members on the Web!

**Coherent Scientific:**
http://www.adam.com.au/~coherent
**Kidger Optics**
http://www.demon.co.uk/kidger/
**Lastek**
http://www.saschools.edu.au/lastek/lastek.html
**Optiscan**
http//www.optiscan.com.au

Please email the editor to add your company's name to this list.

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### Correction

An out of date Optiscan address was printed in the previous issue of the AOS News. The correct details are:

Optiscan P/L
27 Normanby Road
Notting Hill, Vic 3168
Tel: 03 9562 7741
Fax: 03 9562 7742
email: info@optiscan.com.au

## FASTS July circular

The Prime Minister has invited FASTS to join his Science and Engineering Council (PMSEC), where the voice of 40,000 working scientists will be heard at the highest levels of policy formulation.

His letter (in part) reads:

"I am writing to invite you, as President of the Australian Scientific andTechnological Societies, to become an ex-officio member of my Science and Engineering Council. The Government's science, engineering and technology policy includes an important role for the Council in enabling leaders of the science community to bring to the Government's attention their views on issues and priorities in science, technology and engineering. I see your Federation as a key contributor to this role."

The letter continues with an invitation to make a presentation to PMSEC on Sept 13, and contains background on the Council and a list of members.

There are 20 members of PMSEC: the Prime Minister, the Minister for Science and Technology, 6 ex-officio members and 12 members appointed in their personal capacity.

The ex-officio members are:
The Chief Scientist
Dr Don Williams (Chair of ASTEC)
Sir Gus Nossal (President of AAS)
Sir Arvi Parbo (President AATSE)
Professor Fay Gale (President AV-CC)
Dr Joe Baker (President FASTS)

The invitation to join FASTS is recognition of the value of the opinions of grass-roots scientists and technologists. I believe that FASTS will add a fresh and vital voice to PMSEC deliberations.

Your ideas on issues to raise at PMSEC will always be welcome. Please keep this fact in mind as you encounter challenges, opportunities and particularly examples where scientific results have helped society.

1. In Canberra, the Budget approaches. It will be brought down on Tuesday August 20, and there are signs of nervousness in all organisations which depend on government funding.

The Government seems to know what it does NOT want - witness the ruthless axing of the Syndicate Research Scheme and Department of Regional Development - but is not exhibiting the same signs of certainty in what it wants to erect in place of these programs.

The pressure to come up with new policy is enormous. AusIndustry was given nine days to frame a non-tax based replacement for the Syndicate Research Scheme, and this period had to include consultation with industry and financial and research organisations!

FASTS was asked to suggest measures, and made both a written submission and attended a meeting in Canberra with 120 other groups hastily convened to advise the Department. Graham Johnston (the FASTS' representative, and our immediate Past-President) used the Industry section in the FASTS Policy Document as a source of ideas; but some of the plenary speakers at this meeting had less than an hour to assemble their thoughts. The meeting had useful outcomes, but there were rumblings of "policy-making on the run!".

2. Last week Toss Gascoigne and I met six senior officers of the Department of Industry Science and Technology (DIST) to discuss the FASTS' Policy Document. It was a productive two hour meeting, and provided useful insights into how FASTS can interact best with the bureaucracy.

These "nitty-gritty" meetings to look at both the philosophy and detail of policy are an essential support to our discussions with Ministers. We have approached other Departments such as DEETYA (Employment, Education and Training and Youth Affairs) for similar sessions.

3. I have continued to maintain close contact with Minister McGauran, and discussed a number of the issues with him last week. The Minister asked for the substance of these discussions to kept confidential, but they included matters such as: FASTS' appointment to PMSEC; the appointment of the Chief Scientist; impacts of Budget proposals on Australia's long-term programs, and the adverse impact of undermining the Regional development Program.

4. FASTS has been making useful contacts with member Societies. Toss Gascoigne spoke to a group at the Statistical Society Conference in Sydney and delivered a paper to the Ecological Society in Townsville.

He also discussed university funding and the career opportunities for young scientists with Carolyn Allport and Julie Wells of the National Tertiary Education Union; attended the opening of the new Aust Science Teachers Association office by Minister McGauran; and discussed FASTS matters with Chris Crossland of the Coral Reef Society and Helene Marsh of the Mammal Society.

I talked to ASTA President Debbie Smith at a breakfast meeting, and gave a keynote presentation "The challenges to Chemistry in understanding the World's Oceans and their biota" at a Conference on Chemical Education in Brisbane.

I was also a panellist for the discussion "Is there a new set of competencies needed for the graduating chemist?"; and had useful meetings with Barry Noller (President RACI) and Dr Susan Cumming (Executive Director RACI) at this Conference.

These meetings are the most valuable way of gaining an understanding of the concerns of Member Societies. The FASTS' travel budget is nil but we have found other ways to travel to meet with groups across Australia. Please let us know if you believe a FASTS' presence at one of your meetings or activities would be of value.

5. ANZAAS Congress in Canberra in October has taken up a FASTS' suggestion to devote Day 3 to science policy. I am chairing the final plenary session, featuring an address by Minister McGauran.

6. Accounts have now been mailed to all FASTS Corporate, Associate and Observer Members. Please pay these promptly, and direct questions to the Treasurer Marion Burgess (m-

burgess@adfa.oz.au) or Executive Director Toss Gascoigne (fasts@anu.edu.au)

Some Member Societies have been printing the Monthly Circular in their newsletters, while others pass it round by email. You might consider these ways of keeping your membership informed of what FASTS is doing.

7. FASTS gained good media coverage over the month with articles in the Canberra Times, Lab News, R&D Review, the Financial Review and the Age.

Headlines included:
"Sums done, maths doesn't add up"
"Academics warn of damaging decline"
"FASTS policy calls for option to R&D tax concession"
"Secondary science teaching in need of overhaul"
"'Backyard rorts' blamed for loss of tax concession
"Anger over dumping of scheme"

We also issued a media release on the demise of the Syndicate Research Scheme ("R&D tax breaks - there's a better way").

8. November Council
The FASTS Board will shortly decide the agenda for the Council meeting on November 21, and all Member Societies will be invited to attend. One feature will be a repeat of last year's informal dinner at a "cheap and cheerful" local restaurant, which proved a great way of bringing members, journalists, politicians and policy makers together, even if everyone had to pay their own way.

Member Societies are asked to consider nominees for the FASTS Executive. Of particular interest are the positions of President-elect and Treasurer, with current Treasurer Marion Burgess having announced her intention to step down.

9. Our attention has been drawn to the fact that Minister McGauran has received one and one only letter relating to science communication since taking office. This is not much ammunition to take to his senior minister or to the party room.

For those who would like to strengthen his position in Cabinet discussions, write to:
The Honourable P McGauran MP
Minister for Science and Technology
Parliament House Capital Hill Canberra 2600
Fax 06 2734150

10. A National Science Forum "How Science fared in the Budget" will be held on August 26 at CSIRO Limestone Ave in Canberra. The three speakers are the Minister for Science and Technology (Peter McGauran), the Opposition spokesperson (Martyn Evans), and Democrat spokesperson (Natasha Stott-Despoya). Cost is $10, book through Wendy Parsons on (06) 276 6615.

11. The NTEU and students' associations have organised a forum on maintaining government funding for higher education. Speakers include Robyn Williams (Science broadcaster), Helen Razer (2JJJ announcer), Keith Daniel (Corporate Technical Director, Nucleus Ltd), and Eva Cox (1995 Boyer Lecturer).

Monday 5 August 12.15pm SHARP, at Guthrie Lecture Theatre, Faculty of Design and Architecture Building, Level 3, University of Technology, Harris Street Sydney.

Joe Baker, President

**PRELIMINARY ANNOUNCEMENT and CALL FOR PAPERS:**

# THE 11th CONFERENCE OF AUSTRALIAN OPTICAL SOCIETY

## THE UNIVERSITY OF ADELAIDE, 10 - 12 DEC. 1997

The eleventh conference of The Australian Optical Society will be hosted by the Department of Physics and Mathematical Physics at The University of Adelaide in December 1997. The meeting will concentrate on all aspects of optics, lasers, and applications in Australia with contributions invited from all academic institutions, government laboratories and industry. There will also be a number of invited plenary speakers from overseas. The meeting of the AOS will be immediately preceded by a workshop in Quantum Optics. Details of the meetings will be appearing in forthcoming issues, and a web page will be established for registration. This will be a great meeting, and Adelaide is at its best in December!

If you have suggestions for improvements in the form of topics, distinguished invited speakers, exhibitions, sponsors etc., please forward to:

Prof. Jesper Munch, The University of Adelaide, South Australia 5005,
Fax. 08 232 6541, email: jmunch@physics.adelaide.edu.au

## FASTS August circular

The impact of the Budget on S&T is still being weighed up. In a year when "a good result" was measured in terms of how little the cuts were, S&T probably came out as well as any other sector.

Minister Peter McGauran seems to have done well in protecting his territory. The cuts that have been made in the general area of S&T largely fell in the portfolios of Education Minister Amanda Vanstone, and Industry Minister John Moore.

The full effect of Budgetary measures will become clearer when we see how the universities cope with life in Poverty Street, and industry responds to the huge cuts in incentives to undertake R&D.

The failure of Government to support overdue salary increases in universities is a national disgrace.

The effect on the CRCs is uncertain. Although direct funding was increased, the CRCs are sensitive to the climate in universities and industry. It is all part of a complex interlinked science and technology domino effect in Australia.

One unsavoury aspect of the Budget was Treasurer Peter Costello's statement that CSIRO was to receive an extra $115 million. This was pure "pea and thimble" stuff - CSIRO has to pay the whole amount back to Government through asset sales and a new "efficiency dividend" applied to research work.

But ANSTO and AIMS fared worse.

**1. Prime Minister's Science and Engineering Council**
FASTS addresses the Prime Minister directly at PMSEC on September 13, and the content of our message has been carefully considered. The suggestions which came in from Member Societies were a most useful contribution to this process. Thank you! The FASTS' submission will be available on our WWW site straight after the meeting.

**2. FASTS Council Meeting**
FASTS' Council 1996 Member Societies will be asked to nominate their choices for a FASTS "Top Ten Policies" ahead of the meeting of Council on November 21 this year, and these will be debated at Council. This will help identify the issues we pursue most vigorously.

Members should be thinking about nominating a representative, and what issues they want to raise at the meeting at the Academy of Science in Canberra. A more formal letter to all Member Societies about Council is currently being prepared.

**3. Nominations for President-elect**
Who should be the next President? The Board elects the President-elect on November 22. Ideally this person is a working scientist, well-respected professionally, with sufficient time to make an impact, and enough presence to address the Prime Minister and his colleagues confidently on S&T matters.

The President-elect serves in that role for one year before becoming President in November 1997. No previous FASTS' experience is necessary.

**4. ARC Candidate Nominations**
Nominations for the Australian Research Council FASTS has been invited by Professor Max Brennan to nominate candidates for the ARC. This request has been relayed to all Presidents of Member Societies, and several names have already been forwarded to us.

**5. Chief Scientist Position**
Chief scientist Michael Pitman is still acting in this position, but the process of appointing a successor is warming up. Names are being considered and a decision is expected by the end of the year. FASTS's opinion will be sought - the consultative process is not complete.

**6. Career prospects for young research scientists**
This issue is bubbling to the surface, as more young scientists wonder why they ever bothered, when they discover the unrewarding salaries and employment conditions on offer. And this after 10 years hard work through degrees and post-doc experience! FASTS has been discussing this issue with a number of Members and allied groups, and a concerted campaign is being planned.

**7. One day forum on Education**
FASTS will run a one day, high profile forum at the Academy dome on Nov 20th (the day before Council). The aim is to highlight the parlous state of mathematics and science education, and to demonstrate possible solutions.

The Forum hopes to involve other key players such as the Science Academies, the Institution of Engineers, the University Deans of science and education, and teacher groups. The Board has asked Jan Thomas (President of the Australian Mathematical Sciences Council) to coordinate the day.

**8. Contacts with other parties**
FASTS has had useful discussions with the Opposition Shadow Minister (Martyn Evans) and the office of the Democrat spokesperson on S&T, Natasha Stott Despoya.

**9. Contact addresses, subscriptions and newsletters**
Thanks to all those Members who have responded to our request for early payment of subscriptions, and return of contact addresses.

We are always pleased to receive your Society newsletter, especially as so many of them are now carrying news of FASTS activities.

**10. FASTS's media releases**
On the Budget - "Science still afloat. (But where's the Vision?)"
On the Budget - "Science peak bodies on Budget"
On Universities - "University cuts affect science. FASTS: All the wrong signals"
On PMSEC - "FASTS invited to join PM's Science Council. A key contributor"

Headlines of newspaper articles included:
"Coalition bid to end research rorts faces fight"
"FASTS warning on cuts to universities"
"Australian investors lose tax incentives on innovation"
"Science both a winner and a loser in funding"
"Australian universities face disruptive choices"

A discouraging media note are funding threats to Quantum and the ABC Radio Science Unit, and a fall-off in S&T coverage by the Australian newspaper since Julian Cribb left. But promising signs: FASTS is delighted to see the science journal "Nature" opening an office in Melbourne, with Peter Pockley the Australian Correspondent.

Joe Baker, President

LAS TEK A.C.N. 008 153 937

LASTEK Pty. Ltd., Thebarton Campus, University of Adelaide, 10 Reid Street, Thebarton, S.A. 5031, Australia
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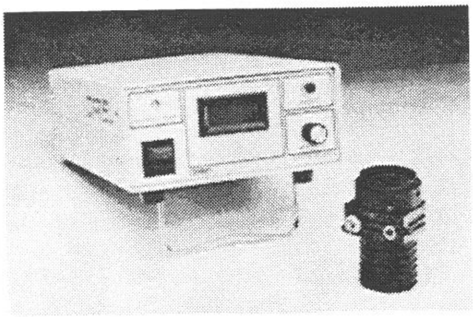
# News Release



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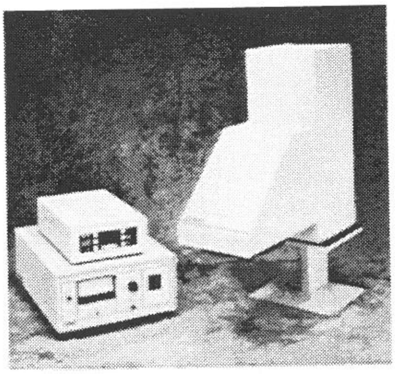

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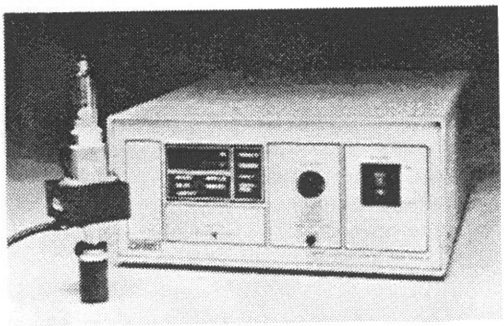

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# Laser Diagnostics in Aerospace Research

*H. Rubinsztein-Dunlop, T.J. McIntyre, P. Barker, A. Thomas, M. Wegener and A. Bishop*
*Department of Physics, University of Queensland, Brisbane, QLD 4072*

***Through the development of powerful laser spectroscopy techniques, new means for advanced diagnostics have emerged. At the University of Queensland these techniques are being applied to the ground-based testing of aerospace vehicles.***

## 1. Introduction

The introduction of tunable laser light sources such as dye lasers and the development of linear and non-linear optical techniques allow virtually any spectroscopic state of an atom or molecule from the far infrared to the vacuum ultraviolet to be observed with high resolution. Common features of laser spectroscopic diagnostic techniques are their high sensitivity, high selectivity, non-intrusiveness and near real-time analysis.

Our particular application of optical diagnostics is in the ground-based testing of aerospace vehicles. Such vehicles returning to the Earth can impact the atmosphere with velocities up to 15 km/s. This motion generates a bow shock on the vehicle through which the air is compressed and heated to temperatures of the order of 10,000 K. In these conditions, non-ideal behaviour of the gas including processes such as excitation, dissociation and ionisation becomes important. An understanding of the influence of these processes on the heating and aerodynamics of the vehicle is necessary to optimise the efficiency of future re-entry and hypersonic transport craft. Ground-based testing coupled with optical diagnostic techniques provides one avenue for improving our understanding of these flows.

The capabilities for experimentally generating such flows have existed for some time. This is particularly true in Australia where major ground-based research facilities exist at the University of Queensland in Brisbane and the Australian National University in Canberra. The motivation behind investigations in these facilities has been to improve the understanding of the interaction of a high energy gas stream with a model at supersonic or hypersonic velocities. Shock tunnels or expansion tubes are used to accelerate the gas to the high velocities which is then passed over a model of interest. Measurements are performed by the use of sensors mounted on the surface of the model or by optical imaging techniques.

At the University of Queensland, two facilities for the simulation of orbital and super-orbital flows have been available to the optical diagnostics group. To study velocities of the order of 2 km/s, a small shock tube was used. Higher velocities, up to 11 km/s, were obtained using the expansion tube, X1 [1]. This facility together with two larger tunnels are being developed uniquely at the University of Queensland for the investigation of super-orbital conditions. These are relevant to studies of future vehicles for interplanetary missions which will enter atmospheres (or return to our own) at velocities above 10 km/s. At these conditions, dissociation and ionisation in the gas will have a significant influence on the design of the vehicle and thus ground-based studies will be of vital importance.

The successful use of optical methods in these studies relies on identifying and developing techniques which can be used at the extreme conditions generated. These flows are characterised by high temperatures, low densities and short test times (sometimes as little as 50 μs). This article discusses a number of techniques that have been developed for use in expansion tubes and shock tunnels at the University of Queensland. Densities and electron concentrations are measured using holographic interferometry. Extensions of this technique may soon allow contaminant species concentration measurements as well as three-dimensional imaging. Temperature is being measured by the use of planar laser-induced fluorescence (PLIF). Recently we have developed a new technique for the measurement of velocity, a parameter which is traditionally difficult to determine. This method, called laser enhanced ionisation velocimetry, is a flow tagging method which uses PLIF imaging to observe the motion of a region in the flow depleted of a given atomic or molecular species.

## 2. Holographic interferometry

Interferometric techniques have long been used in studying flow fields. A beam of light is divided into two, with one part, the object beam, passed through the flow and the other, the reference beam, passed around. When recombined, the beams interfere providing fringes which allow visualisation and quantification of density variations in the flow. With the advent of the laser, holographic techniques have been developed whereby the two interfering beams are recorded holographically -

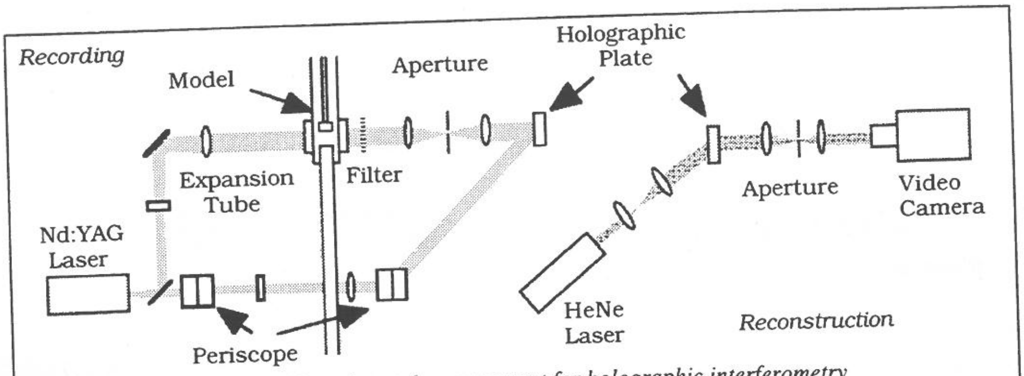



*Figure 1: Experimental arrangement for holographic interferometry*

the reference beam before flow is established and the object beam during the flow. Simultaneous reconstruction of the waves yields an interferogram with the same information as the standard two beam interferometric technique. The major advantage of this method is that both object and reference beams pass through the same optics and windows. This relaxes somewhat the requirements of stability and quality of the optical components.

The experimental arrangement for our holographic interferometry measurements is shown in Fig. 1. The output of an injection seeded Nd:YAG laser provides light at 532 nm with a pulse duration of about 10 ns operating at 10 Hz. The light is divided into the object/reference beam which is passed through the tunnel and the recording beam which is taken around the tunnel by a periscope system and is used to form the hologram. The model is imaged onto the holographic plate through an aperture and a narrow-band filter to remove luminosity from the hot test gas. To maintain power stability and seeding, the laser must be run continuously at 10 Hz necessitating a computer timing system which synchronises firing of the tunnel with the operation of the laser. This system allows recording of the reference hologram immediately prior to tunnel operation followed soon after by the object hologram. Afterwards, the interferogram is formed by illuminating the holographic plate by a helium-neon laser and images are recorded on a CCD camera.

Sample interferograms recorded in the X1 facility are shown in Fig. 2. In each case the flow is from left to right. The straight carrier fringes observed upstream of the bodies are introduced by slightly tilting the recording beam between exposures for the reference and object holograms. This method allows easier data reduction through the use of Fourier transform techniques.

Studies have been performed of flows over cylinders, wedges, a sphere and a simple re-entry model. Fig. 2a shows the flow over an asymmetric wedge recorded at a wavelength of 532 nm. Clearly visible as bends in the fringes are shock waves originating from the tip of the wedge. The angles of these shocks have been measured for a variety of wedges and have compared well with numerical simulations [2]. Fig. 2b shows the flow over a cylinder (also recorded at 532 nm) where much stronger density increases are expected. In this case strong negative fringe shifts are observed behind the bow shock which indicate the presence of electrons. To facilitate quantitative measurements in this case, interferograms need to be recorded at two well separated wavelengths. Since fringe shifts due to atoms and molecules decrease with wavelength while those due to electrons increase, it is possible to use two interferograms to solve simultaneously for both total and electron densities. This has been achieved in the past in studying high velocity flows using Mach-Zehnder interferometry where two wavelengths were combined, passed through the interferometer and then separated before recording on photographic film [3]. The use of holographic techniques opens the possibility for a more elegant

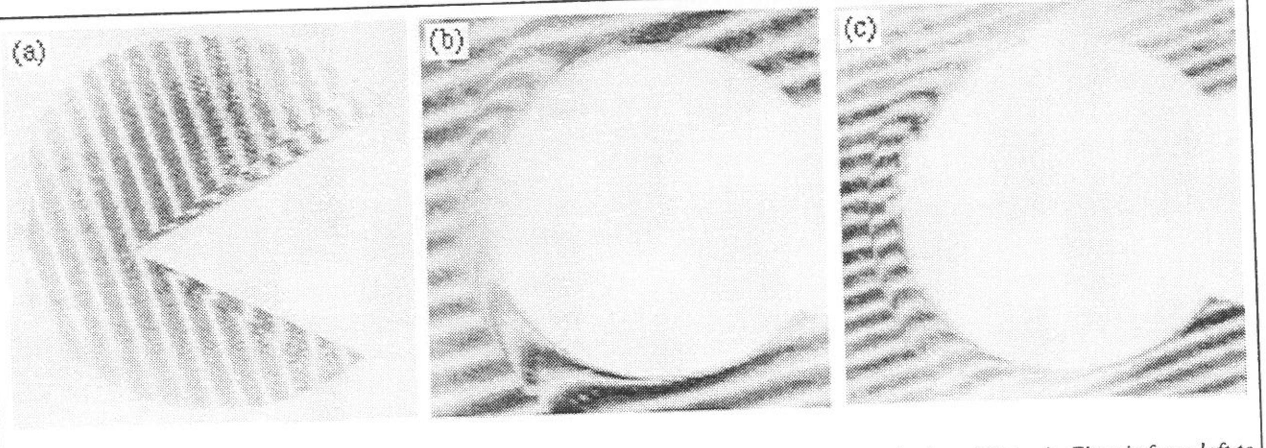



*Figure 2 : Holographic interferograms recorded in the X1 superorbital facility at a flow velocity of 11 km/s. Flow is from left to right. (a) Wedge at 532 nm; (b) Cylinder at 532 nm; (c) Cylinder at 355 nm.*

method where holograms of each wavelength are recorded on a single plate. We have developed a method whereby the second and third harmonics from the Nd:YAG laser are used as the two wavelengths. Both beams are passed through the optical system described above and are recorded on the holographic plate. This results in four overlapping holograms - an object and reference hologram for each wavelength. Upon illuminating the hologram with a helium-neon laser the reconstructed beams for the lower wavelength are diffracted at a larger angle than the higher wavelength so that each interferogram can be observed separately and undisturbed by the other. In fact, both interferograms can be observed by eye in white light by simply looking at the plate from different angles. The interferogram shown in Fig. 2c, recorded with a laser wavelength of 355 nm, was obtained simultaneously with that from Fig. 2b. The fringe shift in this case is smaller indicating that the shifts behind the bow shock are dominated by the presence of electrons. These images are being analysed to provide two-dimensional quantitative information [4].

Holographic interferometry offers a number of other capabilities in performing measurements. We are presently investigating two variations of the technique which will provide further information over that currently obtained. Holography is by nature a three-dimensional method which we currently only use to obtain two-dimensional information. By the introduction of a scatter plate into the object beam immediately prior to the test section, three-dimensional imaging can be performed. That is, interferograms can be obtained from multiple angles from a single holographic plate. This is limited by the viewing angle that the optics and windows provide and could lead to better capabilities of performing tomographic reconstructions of three-dimensional flows. We have successfully achieved this in the X1 facility with limited angle three-dimensional images being recorded. This technique is to be further improved to provide wider ranges of angles. As well, we are currently investigating the use of near-resonant holographic interferometry for species specific measurements. It was proposed that interferometry could be used to measure species number densities by recording interferograms with laser beams tuned near to an absorption line [5]. In its holographic form, two separate lasers, one tuned near to the absorption line and one away from resonance are recorded simultaneously on a holographic plate [6]. When the beams are reconstructed they interfere and fringe shifts are only present due to resonant effects of the probed species allowing relative concentrations to be measured. We have demonstrated this technique in flames detecting sodium [7] and will shortly be implementing it in the tunnel.

## 3. Planar laser-induced fluorescence (PLIF)

Planar laser-induced fluorescence is a species specific method in which the probe interacts only with particular energy levels of a chosen species in the flow. A narrowband laser beam is tuned to the absorption line of the species of interest and passed into the shock tunnel flow. The light is absorbed by the species present in the flow and re-emitted in all directions at wavelengths characteristic of the species. The technique can be used for two-dimensional imaging by forming the laser beam into a sheet and then passing it into the flow. By using a camera imaged at right angles to the sheet, a two-dimensional image is obtained which is related to the distribution of the species in the flow. Unlike interferometry, the image recorded is not integrated across the flow but results only from fluorescence in the thin sheet passed into the flow which can give high spatial and temporal resolution.

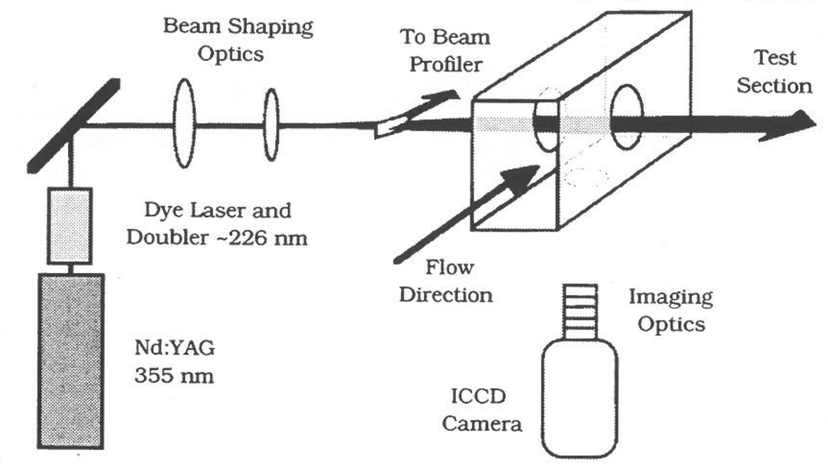
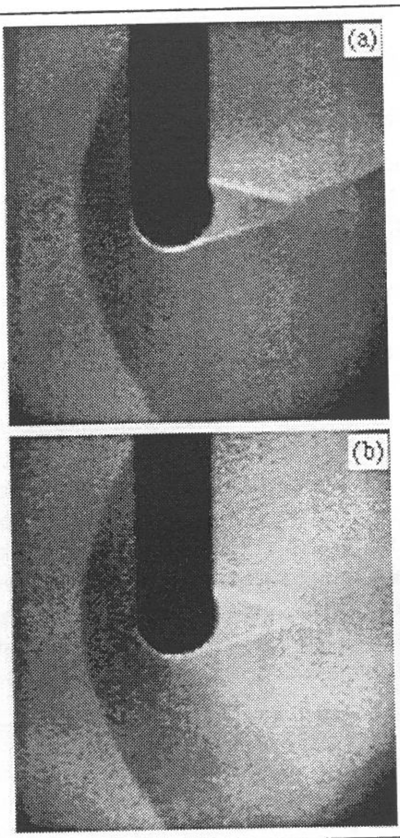



***Figure 3:*** *Experimental arrangement for planar laser-induced fluorescence imaging.*

The experimental arrangement for performing PLIF measurements is shown in Fig. 3. Our measurements have been performed on nitric oxide which has strong absorption bands in the ultraviolet and provides good non-resonant fluorescence which can be easily filtered from scattered laser light. Nitric oxide is also suitable as it is often present in high temperature air flows or, if not, can be added to the test gas before a measurement is performed. The ultraviolet laser light used for NO excitation is obtained by frequency doubling the output of a tunable dye laser pumped by the third harmonic of a pulsed Nd:YAG laser. A small portion of this beam is separated and passed through a flame for tuning purposes. The remainder is formed into a sheet and passed through a fused-silica window into the test section parallel with the flow. Immediately prior to the window, a beamsplitter is placed to direct a small amount of the beam onto a dye cell. The resulting fluorescence from the test cell is imaged onto a CCD camera and is later used to correct the PLIF image for



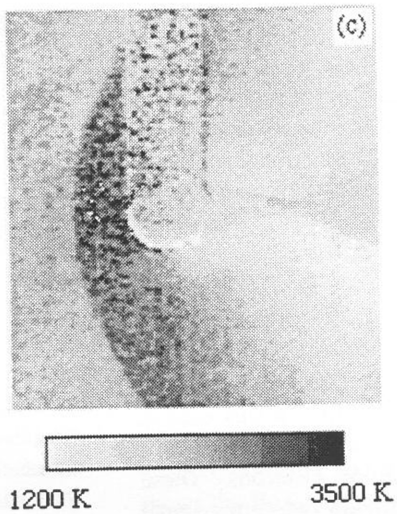




***Figure 4 :*** *Planar laser induced fluroescence images. (a) P2(8) line; (b) P1(29) line; and (c) Temperature from (a) and (c).*

The images show flow from left to right over a small cylinder. The laser sheet enters from the bottom of the picture resulting in the shadow seen above the cylinder. In each image there is a significant signal in the freestream ahead of the shock due to the NO present in the test gas. As the flow passes through the shock this signal can either increase or decrease dependent on the energy level probed and the amount of collisional quenching that occurs.

variations in intensity across the beam. The fluorescence from the flow is imaged onto an intensified CCD camera which can be gated down to durations of 5 ns. To discriminate against scattered laser light as well as to remove natural luminosity from the flow, a number of filters and/or wavelength dependent mirrors are used. Even so, a small background signal is observed which can be recorded and subtracted from the PLIF images.

The laser is tuned to the absorption line originating from a particular rotational energy level in the zeroth vibrational level of the NO ground state. The light excites the molecule into a particular rotational level of the zeroth vibrational level of the excited A electronic state. Collisions in the gas rapidly transfer this population to other rotational states (rotational energy transfer), to other vibrational states (vibrational energy transfer) and back down to the ground state (quenching). Molecules remaining in excited states can fluoresce decaying down to various vibrational levels in the ground electronic state. The fluorescence collected is the broadband fluorescence from the collisionally redistributed upper states to the lower electronic state. This signal is dependent on a number of parameters including collection optics efficiency, the number density of the absorbing species, the temperature of the gas, the spectral convolution of the laser and absorption lineshapes, the strengths of the transitions and the electronic quenching rate for the upper state [8].

PLIF images are shown in figures 4a and 4b. The measurements were performed in the small shock tunnel using a mixture of 5% NO in nitrogen as the test gas.

In principle it is possible to determine the absolute population of these rovibrational energy levels from the strength of the signal. In practice this is difficult as the detection system must be carefully calibrated and uncertainties remain on collisional quenching rates. However, to determine temperature, it is only necessary to measure the relative populations in two rotational levels. By taking the ratio of two images recorded using transitions from two different lower states, the detection efficiencies and quenching rates can be presumed to be the same in each case and cancel out. The temperature thus determined is given in Fig. 4c. It shows clearly the increase in temperature of the gas as it passes through the shock front with the maximum temperature being observed immediately in front of the body where the gas is brought almost to rest. Due to the high pressure in this region, there is strong quenching of the signals and thus the temperature determination is less accurate. The figure also shows the decrease in the temperature of the gas as it passes around the body. Comparisons of these measurements with computer simulations of the flow are in progress.

**4. Laser enhanced ionisation velocimetry (LEIV)**

Laser enhanced ionisation velocimetry is based upon resonant excitation of a species present or seeded into the flow and subsequent collisional ionisation. The resulting ground state depletion is detected by probing this state with delayed resonant excitation and observing the diminished fluorescence signal along the thin line written into the probe beam by the excitation laser or lasers. By observing the depleted region at different delays the velocity of the flow can be obtained. In this method a "dark" line representing the depleted region in the flow is followed in time. Alternatively flow tagging velocimetry can be performed on ionic species. In this

case the atomic species is firstly resonantly excited to a higher lying electronic state, then photoionised. The created ion is then resonantly excited and fluorescence from the excited ion probed. By delaying the resonant excitation of the ion and following it in time the velocity is determined. In this case a bright line of ionic fluorescence will be created. In principle LEI velocimetry can be carried out using a wide range of atomic species. Available dye lasers enable us to access the transitions ranging from the ultraviolet spectral region to the infrared, with power outputs often in excess of those needed for saturating the transitions, so that the majority of atomic species can be effectively excited utilising one or two step resonant processes. The choice of species used is dependent upon the particular environment in which the method is to be applied. In most cases we wish to use species which are constituents of the flow. If, however, a useable species is not naturally present it is possible, in many cases, to seed it into the flow without disturbing the general flow behaviour.

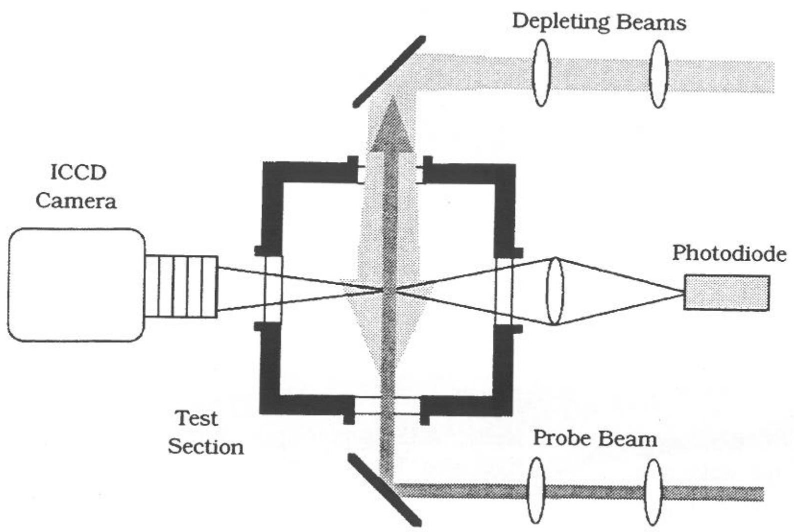



***Figure 5** : Schematic of the layout for the LEIV measurements. Flow is out of the page.*

We have used LEIV firstly for measurements of flame velocity [9] and secondly for velocity measurements in a shock tube [10]. The experiments in both of these environments were performed on sodium seeded into the flow. The lasers used in the experiments have pulse widths of less than 10 ns ensuring high temporal resolution or flow stopping ability, which is of particular importance in fast flows. A careful spectroscopic investigation to determine the best choice for a two step excitation process followed by collisional ionisation was performed to ensure high ionisation efficiency in sodium.

The experimental set up used for LEI velocimetry in a shock tube and flame is shown in Fig. 5. Two dye lasers pumped by a common pump laser provide the means for two step resonant excitation (3s-3p, 3p-7d) which is followed by collisional ionisation. The third dye laser pumped by a separate pump laser is used to probe the depletion of the neutrals (3s-3p transition). The tagging and probe laser beams are directed into the interaction region - flame or shock tube. The first part of the experiment is concerned with a spectroscopic investigation of the species used for tagging (in our case Na) with the purpose of establishing the excitation scheme leading to the largest possible neutral atoms depletion. These experiments are carried out in an air-acetylene flame. For velocity measurements, the tagging and probe laser beams are expanded into thin sheets of light using an appropriately chosen combination of spherical and cylindrical lenses and oriented at right angles to each other. A lens is positioned outside the interaction region in order to collect and image the planar laser induced fluorescence signal from the untagged atoms in the flow. This image is detected on an ICCD camera and stored digitally. The beams viewed by the ICCD camera appear as a "thin" line of the

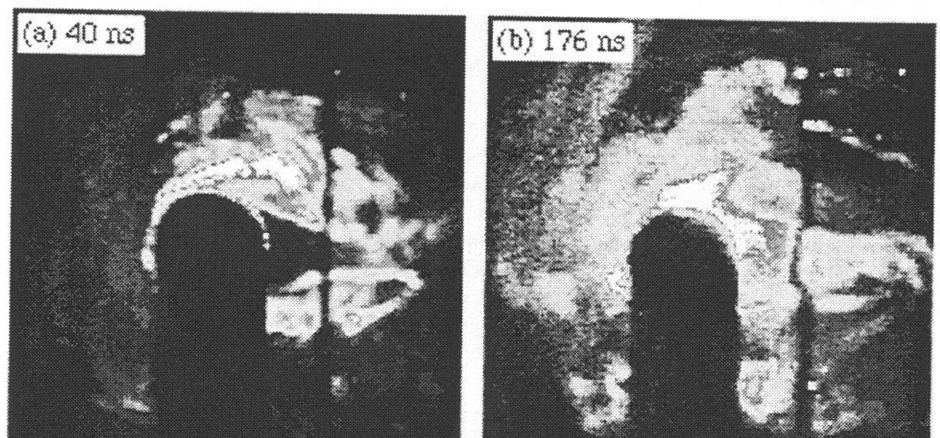



***Figure 6** : LEIV Images recorded behind a cylinder with a flow velocity of about 1.7 km/s. Flow is from left to right. Tagged region is the dark line behind the body.*

tagged laser beams on the background of a "wide" probe laser beam.

A variety of tagging-to-probe delay times were used for determination of the velocity. In the shock tube experiments, sodium was seeded into the flow by placing a thin rod coated with a NaCl solution in the centre of the flow just upstream from the region in which the measurements were performed - the test section. The position of the rod was chosen to allow sufficient time for the sodium to be distributed throughout the test gas before reaching the test section. In the exp-eriments performed in the flame, an aqueous sodium solution of a desired concentration was aspirated into the premixed combustion gases by a nebulising head.

The velocity measurements in the shock tube were performed in the free-stream flow and in the wake of a cylindrical body. Figures 6a and 6b represent examples of the flow behind the cylinder containing the depleted tagged region corresponding to a depletion-probe delay of 40 ns and 176 ns, respectively. The dark circular region in each image is the outline of the body. The shadow of this cylinder produced by the probe laser sheet extends to the bottom of the page. By changing the tagging-to-probe delay time, it is possible to follow the evolution of the tagged region in time and observe the differences in the velocity around and behind the body. We showed that the present technique does not require uniform seeding of the flow as it relies on the detection of a spatially displaced, depleted region of the flow. The maximum delay time between the depletion and detection of the flow region that can be used for velocity determination is governed by the loss of contrast between the depleted "dark" region and surrounding two-dimensional "bright" fluorescence. For the low velocities measured in the flame (approximately 10 m/s), the loss of contrast can be understood in terms of increase in the recombination rate when the species concentration is high and in terms of diffusion for low concentrations. However, when the method was used for the higher velocity flows of Fig. 6, shorter delays were used so that diffusion of the tagged line was not significant.

At present we are investigating spectroscopically the applicability of other species for velocity measurements either by LEIV or by measuring an increase and subsequent displacement of ionic species created by laser excitation and photo ionisation. We also plan to use LEIV in the superorbital expansion tube where the test gas velocities can reach 15 km/s.

## 5. Further work at the University of Queensland

Our current goal is to continue the development and application of laser-based methods in the characterisation of flows in super-orbital facilities. New larger experimental facilities are currently being constructed and tested and characterisation of the flow by optical methods is vital in ensuring their success. Two-dimensional imaging of density, electron concentration, temperature and velocity will provide valuable information which, when complemented with surface measurements, will allow comparison with numerical simulation of the flow leading ultimately to better aerodynamic and aerothermal design of re-entry vehicles.

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# Ultra-violet Laser Micro-machining

*Elizabeth K. Illy, Alison C.J. Glover and James A.Piper*
*Centre for Lasers and Applications, Macquarie University, Sydney 2109*

***As the demand for microscopic structures grows, the techniques required to produce these devices continue to draw more attention. In this article we review micro-machining results that have been achieved at the Centre for Lasers and Applications. The arrangement for high speed ultra-violet (uv) micro-machining of organic materials, using a high beam quality frequency doubled copper vapour laser (CVL), is also described.***

***Material removal rates per pulse are similar to other uv sources but the high pulse repetition frequency of the uv-CVL results in enhanced material removal rates of up to 100 times faster than other standard commercial UV sources.***

## 1. Introduction

A growing number of industrial applications require a UV laser source for micro-machining. Examples include the manufacture of micro-electronic circuits, micro-drilling of medical catheters, the production of ink-jet printer nozzles, laser micro-marking, drilling of micro-orifices for leak testing and medical flow controllers[1]. Unlike infrared (IR) laser systems such as Nd:YAG or $CO_2$ lasers, which are often used for large scale machining of metals, UV lasers perform operations which would be difficult or impossible to achieve with long wavelength laser technologies.

There are a number of advantages of UV laser sources for micro-machining. Firstly, strong absorption of organic materials in the UV results in clean ablation of precise features with no charring or melting of the samples; secondly an ablative photo-decomposition or 'cold' ablation process ensures production of structures with minimal heat effected zones; and thirdly the high spatial resolution due to their short wavelength enables the machining of features only a few microns in size with better than one micron precision[2]. The large difference in the uv absorption coefficient between polymers and metals makes uv sources ideal for the removal of one type of material from the other, for example in wire stripping of micro-circuit manufacture.

Presently the most established technology for uv micro-machining is the rare gas halide excimer laser, of which the most proven systems are the krypton fluoride excimer operating at 248nm and the xenon chloride excimer laser operating at 308nm. Even though the reliability and accessibility of excimer lasers has improved in recent years[1][3] there still remains some fundamental limitations. The foremost is the low pulse repetition frequencies (10-100 Hz) and low beam quality. Excimer lasers have the advantage of high pulse energies. However, depending on the mask and imaging system used, a large percentage of this energy may not be utilised. In addition, with the low pulse repetition frequency limits the production rates attainable for some applications even when complex multi-beam parallel processing stations are employed.

Recent developments in beam quality and frequency doubling of the copper vapour laser (CVL) [4-6] provide a realistic alternative UV laser source for micro-machining and other applications. The UV-CVL has the desirable features of high beam quality, short pulse length, high pulse repetition frequencies (prf's) (up to 20kHz) and substantial average powers at 255nm (second harmonic generation). Powers up to 4.7W have been achieved at 10 kHz [7]. Pulse energies of several hundred μJ at the sample surface from the UV-CVL are comparable to those achieved from excimer sources. The UV-CVL can easily provide the fluences (0.1-20 $J/cm^2$) that are necessary for the machining of polymers, ceramics, and metals [8][9].

Since the early development of the UV-CVL we have been pursuing micro-machining applications, with particular emphasis on micro-hole drilling in polymers. Our previous results [10]-[12] are very similar to results achieved using an excimer laser source for the ablation of polymers, with the exception that material removal rates are up to 100 times faster. In this article we describe the UV-CVL drilling system, show examples of the results which can be obtained with the UV-CVL and present ablation rates for PETG.

## 2. Experimental Procedure

The CVL used in this investigation was based on a commercially available water-cooled laser built by Dynamic Light P/L which was modified to provide the beam quality and beam pointing stability necessary for micro-machining. An M=100 unstable resonator was used on the nominally 12 W CVL. The laser was

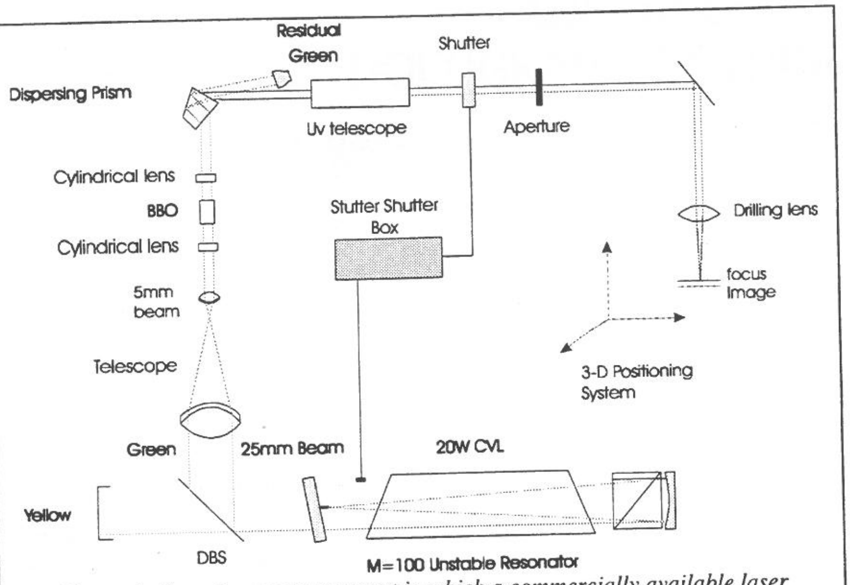


*Figure 1: Experiment arrangement in which a commercially available laser has been modified to provide the beam quality and beam pointing stability necessary for micro-machining*

for most efficient frequency conversion. After recollimation with another 100mm cylindrical lens the green and UV beams were separated using a UV grade silica Pellin-Broca prism.

With this system UV outputs of up to 1W were readily obtained. Typically the peak conversion efficiency was up to 40%, although the doubling system was configured for reliable operation on a daily basis and not for maximum conversion efficiency. The pulse duration was 35 ns at base and the pulse averaged beam divergence was 55 μrad. The UV power stability over 8 hours was ± 5%.

operated at a high pulse repetition frequency (prf) of 4.25 kHz and the buffer gas was a mix of 0.8% hydrogen and neon. The arrangement can be seen in Fig. 1.

From the two visible CVL wavelengths, 511 nm (green) and 578 nm (yellow), it is possible to generate three UV wavelengths. Second harmonic generation of the green provides 255 nm, second harmonic generation of the yellow provides 289 nm and the sum frequency generation provides 272 nm. The generation of these UV wavelengths in beta barium borate (BBO) has been described by Coutts & Brown [4] and Coutts [5]. The results presented in this paper were obtained using 255nm (doubled green).

The green and yellow wavelengths were separated by a dichroic beamsplitter. The green was de-magnified 5 times reducing the beam diameter from 25 mm to 5 mm. The beam was spatially filtered to remove the highly divergent amplified spontaneous emission component (ASE) which does not contribute to the doubling of the green. The non-ASE component (5W green)was then focussed using a 100mm cylindrical focussing lens to a line within the BBO doubling crystal

The UV beam was shuttered using a combination of a fast reed shutter and direct electronic control of the CVL discharge circuit, to allow a specific number of pulses to ablate the material. An aperture was also used to ensure that the UV beam was circular, and most importantly to act as a mask for the optical delivery system. The size of the aperture could be varied to allow ablation of the samples at different fluences.

The samples were mounted on a 3-axis computer controlled positioning system (Newport 423 stages with 860A actuators and 860-C2 controller). The average power at the sample was measured using a Scientech calorimetric power meter. The samples were drilled in air and no assist gas was used. The depth of the ablated region was measured using a Sloan Dektak II profilometer.

## 3. Results and Discussion

The high absorption of organic materials in the UV region results in clean ablation by a predominantly photochemical process. The molecular bonds are broken and the material is ablated, as opposed to melted, resulting in a minimal heat effected zone. Examples of clean ablation of organic materials obtained using the

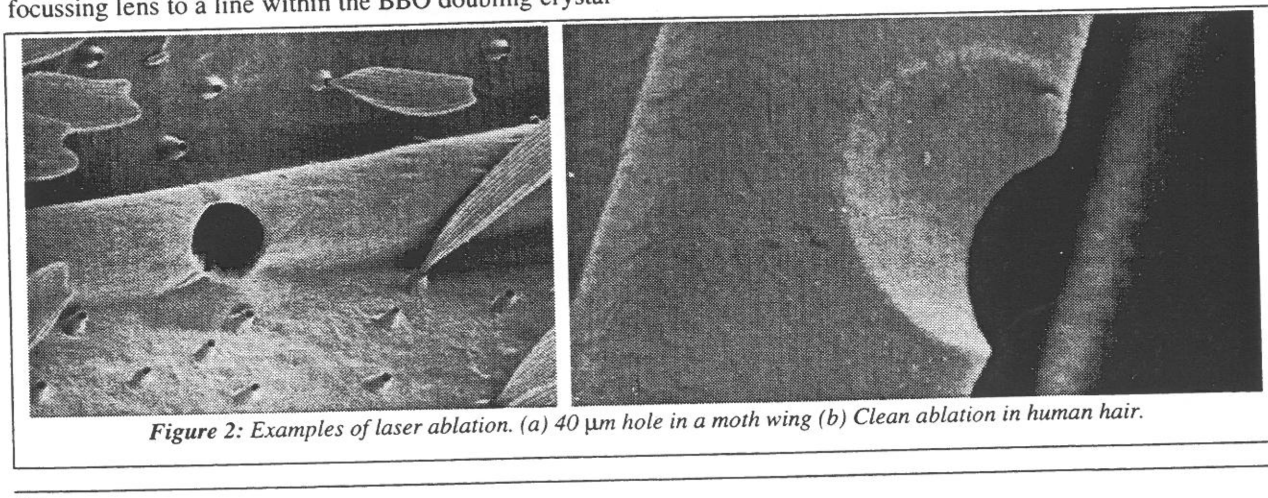

*Figure 2: Examples of laser ablation. (a) 40 μm hole in a moth wing (b) Clean ablation in human hair.*

UV-CVL can be seen in the scanning electron micrographs of Fig. 2. Fig. 2(a) shows a 40 µm hole in a moth wing, and Fig 2(b) shows the clean ablation of 60 micron thick human hair.

Investigation of the ablation rates of polymers such as PETG and polyimide, or kapton, (which is used in the fabrication of micro-electronic circuits) provides information about the conditions necessary for effective laser micro-machining. The ablation rate indicates the amount of material that can be removed per laser pulse as a function of source energy density or fluence and depends strongly on the source wavelength and the absorption coefficient of the sample. The ablation rate results presented here are for PETG. The absorption coefficient of PETG was measured to be $1.25 \times 10^5 cm^{-1}$. The etch depths were measured using profilometry and the average depth of the ablated region was calculated.

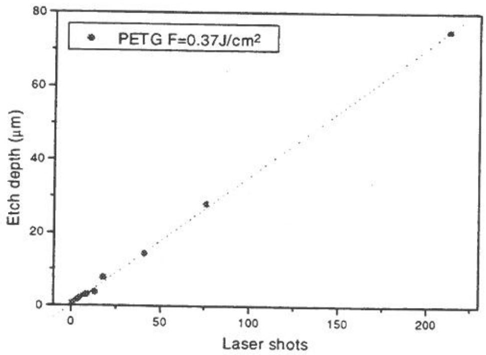


***Figure 3:*** *Etch rate for PETG at 0.37 $J/cm^2$.*

The etch depth was plotted as a function of number of laser pulses for between 1 and 213 pulses. The slope of this graph is then measured to calculate the ablation or etch rate for the specific fluence. Fig. 3 shows the results for PETG of etch depth verses 1-213 laser pulses at a fluence of 0.37 $J/cm^2$. For this fluence the etch depth scales linearly with number of laser pulses, as expected. The etch depth per pulse was calculated to be 0.35 µm. Hence to drill through a sample 70 µm thick requires approximately 210 laser pulses or an exposure of 50 ms.

This information is used to determine and control the shape of laser micro-machined holes. These holes have many applications, including the regulation of flow of intravenous drugs and medical filters. Using the techniques we have developed, it is possible to drill holes that range in size from 3µm to 200 µm in diameter with a reproducibility of a few percent of the hole's area. The materials successfully drilled include polyimide (kapton), PET (mylar) polycarbonate, glass, silicon, and aluminium foil. Fig. 4 shows an SEM image of 70 µm size holes in PETG. Note the clean ablation and consistency in hole size.

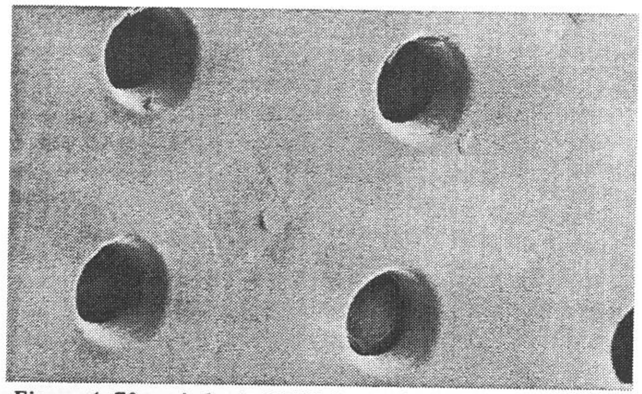

***Figure 4:*** *70 µm holes in PETG for medical flow controllers.*

## 4. Conclusions

We believe the UV-CVL represents an attractive alternative to conventional excimer laser technologies. The UV-CVL is capable of providing ablation rates similar to those obtained using an excimer laser source with the advantage of increased pulse repetition frequencies (prf) and hence increased material removal rates, high beam quality, short pulse length and substantial average powers.

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## Color and Light in Nature

David K. Lynch and William Livingstone
Cambridge University Press, 1995
254 pp, US$29.95, Softback.

This is a book for all those who have ever wondered about light and colour, and the way they are revealed so spectacularly in nature in effects such as rainbows, halos and green flashes. It is very well-written, with numerous diagrams and photographs, and invites the reader to open their eyes and enjoy the rich variety of optical phenomena which can be found in nature. In addition, the book provides clear explanations of the underlying physics of the phenomena, which can reveal otherwise unexpected and beautiful aspects of the observed effects.

The authors acknowledge that their book was inspired by the classic "Light and Colour in the Outdoors," by Marcel Minnaert, first published in 1937, and indeed their title unashamedly echoes his. Their subject matter is similar, but extends his work, taking advantage of the progress in research since 1937 to explain the physics, and the development of reliable techniques of colour photography to show the reader exactly what to look for. They are professional astronomers, and acknowledge assistance and inspiration from many other individuals and several Optical Society of America topical meetings on the subject.

The authors provide one of the clearest and most comprehensive treatment of this subject area that I have ever seen in a single volume. They begin with a chapter on the physics of shadows, answering questions about their shape, their colour, and the effect of perspective when viewing mountain shadows on the ground. In the next chapter, they move up into the air, addressing issues such as the colour and the clarity of the sky, explaining why the sky is whiter near the horizon, and occasionally purple after sunset. The effects of atmospheric refraction are treated well, with illustrations of various mirage phenomena and distortions of the setting sun.

The next three chapters consider the interaction of light and water. The commonplace effect of light reflections from the surface of lakes or the ocean yields an unexpectedly wide variety of patterns, if only one knows the conditions under which to look. Water drops in the air give rise to rainbows, fogbows, coronas and glories, and the these effects are well explained with some fascinating photographs. One in particular shows an effect I have never previously observed; a broken rainbow formed from raindrops and seaspray. Those who have ever spent time in colder climates will know that atmospheric ice crystals can give rise to spectacular pillars, halos and arcs, and all of these effects are also well-explained and illustrated in the next chapter.

There is a chapter on naked-eye astronomy - a timely reminder that despite the ease of downloading digital images from Hubble off the internet, there is a great deal of physics to be seen simply by going outdoors on a clear night. Also in this context, the last chapter is all about observing, providing the reader with useful tips and techniques to observe and photograph the optical phenomena described previously.

The book is not really a monograph, but its scope is wide, and there are frequent references in the text for those who wish to follow up particular effects in more detail. It is well written and illustrated, and the physics of a wide range of optical phenomena is explained clearly. I found it difficult to read continuously, however, as I kept on getting up to go outside and have a look for some effect or other which was described in the text. This illustrates to me the great advantage of this particular book; by treating such a wide range of effects, it is an all-weather, all-latitude guide to optical phenomena. No matter where you live, there will be something described in this book that you can look and marvel at. For all physicists, present and future, this book is strongly recommended!

John Dudley
Department of Physics
University of Auckland

## Principles of Three-Dimensional Imaging in Confocal Microscopes

Min Gu
World Scientific (1996) Singapore
x+337pp., A$58 (hardcover)
ISBN 9810225504

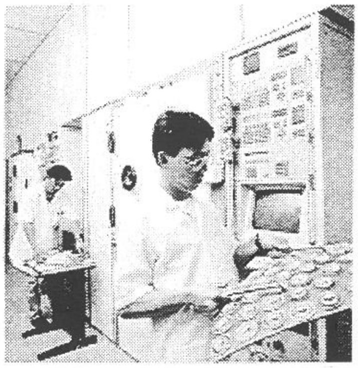
This book is not only the first book on confocal scanning microscopic imaging written by an Australian author, but also the first book that gives a systematic analysis of the three-dimensional (3-D) imaging properties in confocal microscopy. Confocal microscopy has been developed for the past fifteen years and its ability of 3-D imaging has made it a useful and important tool in various practical fields. This book gives a methodical analysis of the 3-D imaging properties of confocal microscopy based on the concept of the 3-D transfer function and the degree of coherence of the imaging systems. The book contains ten chapters and the author logically organises the contents in three parts. The concept of the 3-D transfer function is introduced in the first part included in the first two chapters. 3-D space invariance in a thin lens imaging system is first proved and the corresponding 3-D transfer function is derived by performing the 3-D Fourier transform of a 3-D point spread function. In the second part (Chapters 3-5), three basic types of confocal microscopes behaving as coherent, partially coherent, and incoherent systems, respectively, are discussed. The author clearly points out

that the fundamental difference among them is the degree of coherence. As a result, only three basic types of the transfer functions, the coherent transfer function, the transmission-cross coefficient, and the optical transfer function, are needed to describe the imaging performance. In the last part (Chapters 6-10), the author introduces some recent developments in confocal microscopy including multi-photon fluorescence imaging, fibre-optic imaging, imaging under ultrashort pulsed laser illumination, and 4Pi imaging. This part will be a valuable guide for the future developments in confocal microscopy. The book also discusses various imaging properties such as aberration, size of pinhole, pupil functions of lenses, and etc., according to the 3-D transfer function presentation. Different optical arrangements have been compared with an insight into their inter-relationship.

The author of this book has been actively involved in the area of confocal microscopy for many years. Most of the author's research work in this field has been published in various international refereed journals when he worked in the University of Sydney and Victoria University of Technology. However the new book is self-contained and easy to understand. It is suitable for undergraduate and graduate courses in optical imaging. In addition the completeness of this book makes it an excellent handbook for researchers involved in the field of confocal microscopy.

Xiaosong Gan
Department of Applied Physics
Optoelectronic Imaging
Victoria University of Technology

# Advanced Thin Films



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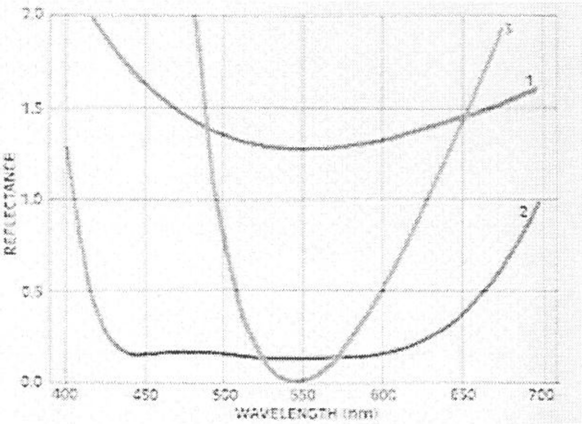


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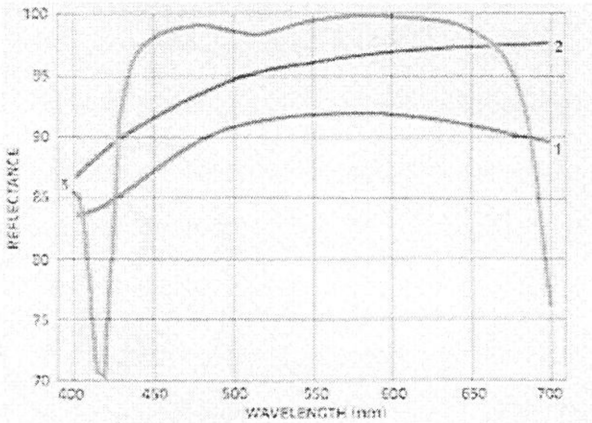


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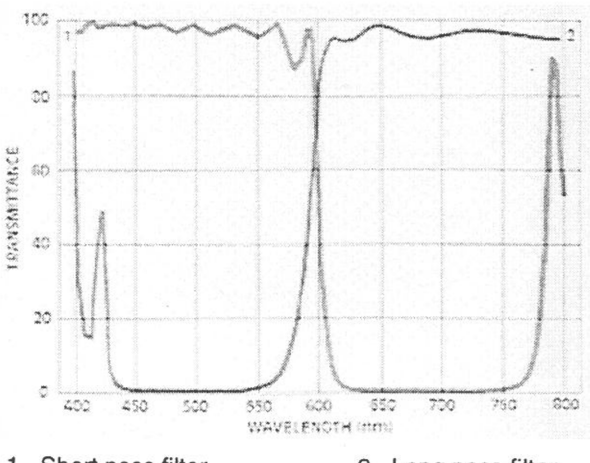


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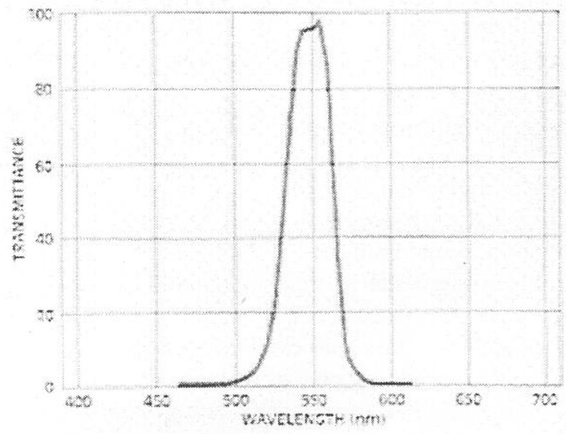


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# $\chi^{(2)}$ - Second order nonlinear optics: from fundamentals to applications.

*Andrew White*
*Australian National University*
*Winner of the 1996 AOS Postgraduate Prize*

Nonlinear optics was born in 1961 with the observation of second harmonic generation by Franken et. al. By 1965, in an incredible burst of creative physics, all of the basic second order nonlinear optical interactions had been predicted and modelled (sum, second, and difference frequency generation, and optical parametric oscillation and amplification) as had techniques for achieving these interactions (Type I-, Type II-, and Quasi- phase matching, or QPM). After this early success the field was relatively quiescent for the next twenty years: in practical terms second order nonlinear optics was seen as something of a curiousity. However since the mid-80's the field has experienced a revival, to the point where it now find applications ranging from quantum optics to the new generation of commercially available light sources (Spectra-physics Millennia, Lightwave visible misers, etc.).

From 22nd - 26th April this year an international conference on second order nonlinear optics was held at the Centre de Physique des Houches, France. To foster an atmosphere suitable for intensive discussions, participation was limited to 73 people; there were seven sequential sessions a day; two three hour poster sessions; and four hours every afternoon allocated for discussions.

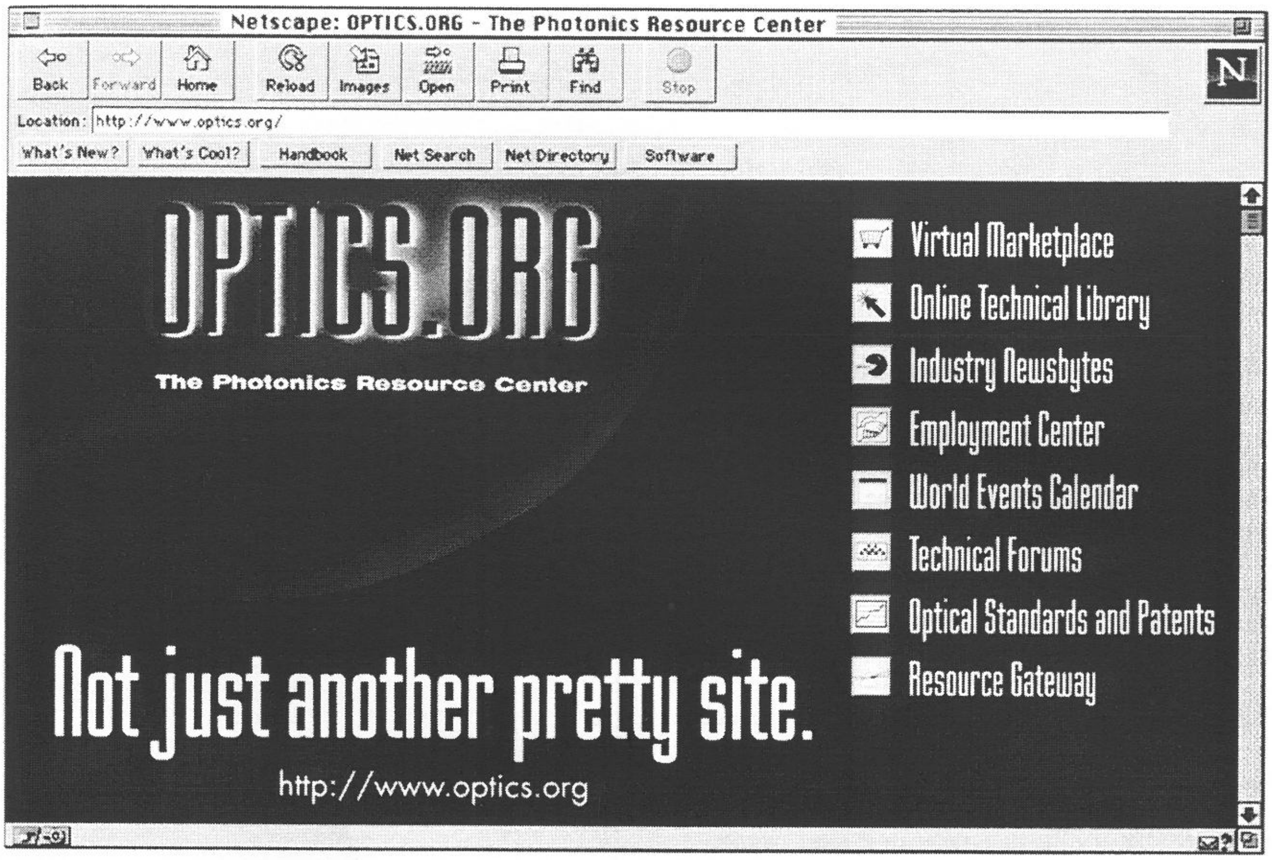
Monday morning of the conference saw David Hanna (Southampton), and Marty Fejer (Stanford) introduce a topic that visibly nailed the audience to their seats, and became an enduring theme of the conference: *engineered nonlinear materials*. Materials have always been the bottleneck in $\chi^{(2)}$ systems: despite 30 years of material research, only a handful of crystals are hardy and useful enough to be commercially available. By periodically inverting the medium every coherence length, QPM side-steps the angle, temperature and polarisation constraints of Type I & II phasematching. Both Southampton and Stanford presented amazing results for QPM engineered lithium niobate - called PPLN ("pipplin" - Periodically Poled Lithium Niobate). We will hear more of this material: already this year every second order nonlinear process has been demonstrated with amazing efficiencies. Stanford recently achieved 40% conversion for a CW beam on a *single pass* through 50 mm of PPLN! (2.25 W@532 nm from 5.6 W@1064nm). After this session nearly every speaker for the rest of the week prefaced their results with a comment like "of course, this can be much improved once PPLN becomes widely available".

The highlight of the nonlinearities in waveguides session was a talk by Philip Russel (Southampton) under the theme "no more expensive crystals, only cheap glasses". Philip introduced the acronym EFISH - Electric Field Induced SHG in glass fibres. Spurred on by the very high nonlinearity (6 pm/V) induced optically at the University of New South Wales, Southampton has already achieved strong nonlinearities (~2pm/V) with the EFISH technique.

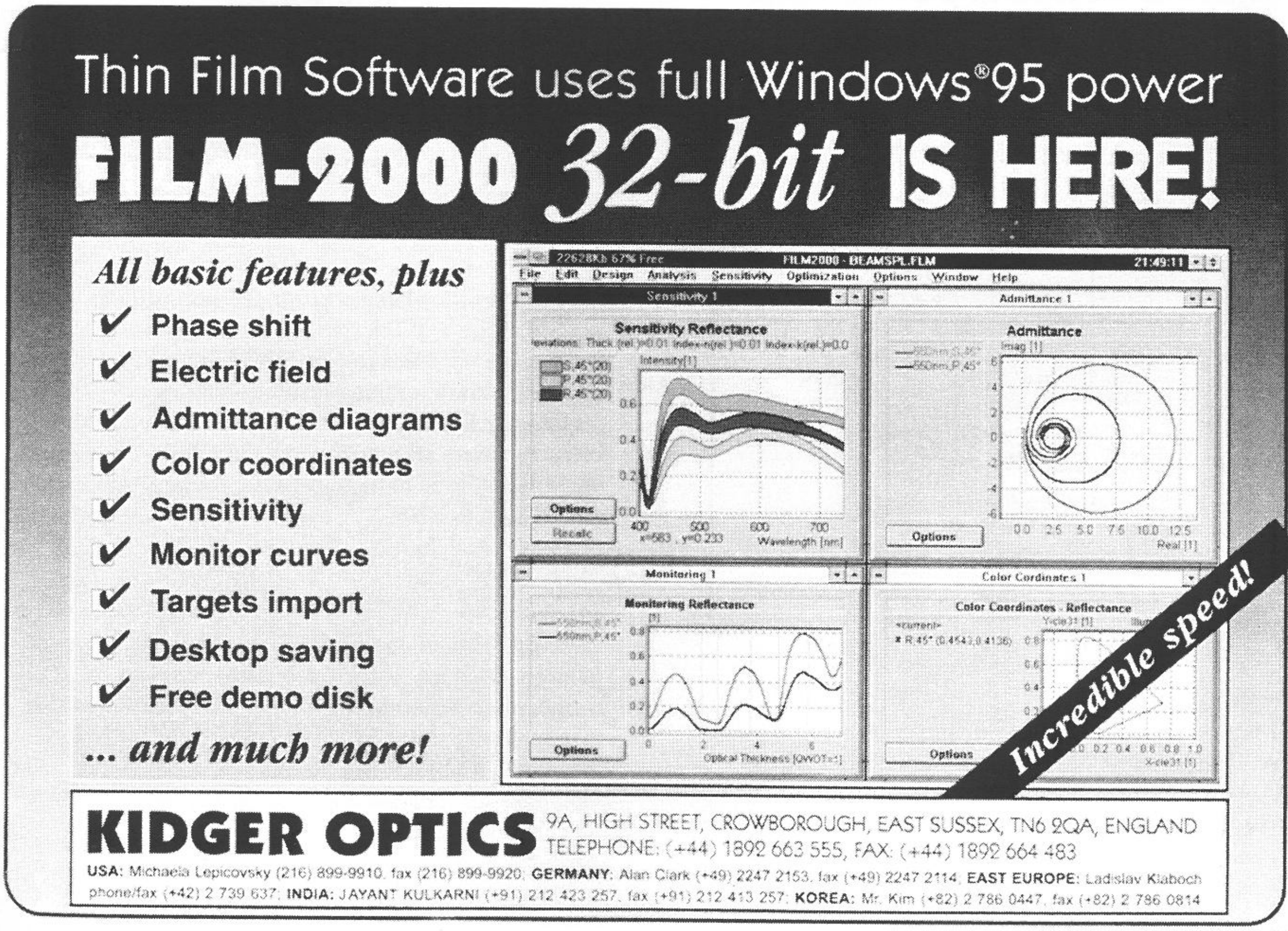
Optical parametric oscillators have now entered their maturity, with many speakers presenting results on both pulsed and CW configurations. Malcolm Dunn (St Andrews), gave an excellent tutorial on every flavour of CW OPO: singly, doubly, and triply resonant; active (intracavity with a laser) and passive (external to a laser) configurations. The tutorial was accompanied by impressive experimental results leaving many in the audience in no doubt that these technologies will soon be commercially available. (Update: St Andrew's recently demonstrated an active singly resonant OPO, where at high pump rates the power available at the tuned wavelength equals that of the laser *sans* the OPO.)

$\chi^{(2)}$ systems have found wide application. Several groups (Aarhus, Polzik; Canberra, Bachor; French Telecom, Levenson; Konstanz, Mlynek) all presented record results in squeezing or quantum non demolition (QND) using $\chi^{(2)}$ processes. The recently defined technique of "cascaded" $\chi^{(2)}$ nonlinearities, which offers all-optical switching and nonlinear phase shifts, was discussed for both pulsed (Florida, Stegeman) and CW configurations. Franco Wong (MIT) outlined an all $\chi^{(2)}$ frequency chain that links visible frequencies to gigahertz in seven steps: he proposes an entire optical chain on a 3" PPLN wafer! Numerous other applications, from spectroscopy to image amplification were presented, the most ambitious being the French program SILVA (Atomic Vapour Laser Isotope Separation) a program to obtain all French atomic fuel via laser separation rather than centrifuging. SILVA plans to replace all the copper lasers that are currently used for industrial two-step ionisation with frequency doublers: this requires development of very high power doubling systems.

I wish to thank the Australian Optical Society for the chance to attend this conference, which I certainly would not have been able to attend without the help of the Postgraduate Travel Prize. My attendance at this conference led to a new international collaboration and new research directions. I strongly encourage all PhD-student members of the AOS to apply for this prize. (You never know, if the demand is great enough they may give out more of them!)




For information on how your company can join, contact Marybeth Manning, marybeth@spie.org. 360/676-3290, 360/647-1445 (fax)



# 1996 AOS Membership List and Statistics

prepared by Esa Jaatinen
Hon Treasurer AOS

The range of areas and activities that constitutes 'Optics' is continually growing. So much so that today, some of the many interests of AOS members are not adequately described by any of the 17 categories offered on the AOS subscription form. Some pursue their interests for professional reasons while others simply because they are intrigued and fascinated by a particular area. Whatever the reason, this makes the AOS a very diverse group, and one that is hard to pigeon-hole. The following information has been compiled to help get some idea of what the AOS is, by looking at the membership in terms of our interests, occupations and where we live. At the conclusion of this report a detailed member listing is also given.

The following reflects the composition of the AOS membership on Monday the 14th of October 1996. On that date there were 307 members who were financial for 1996. Of these 14 were corporate, 5 life, 15 honorary, 231 regular and 42 were student members. These members are spread throughout Australia and neighbouring countries in the proportions indicated in figure 1.

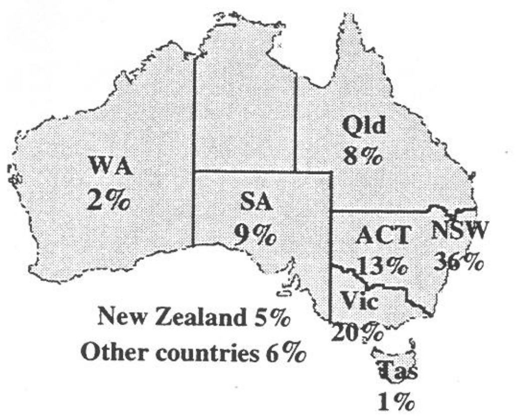



***Figure 1:** The distribution of AOS members*

## *Affiliations:*

Many members are affiliated with other science groups or societies. 102 AOS members are Optical Society of America (OSA) members, 129 are members of the Australian Institute of Physics (AIP), and 42 are members of the International Society for Optical Engineering (SPIE). 10 enthusiastic AOS members currently subscribe to all three affiliated societies.

## *Employment:*

Employment opportunities in science and engineering are of interest to many. Figure 2 shows the breakdown of the membership into some broad employment categories.

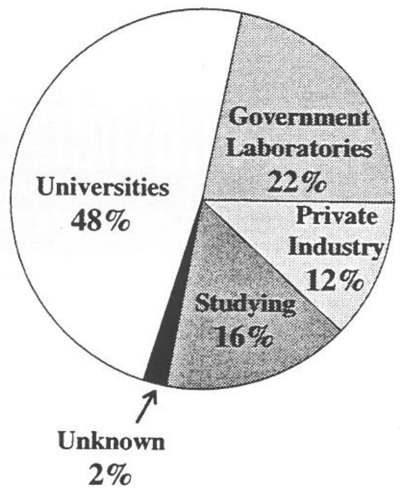



***Figure 2:** Where AOS members are employed*

Here government laboratories refers to institutes such as CSIRO, DSTO, Telecom Research Laboratories and the Bureau of Meteorology. The university category includes tertiary teaching institutes and pure research centres (eg CRCs, Mt Stromlo Observatory). Private industry covers all non-government employment from the self-employed to those working for large industrial groups such as BHP.

## *Interests:*

The members of the society have a wide range of interests in optics. Table 1 shows the numbers of AOS members interested in the various categories of optics that appear on the AOS subscription form. 14 of those members who selected categories 18, 19 or 20 indicated an interest in atom optics, and 7 were interested in microscopy.

| Category | First Preference | Second Preference | Third Preference |
|---|---|---|---|
| 1. Astronomical Optics | 21 | 11 | 7 |
| 2. Atmospheric Optics | 13 | 4 | 4 |
| 3. Communications & Fibres | 39 | 21 | 14 |
| 4. Electro-optics | 20 | 27 | 18 |
| 5. Fabrication & Testing | 11 | 9 | 11 |
| 6. Information Processing | 7 | 7 | 9 |
| 7. Lasers | 53 | 48 | 36 |
| 8. Optical Design | 16 | 28 | 22 |
| 9. Optical Physics | 18 | 36 | 30 |
| 10. Radiometry, Photometry & Colour | 8 | 17 | 6 |
| 11. Spectroscopy | 16 | 23 | 27 |
| 12. Thin Films | 9 | 8 | 11 |
| 13. Vision | 8 | 5 | 7 |
| 14. Quantum Optics | 20 | 8 | 13 |
| 15. Nonlinear Optics | 19 | 29 | 24 |
| 16. Teaching | 5 | 9 | 24 |
| 17. Holography | 9 | 4 | 9 |
| 18. | 33 | 12 | 10 |
| 19. | - | 7 | 1 |
| 20. | - | - | 1 |

***Table 1:* Interests of AOS members**

## *Member Listing:*

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**Prof. Ben Gascoigne**
3 Anstey St
Pearce ACT 2607
Primary field of interest: 1

**Prof. R. Hanbury-Brown**
White Cottage
Penton Mewsey Near Andover
Hants SP11 ORQ
UK
Tel: 026477 2334 Fax:
Primary field of interest: 0

**Dr Parameswaran (Hari) Hariharan**
CSIRO Division of Applied Physics
PO Box 218 Lindfield NSW 2070
Tel: 02 413 7783 Fax: 02 413 7200
email: hari@swifty.dap.csiro.au
Primary field of interest: 14

**Dr. Beattie Steel**
6 Abernethy St
Seaforth NSW 2092
Tel: 02 948 5818 Fax: 02 805 8983
Primary field of interest: 5

**Prof. Emil Wolf**
University of Rochester
Dept of Physics and Astronomy
Rochester New York 14627
USA
Tel: 716 275 4397 Fax:
Primary field of interest: 1

### Honorary Members:

**A.I.P.**
Australian Institute of Physics
1/21 Vale Street
North Melbourne
VIC 3051

**Dr A K Chakraborky**
Calcutta University
Dept of Physics
92 Acharya Prafulla Chandra Rd
Calcutta 700 009 INDIA

**Dr M W Chang**
National Central University
Optical Sciences Centre
Chung-Li 32054
TAIWAN

**Mme Francoise Chavel**
EOS Main Secretariat
BP 147, F-91403, Orsay Cedex
FRANCE

**Dr Toss Gascoigne**
Executive Director, FASTS
PO Box 218
Deakin West
ACT 2600
email: fasts@anu.edu.au

**Dr A Handojo**
Teknik Fisika ITB
JI Ganesha 1O
Bandung 4O132
INDONESIA

**Jan McInnis**
Optical Society of America
2010 Massachusetts Ave, NW
WASHINGTON DC
USA 20036-1023

**Mr Guy Nolch**
Editor -
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Control Publications Pty Ltd
14 Acheron Street Doncaster
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**James E. Pearson**
Executive Director SPIE
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USA

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Korea Inst of Science and Tech
Physics Dept
PO Box 150 Chongyangni Seoul 131
KOREA

**SIRA Limited**
South Hill
(Mr Lionel Baker)
Chislehurst Kent BR7 5EH
UK
Tel: 01 467 2636 Fax:
Primary field of interest: 3

**Dr S C Tam**
Nanyang Technological Inst
School of Mechanical Eng
Nangyang Ave SINGAPORE 2263

## Honorary Members:

**Prof. Wang Daheng**
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Pres Chinese Optical Society
52 San Li-He Road Beijing CHINA

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Fudan University
Kangpin Street 152 Lane
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(Mr Michael Fulton)
14 Fifth Lok Yang Road
Singapore 2262
Tel: 65 265 5122 Fax: 65 265 1479
Primary field of interest: 12

**British Aerospace Australia**
(Mr Gerry Smith)
PO Box 180
Salisbury
SA 5108
Tel: 08 256 0211 Fax: 08 255 9117
email: gsmith@awadi.com.au
Primary field of interest: 4

**Coherent Scientific Pty Ltd**
(Mr Norman Jones)
116 Burbridge Road
HILTON
SA 5033
Tel: 08 352 1111 Fax: 08 352 2020
email: 100351.1471@compuserve.com
Primary field of interest: 7

**Francis Lord Optics**
Att: Mr Alan Fry
33 Higginbotham Rd
Gladesville
NSW 2111
Tel: 02 807 1444 Fax: 02 809 7136
Primary field of interest: 5

**Hadland Photonics Pty Ltd**
(Mr Harold Biram)
19A Hampshire Road
Glen Waverley
Vic 3150
Tel: 03 9560 2366 Fax: 03 9560 8402
Primary field of interest: 18 high speed photography video instru.

**Kidger Optics Limited**
9A High St
(Dr Michael Kidger)
Crowborough East Sussex
TN6 2QA
UK
Tel: 0892 663555 Fax: 0892 664483
Primary field of interest: 8

**Laser Electronics (operations) Pty Ltd**
Mr R Craig Holberton
Marketing Manager
PO Box 359
SOUTHPORT
QLD 4215
Tel: 07 5596 0177 Fax: 07 5596 3530
Primary field of interest: 7

**Lastek Pty Ltd**
(Mr. Alex Stanco)
GPO Box 2212
Adelaide
SA 5001
Tel: 08 8443 8668 Fax: 08 8443 8427
email: lastek@saschools.edu.au
Primary field of interest: 11

**OptiScan Pty Ltd**
c/o Roger Wallis, General Manager
27 Normanby Road
Notting Hill
VIC 3138
Tel: 03 9562 7741 Fax: 03 9562 7742
email: rogerw@optiscan.com.au
Primary field of interest: 18 Confocal Microscopy

**Raymax Applications P/L**
John R Grace
16 Ross Street
Newport Beach
NSW 2106
Tel: 02 9979 7646 Fax: 02 9979 8207
Primary field of interest: 7

**Rofin Australia Pty Ltd**
Unit 4 42-44 Garden Boulevard
DINGLEY
VIC 3172
Tel: 03 558 0344 Fax: 03 558 0252
Primary field of interest: 8

**Spectra-Physics Pty, Ltd**
(Mr Ian Butler)
25 Research Drive
CROYDON
VIC 3136
Tel: 03 9761 5200 Fax: 03 9761 5600
email: COMPUSERV
Primary field of interest: 18 Photonics Supplier

**Warsash Pty Ltd**
(Mr. Bill McFadden)
PO Box 1685
STRAWBERRY HILLS
NSW 2012
Tel: 02 319 0122 Fax: 02 318 2192
Primary field of interest: 4

## Regular Members:

Dr Nail Akhmediev
Optical Sciences Centre
ANU
GPO Box 4
CANBERRA
ACT 2601
Tel: 06 249 0191 Fax: 06 249 5184
email: nna124@rsphy1.anu.edu.au
Primary field of interest: 12

Dr Brendan Edward Allman
c/o Shaun Griffin
School of Physics
University of Melbourne
Parkville
VIC 3052
Tel: 1 573 882 5325 Fax: 1 573 882 4195
email: allman@reactor.murr.missouri.edu
Primary field of interest: 9

Mr Tom Amos
Wave Link Systems Pty Ltd
PO Box 284
MORTDALE
NSW 2223
Tel: 02 580 4877 Fax: 02 264 9868
Primary field of interest: 3

Mr Don Anderson
Bureau of Meteorology
STAW (Atmosphere Watch), 27th Floor
GPO Box 1289K
Melbourne
Vic 3001
Tel: 03 9669 4235 Fax: 03 9669 4736
email: d.anderson@bom.gov.au
Primary field of interest: 2

Dini Andiani
Puslitbang KIM-LIPI
Komp. Puspiptek, Serpong
Tangerang - 15314
INDONESIA
Tel: (021) 756 0562 x 3056 Fax: 021 7560568
Primary field of interest: 6

Dr Adrian Ankiewicz
Australian National University
Optical Sciences Centre, I.A.S.
CANBERRA
ACT 0200
Tel: 06 249 2471 Fax: 06 249 5184
email: ana124@phys.anu.edu.au
Primary field of interest: 3

Stephen Argall
c/- 3 Cedric Avenue
Redwood Park
SA 5097
Tel: 0011 1 519 473 4461 Fax: 0011 1 519 661 2033
email: sargall@lucille.physics.uwo.ca
Primary field of interest: 2

Dr. Brian Armstrong
5 Saunders St
Narrabri
NSW 2390
Tel: 067 92 1019 Fax:
Primary field of interest: 2

Assoc Prof David Atchison
School of Optometry
Queensland University of Technology
Locked Bag No. 2
Red Hill
Qld 4059
Tel: 07 3864 5711 Fax: 07 3864 5665
email: d.atchison@qut.edu.au
Primary field of interest: 13

Mr Errol Atkinson
CSIRO Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: (02) 9413 7795 Fax: (02) 9413 7200
email: errol@swifty.dap.csiro.au
Primary field of interest: 10

**Regular Members:**

Dr Hans Bachor
Department of Physics
ANU
CANBERRA
ACT 0200
Tel: 06 249 2811 Fax: 06 249 0741
email: hans@aerodec.anu.edu.au
Primary field of interest: 14

Dr John Bahr
University of Otago
Dept of Physics
Dunedin
NEW ZEALAND

Tel: 64 3 4797806 Fax: 64 3 4790964
email: bahr@physics.otago.ac.nz
Primary field of interest: 2

Dr Ken Baldwin
ANU Laser Physics Centre
Reseach School of Physical Sciences
Canberra
ACT 0200
Tel: 06 249 4702 Fax: 06 249 0029
email: kenneth.baldwin@anu.edu.au
Primary field of interest: 18 - atom optics

Dr Ian Bassett
Optical Fibre Technology Centre
University of Sydney
NSW 2006
Tel: 02 351 1914 Fax: 02 351 1910
email: basset@physics.su.oz.au
Primary field of interest: 3

Dr Greg W. Baxter
Dept of Applied Physics
Victoria University
PO Box 14428MMC
Melbourne
VIC 3000
Tel: 03 9688 4277 Fax: 03 9688 4698
email: gregory=baxter@vut.edu.au
Primary field of interest: 16

Mr Tim Bedding
School of Physics
University of Sydney
NSW 2006
Tel: 02 351 2680 Fax: 02 660 2903
email: bedding@physics.usyd.edu.au
Primary field of interest: 1

Mr Miguel Blanco
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7317 Fax: 02 413 7200
email: mmb@swifty.dap.csiro.au
Primary field of interest: 6

Mr. Gabe Bloxham
Mount Stromlo Observatory
Private Bag
WESTON POST OFFICE
ACT 2611
Tel: 06 249 0238 Fax: 06 249 0233
email: gabe@mso.anu.edu.au
Primary field of interest: 1

Mr. Robert Peter Bonnell
Unit 77
13 Moseley St.
Glenelg
SA 5045
Tel: 08 294 8617 Fax:
Primary field of interest: 2

Assoc Prof Lindsay Botten
Univ of Technology Sydney
School of Mathematical Science
PO Box 123
Broadway
NSW 2007
Tel: 02 9514 2247 Fax: 02 9514 2260
email: lindsay@zen.maths.uts.edu.au
Primary field of interest: 9

Ms Susan Bowles
SSMD-FB
AMRL, DSTO
PO Box 4331
Melbourne
VIC 3001
Tel: 03 6267859 Fax: 03 6267087
email: susan.bowles@dsto.defence.gov.au
Primary field of interest: 9

Dr Nicholas Brown
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7157 Fax: 02 413 7200
email: nickb@dap.csiro.au
Primary field of interest: 7

Dr Peter Browne
Schl. of Mathematics & Physics
Macquarie University
North Ryde
NSW 2109
Tel: 02 850 8901 Fax: 02 850 8983
email: peterb@mpce1.mpce.mq.edu.au
Primary field of interest: 7

Mr Ronald Werner Bulla
CSIRO Div Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7078 Fax: 02 413 7631
email: rbulla@dap.csiro.au
Primary field of interest: 5

Dr. Clive Burton
Sola Int'l Holdings Ltd
PO Box 306
Lonsdale
SA 5160
Tel: 08 392 8362 Fax: 08 392 8400
email: cburton@sola.com.au
Primary field of interest: 12

Dr. Duncan Butler
CSIRO Division of Applied Physics
PO Box 218
LINDFIELD
NSW 2070
Tel: 02 413 7302 / 719 9042 AH Fax: 02 413 7200
email: duncanb@swifty.dap.csiro.au
Primary field of interest: 10

Mr Ryan Campbell
31 Cowley Crescent
Prospect
NSW 2149
Tel: 047 516 330 Fax: 047 516 392
Primary field of interest: 18 Process Control

Dr. Andrew Chalmers
Manukau Institute of Technology
Private Bag 94-006
Manukau City
Auckland
NEW ZEALAND
Tel: 09 274 6009 Fax: 09 273 0701
email: chalmers@manukau.ac.nz
Primary field of interest: 18- Machine Vision/Image Processing

Dr Christopher Chantler
School of Physics
University of Melbourne
PARKVILLE
VIC 3052
Tel: 03 344 5437 Fax: 03 347 3732
email: chantler@physics.unimelb.edu.au
Primary field of interest: 11

Mr. John Chapman
126 Raglan Road
North Perth
WA 6006
Tel: 09 482 1682 Fax: 09 482 1157
email: chapmanj@mail.iinet.net.au
Primary field of interest: 10

Dr. Philip Chapple
LSOD
DSTO Salisbury
PO Box 1500
Salisbury
SA 5108
Tel: 08 8259 7153 Fax: 08 8259 6638
email: philip.chapple@dsto.defence.gov.au
Primary field of interest: 6

Dr Kin Seng Chiang
Dept. of Electronic Engineeering
City University of Hong Kong
83 Tat Chee Avenue
Kowloon
Hong Kong
Tel: 852 2788 9605 Fax: 852 2788 7791
email: eeksc@cityu.edu.hk
Primary field of interest: 3

Ms Susanne Chiew
70 Oleander Ave
Baulkam Hills
NSW 2153
Tel: 02 624 2853 Fax:
Primary field of interest: 3

Dr Pak Lim Chu
University of NSW
Electrical Engineering School
PO Box 1
Kensington
NSW 2033
Tel: 02 697 5304 Fax: 02 662 2087
email: p.chu@unsw.edu.au
Primary field of interest: 3

Philip Ciddor
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 9413 7159 Fax: 02 9413 7200
email: pec@dap.csiro.au
Primary field of interest: 9

**Regular Members:**

Dr Barry Clark
DSTO Air Operations Division
Aeronautical & MaritimeResearch Lab
506 Lorimer St
Fishermens Bend
Vic 3207
Tel: 03 647 7730 Fax: 03 646 3433
email: barry.clark@dsto.defence.gov.au
Primary field of interest: 13

Mr. Colin Cochran
Electro Optic Systems Pty Ltd
8 McCubbin St
WESTON
ACT 2611
Tel: 06 299 2470 Fax: 06 249 2477
Primary field of interest: 8

Carol Cogswell
Department of Physical Optics
School of Physics
University of Sydney
NSW 2006
Tel: 02 351 3201 Fax: 02 692 0923
email: cogswell@physics.su.oz.au
Primary field of interest: 18 optical microscopy

Dr Graeme Cole
School of MPS
Murdoch University
Murdoch
WA 6150
Tel: 09 360 2364 Fax: 09 310 1711
email: graeme@cs.murdoch.edu.au
Primary field of interest: 10

Mr. Peter Conroy
Mount Stromlo Observatory
Private Bag
WESTON CREEK
ACT 2611
Tel: 06 247 4937 Fax: 06 249 0213
email: conroy@merlin.anu.edu.au
Primary field of interest: 1

Dr Gregory Cowle
Electrical Engineering
University of Sydney
Building TO3
NSW 2006
Tel: 02 351 3222 Fax: 02 351 3847
email: greg@ee.usyd.edu.au
Primary field of interest: 7

Prof. Lawrence Cram
School of Physics
The University of Sydney
NSW 2006
Tel: 02 9351 2537 Fax: 02 9351 7726
email: lcram@physics.usyd.edu.au
Primary field of interest: 16

Mr Steven Raymaond Croft
Optical Microscope Unit
James Cook University
Townsville
QLD 4811
Tel: 077 81 4418W 077 790885H
Fax: 077 81 4044
email: stevencroft1@jcu.edu.au
Primary field of interest: 18 microscopes

Associate Prof Stephen Dain
School of Optometry
UNSW
NSW 2052
Tel: 02 9385 4629 Fax: 02 9313 8602
email: s.dain@unsw.edu.au
Primary field of interest: 10

Dr Bryan Dalton
University of Queensland
Physics Department
ST LUCIA
QLD 4072
Tel: 07 365 3427 Fax: 07 365 1242
email: dalton@physics.uq.oz.au
Primary field of interest: 14

Mr. Clive Davenport
GBC Scientific Equipment P/L
PO Box 1226
Dandenong
Vic 3175
Tel: 03 213 3666 Fax: 03 213 3677
Primary field of interest: 8

Prof. John Davis
Chatterton Astronomy Dept
School of Physics
University of Sydney
NSW 2006
Tel: 02 351 3604 Fax: 02 660 2903
email: davis@physics.usyd.edu.au
Primary field of interest: 1

Dr Judith Dawes
School of MPCE
Macquarie University
North Ryde
NSW 2109
Tel: 02 850 8903 Fax: 02 850 8983
email: judith@macadam.mpce.mq.edu.au
Primary field of interest: 7

Dr Martijn de Sterke
School of Physics
University of Sydney
Sydney
NSW 2006
Tel: 02 351 2906 Fax: 02 660 2903
email: desterke@physics.usyd.edu.au
Primary field of interest: 15

Mr David Death
CSIRO Minerals
PMB 5
Menai

NSW 2234
Tel: 02 710 6724 Fax: 02 710 6789
email: death@mpe67.dmpe.csiro.au
Primary field of interest: 11

Dr John Dudley
Dept of Physics
University of Auckland
Private Bag 92019
Auckland
NEW ZEALAND
Tel: +64 9 3737599 Fax: +64 9 3737445
email: jmd@phy.auckland.oc.nz
Primary field of interest: 7

Dr. Ben Duval
BHP Research
Newcastle Laboratories
PO Box 188
Wallsend
NSW 2287
Tel: 049-512-444 Fax: 049-502-126
Primary field of interest: 4

Dr Sigurd Dyrting
Dept of Physics
University of Queensland
St Lucia
Qld 4072
Tel: 07 3365 3420 Fax: 07 3365 2142
email: dyrting@physics.uq.oz.au
Primary field of interest: 18 - atom optics

Mr John Eberhardt
CSIRO Minerals
Private Mail Bag #5
MENAI
NSW 2234
Tel: 02 710 6723 Fax: 02 710 6789
email: john.eberhardt@minerals.csiro.au
Primary field of interest: 2

Dr Ian Edmonds
School of Physics
Qld Uni Tech
PO Box 2434
Brisbane
QLD 4000
Tel: 07 3864 2584 Fax: 07 3864 1521
email: i.edmonds@qut.edu.au
Primary field of interest: 8

Dr Geoff Edwards
Japan-Australia Technical Cons
JATCO (Australia) Pty Ltd
12-20 Hobsons Plc
Adelaide
SA 5000
Tel: 08 410 2399 Fax: 08 410 0530
email: jatco@ozemail.com.au
Primary field of interest: 7

Prof. Paul Edwards
University of Canberra
P.O. Box 1
Belconnen
ACT 2626
Tel: 06-2012515 Fax: 06-2015227
email: Paule@ise.canberra.edu.au
Primary field of interest: 3

Mr Stephen Elgar
113 Murrell Road
Para Hills
SA 5096
Tel: 08 259 5141 Fax: 08 259 5688
email: stephen .elgar@dsto.defence.gov.au
Primary field of interest: 4

Dr. Roderick Esdaile
Australian Trade Commission
3000 Town Center
Suite 2025
Southfield, MI 48075-1152

Tel: 1 810 208 0500 Fax: 1 810 208 0508
email: rje@mlb.dmt.csiro.au
Primary field of interest: 12

Mr David Farrant
CSIRO
Div of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7211 Fax: 02 413 7200
email: davidf@dap.csiro.au
Primary field of interest: 6

**Regular Members:**

Dr Peter Farrell
Optical Technology Research Lab
Dept. of Applied Physics
Victoria University
PO Box 14428 MMC, Melbourne
VIC 3000
Tel: 03 9688 4282 Fax: 03 9688 4696
email: peter=farrell@vut.edu.au
Primary field of interest: 11

Dr Pal Fekete
Dept Physical Optics
School of Physics
Uni Sydney
NSW 2006
Tel: 02 9351 3941 Fax: 02 9351 7727
email: p.fekete@physics.usyd.edu.au
Primary field of interest: 18 - adaptive optics

Dr Zbigniew Ficek
University of Queensland
Dept of Physics
BRISBANE
QLD 4072
Tel: 07 3365 3409 Fax: 07 3365 1242
email: ficek@physics.uq.oz.au
Primary field of interest: 14

Dr. Simon Fleming
Australian Photonics CRC
101 National Innovation Centre
Australian Technology Park
Eveliegh
NSW 1430
Tel: 02 335 0926 Fax: 02 335 0910
email: s.fleming@oftc.usyd.edu.au
Primary field of interest: 3

Dr. Guy Fletcher
School of MCPE
Macquarie University
NSW 2109
Tel: 02 850 8930 Fax: 02 850 8115
email: guy@mpce.mq.edu.au
Primary field of interest: 9

Mr Victor Florea
Telectronics Pty Ltd
2 Sirius Road
LANE COVE
Sydney
NSW 2066
Tel: 02 413 6804 Fax: 02 413 6789
email: victorf@tps.com
Primary field of interest: 7

Dr. Greg Forbes
Macquarie University
School of MCPE
North Ryde
NSW 2109
Tel: 02 850 8908 Fax: 02 850 8983
email: forbes@mpce.mq.edu.au
Primary field of interest: 8

Dr. Bruce Forgan
Bureau of Meteorology
SRIN/OEB
PO Box 1289K
Melbourne
Vic 3001
Tel: 03 9669 4599 Fax: 03 9669 4736
email: b.forgan@bom.gov.au
Primary field of interest: 2

Mr Phil Francis
RMIT
Applied Physics Department
PO Box 2476V
Melbourne
Vic 3001
Tel: 03 9660 2969 Fax: 03 9660 5290
email: philf@rmit.edu.au
Primary field of interest: 11

Dr R H Frater
CSIRO
Institute ISE
PO Box 93
North Ryde
NSW 2113
Tel: 02 887 8220 Fax: 02 887 2736
email: rfrater@iise.csiro.au
Primary field of interest: 1

Mr Christopher Hayes Freund
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7122 Fax: 02 413 7200
email: chrisf@dap.csiro.au
Primary field of interest: 18 Instr Design

Dr James Gardner
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7323 Fax: 02 413 7200
email: jlg@dap.csiro.au
Primary field of interest: 10

Dr. Gorachand Ghosh
Electrotechnical Laboratory
Optoelectronics Division
Ministry of Internat. Trade & Industry
1-1-4, Umezono, Tsukuba-305
Japan
Tel: 02 351 3941 Fax: 02 692 0923
email: gora@physics.usyd.edu.au
Primary field of interest: 15

Dr. Stephen Thomas Gibson
UV Physics Unit
RSPhysSE
ANU
Canberra
ACT 0200
Tel: 06 249 2296 Fax: 06 249 0390
email: stephen.gibson@anu.edu.au
Primary field of interest: 18 Computational Physics

Mr. Peter Gillingham
W M Keck Observatory
P O Box 6212
Kamuela HI96743
USA
Tel: 1 808 885 7887 Fax: 1 808 885 4464
email: pgillingham@keck.hawaii.edu
Primary field of interest: 1

Michael Gillyon
11 Armagh Crs
Salisbury Downs
SA 5108
Tel: 08 258 3049 Fax:
email: michael.gillyon@dsto.defence.gov.au
Primary field of interest: 4

Dr Muhammed Ashraf Gondal
King Fahd Uni. of Petroleum & Minerals
Box 372
DHAHRAN 31261
Saudi-Arabia

Tel: 00966-3-8605395 Fax: 00966-3-8604281
email: rsis20b@saupmoo.bitnet
Primary field of interest: 7

Dr. Dmitri Gramotnev
8/38 Gordon St
Glenelg
NOT AT THIS ADDRESS!!!!!
S.A. 5045
Tel: 08 376 1501 Fax:
Primary field of interest: 3

Dr Ken Grant
Communications Division
PO Box 1500
Salisbury
SA 5108
Tel: 08 259 5581 Fax: 08 259 6328
email: ken.grant@dsto.defence.gov.au
Primary field of interest: 4

Dr Min Gu
Department of Applied Physics
Victoria Umiversity of Technology
PO Box 14428, MCMC
VIC 8001
Tel: 03 96884284. Fax: 03 96884698
email: ming@dingo.vut.edu.au
Primary field of interest: 9

Dr Tim Gureyev
CSIRO Div. of Forestry & Forest Products
Private Bag 10, Clayton Sth MDC
Clayton
Vic 3169
Tel: 03 9542 2646 Fax: 03 9543 6613
email: t.gureyev@ffp.csiro.au
Primary field of interest: 9

Dr Peter Hannaford
CSIRO Div. Materials Science & Technology
Private Bag 33
Rosebank MDC
CLAYTON
VIC 3169
Tel: 03 542 2874 Fax: 03 544 1128
email: hannafor@rivett.mst.csiro.au
Primary field of interest: 18 atom optics

Dr John Harvey
Physics Dept.
University of Auckland
Private Bag 92019
AUCKLAND
New Zealand
Tel: +64 93 737599 ext 8831 Fax: +64 93 737445
email: j.harvey@auckland.ac.nz
Primary field of interest: 16

Dr. John Haub
School of Chemistry
Macquarie University
Ryde
Sydney
NSW 2109
Tel: 02 850 8299 Fax: 02 850 8313
email: cm_haub@hope.ocs.mq.edu.au
Primary field of interest: 7

## Regular Members:

Mrs Ann Hazard
21 Earnshaw St
Gladesville
NSW 2111
Tel: 02 9850 8126 Fax: 02 9850 8115
Primary field of interest: 3

Dr. Norman Heckenberg
University of Queensland
Physics Department
St Lucia
Qld 4072
Tel: 073 365 3369 Fax: 073 365 1248
email: heckenberg@physics.uq.oz.au
Primary field of interest: 7

Zoltan Hegedus
CSIRO
Div of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7211 Fax: 02 413 7200
Primary field of interest: 5

Dr. John Hermann
DSTO Land, Space & Optoelectronics Div.
PO Box 1650
Salisbury
SA 5108
Tel: O8 259 7159 Fax: 08 259 5796
email: jth@dstos3.dsto.gov.au
Primary field of interest: 15

Dr. Arthur Ho
CRCERT
UNSW
Sydney
NSW 2052
Tel: 02 9385 0223 Fax: 02 9385 0243
email: a.ho@cclru.unsw.edu.au
Primary field of interest: 13

Dr Frank Honey
Managing Director
SpecTerra Systems Pty. Ltd.
2 Leura Street
Nedlands
WA 6009
Tel: 09 386 2992 Fax: 09 386 2635
email: specterr@yarrow.wt.com.au
Primary field of interest: 8

Dr Michael Hrynevych
Dept. of Physical Optics
School of Physics, A28
University of Sydney
NSW 2006
Tel: 02 9351 5958 Fax: 02 9351 7727
email: mick@physics.usyd.edu.au
Primary field of interest: 1

Abbie Angharad Hughes
I.A.S. Optical Sciences Centre
c/o 41 Outlook Drive
Eaglemount
VIC 3084
Tel: 03 487 1618 Fax:
email: abbies@ariel.ucs.unimelb.edu.au
Primary field of interest: 13

Dr Roy J. Hughes
DSTO
PO Box 1500
Salisbury
S A 5108
Tel: 08 259 5683 Fax:
email: roy.hughes@dsto.defence.gov.au

Dr. Richard Hunstead
Astrophysics Department
School of Physics
University of Sydney
NSW 2006
Tel: 02 351 3871 Fax: 02 660 2903
email: rwh@astrop.physics.usyd.edu.au
Primary field of interest: 1

Dr. Barry Inglis
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7460 Fax: 02 413 7383
email: inglis@dap.csiro.au
Primary field of interest: 3

Dr. Esa Jaatinen
CSIRO Division of Applied Physics
PO Box 218
LINDFIELD
NSW 2070
Tel: 02 413 7269 Fax: 02 413 7200
email: esaj@dap.csiro.au
Primary field of interest: 7

Dr William Jagger
Monash University
Dept of Ecology & Evolutionary
Clayton
Vic 3168
Tel: 03 905 3806 Fax: 03 565 5613
email: wsjagger@vaxc.cc.monash.edu.au
Primary field of interest: 13

A/Prof. Brian James
University of Sydney
School of Physics
Sydney
NSW 2006
Tel: 02 351 2712 Fax: 02 692 0923
email: b.james@physics.usyd.edu.au
Primary field of interest: 11

Mr Peter Johnson
School of Science
Griffith University
Nathan
Qld 4111
Tel: 07 3875 7588 Fax:

Mr. Damien Jones
PRIME OPTICS
17 Crescent Rd
EUMUNDI
QLD 4562
Tel: 07 5442 8831 Fax: 07 5442 8804
email: djajones@ozemail.com.au
Primary field of interest: 8

Dr Deborah Kane
School of MPCE
Macquarie University
NSW 2109
Tel: 02 9850 8907 Fax: 02 9850 8983
email: mp_kane@hope.ocs.mq.edu.au
Primary field of interest: 7

Mr. Rajeev Katti
School of Maths and Physics
Macquarie University
North Ryde
NSW 2109
Tel: 02 850 8126 Fax: 02 850 8115
email: rajeev@mpce.mq.edu.au
Primary field of interest: 4

Dr. Paul Kinsler
Department of Physics
University of Sheffield
Sheffield S3 7RH
United Kingdom

Tel: 44 114 2824283 Fax: 44 114 2728079
email: p.kinsler@sheffield.ac.uk
Primary field of interest: 14

Dr Yuri Kivshar
Optical Sciences Centre
RSPhysSE
Australian National University
Canberra
ACT 0200
Tel: 06 249 3081 Fax: 06 249 5184
email: yk124@rsphysse.anu.edu.au
Primary field of interest: 15

Prof. Anthony George Klein
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 344 5421 Fax: 03 347 4783
email: klein@physics.unimelb.edu.au
Primary field of interest: 9

Dr Andrew Klekociuk
Channel Highway
Kingston
TASMANIA 7050
Tel: 002 323 382 Fax: 002 323 496
email: andrew_kle@antdiv.gov.au
Primary field of interest: 2

Dr. Elmars Krausz
Research School of Chemistry
Australian National University
Canberra
ACT 0200 2601
Tel: 06-249-3577 Fax: 06-249-0750
email: krausz@rsc.anu.edu.au
Primary field of interest: 7

Mr Michy Kris
Sola International Holdings
PO Box 306
Lonsdale
SA 5160
Tel: 08 392 8392 Fax: 08 392 8400
email: mkris@sola.com.au
Primary field of interest: 5

Dr. Wieslaw Krolikowski
Laser Physics Centre
ANU
Canberra
ACT 2601
Tel: 06 249 4244 Fax: 06 249 0029
email: wzk111@rsphy1.anu.edu.au
Primary field of interest: 15

Dr Peter Krug
Optical Fibre Technology Centre
University of Sydney
NSW 2006
Tel: 02 335 0921 Fax: 02 335 0910
email: krug@oftc.su.oz.au
Primary field of interest: 3

## Regular Members:

Alfred Kruijshoop
Telecom Research Laboratories
PO Box 249
Clayton
vic 3168
Tel: 03 253 6622 Fax: 03 253 6666
email: a.kruijshoop@trl.oz.au
Primary field of interest: 3

Mr Kieran Larkin
Dept of Physical Optics
School of Physics
University of Sydney
SYDNEY
NSW 2006
Tel: 02 9351 3979 Fax: 02 9351 7727
email: k.larkin@physics.usyd.edu.au
Primary field of interest: 18 - 3-D imaging theory

Dr Susan Hilary Law
52 Victoria Ave
Concord West
NSW 2138
Tel: 02 351 2104(W) 02 743 5598(H) Fax: 02 351 3847
email: suel@ee.usyd.edu.au
Primary field of interest: 18 plasma diagnostics

Dr Margaret Law
30A Clark Avenue
Scandore
SA 5037
Tel: (08) 300 4400 Fax: (08) 349 7420
email: margaret@vsl.com.au
Primary field of interest: 7

Mr Malcolm Lawn
CSIRO
Div of Applied Physics
PO Box 218
LINDFIELD
NSW 2070
Tel: 02 413 7101 Fax: 02 413 7200
email: malcolml@dap.csiro.au
Primary field of interest: 11

Mr Achim Leistner
CSIRO
Div of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7077 Fax: 02 413 7200
email: achim@dap.csiro.au
Primary field of interest: 5

Prof. William Levick
Division of Neurosciences
John Curtin School of Medical Sciences
GPO Box 334
Canberra
ACT 2601
Tel: 06 249 2525 Fax: 06 249 2687
email: william.levick@anu.edu.au
Primary field of interest: 13

Mr. Philip Lingard
P.O. Box 154
Summer Hill
NSW 2130
Tel: 02 798 9606 Fax: 02 798 9606
Primary field of interest: 5

Dr John Love
Optical Sciences Centre
ANU
Canberra
ACT 0200
Tel: 06 249 4691 Fax: 06 249 5184
email: jdl124@phys.anu.oz.au
Primary field of interest: 3

Mr Martin Lowe
CSIRO
Div Materials Science & Techno
Locked Bag 33
Clayton
Vic 3168
Tel: 03 542 2876 Fax: 03 544 1128
email: lowe@rivett.mst.csiro.au
Primary field of interest: 7

Prof. Barry Luther-Davies
Laser Physics Centre
RSPhysSE
Australian National University
ACT 0200
Tel: 06 249 4244 Fax: 06 242 0029
email: bld111@rsphy1.anu.edu.au
Primary field of interest: 7

Mr John Macdonald
28 Lawrence St
BRIGHTON
VIC 3186
Tel: 03 592 7518 Fax:
Primary field of interest: 9

Prof. William MacGillivray
Griffith University
School of Science
NATHAN
QLD 4111
Tel: 07 3875 7271 Fax: 07 3875 7656
email: w.macgillivray@sct.gu.edu.au
Primary field of interest: 14

Dr. Arthur Maddever
BHP Research
Newcastle Laboratories
PO Box 188
Wallsend
NSW 2287
Tel: 049 512 444 Fax: 049 502 126
email: maddever.arthur.am@bhp.com.au
Primary field of interest: 18 sensing

Mrs Yukie Mak
Dept of Electrical & Electronic Eng
Univ of Western Australia
Nedlands
WA 6009
Tel: 09 380 2532 Fax: 09 380 1065
email: yukie@ee.uwa.edu.au
Primary field of interest: 17

Mr Siegfried Manietta
4 Powers Road
Kholo
QLD 4306
Tel: 07 3875 3170 Fax: 07 3875 3199
email: S.Manietta@qca.gu.edu.au
Primary field of interest: 16

Mr. Ian Mansfield
Longman Optical
Technopark
Glenorchy
Tas 7010
Tel: 002 718 1O5 Fax: 002 720 768
Primary field of interest: 1

Dr Neil Manson
ANU
Laser Physics Centre
R S Phys S E
CANBERRA
ACT 0200
Tel: 06 249 4204 Fax: 06 249 0029
email: neil.manson@anu.edu.au
Primary field of interest: 7

Dr Albert Mau
CSIRO
Division of Chemicals and Polymers
Private Bag 10
Clayton
VIC 3168
Tel: 03 9542 2591 Fax: 03 9542 2589
email: a.mau@chem.csiro.au
Primary field of interest: 7

Dr David Ernest McClelland
ANU Faculty of Science
Dept Physics & Theoretical Phy
GPO Box 4
Canberra
ACT 0200
Tel: 06 249 2810 Fax: 06 249 0741
email: david.mcclelland@anu.edu.au
Primary field of interest: 14

Dr. Alexander Ian McIntosh
Dynamic Light Ltd
PO Box 384
Wahroonga
NSW 2076
Tel: 02 482 1580 Fax: 02 482 1581
email: aimc@eworld.com
Primary field of interest: 7

Dr. Peter McIntyre
Department of Mathematics & Statistics
University College (UNSW)
ADFA
Canberra
ACT 2600
Tel: 06 268 8896 Fax: 06 268 8886
email: p-mcintyre@adfa.edu.au
Primary field of interest: 13

Dr Timothy McIntyre
Dept of Physics
Uni of Queensland
St Lucia
Qld 4072
Tel: 07 3365 3413 Fax: 07 3365 1242
email: mcintyre@physics.uq.edu.au
Primary field of interest: 11

Prof. Bruce Harold John McKellar
Faculty of Science
University of Melbourne
Parkville
VIC 3052
Tel: 03 9344 6407 Fax: 03 9344 5803
email: mckellar@physics.unimelb.edu.au
Primary field of interest: 2

Dr Iain McKinnie
Dept of Physics
University of Otago
Dunedin
New Zealand
Tel: 64 3 479 7749 Fax: 64 3 479 0964
email: mckinnie@physics.otago.ac.nz
Primary field of interest: 7

## Regular Members:

Dr. Ross McPhedran
Dept of Theoretical Physics
School of Physics
The University of Sydney
NSW 2006
Tel: 02 692 3872 Fax: 02 660 2903
email: ross@physics.su.oz.au
Primary field of interest: 3

Mr Murray Meharry
13 Greensview Rd
Banksia Park
SA 5091
Tel: 08 264 2734 Fax:
Primary field of interest: 4

Miss Carol Louise Miles
Selim Systems
4/300 Armagh Street
Christchurch
New Zealand 8001
Tel: 0064 3 366-7567 Fax: 0064 3 366-7567
Primary field of interest: 17

Dr Paul Miller
DSTO
Land, Space & Optoelectronics Division
PO Box 1500
SALISBURY
SA 5108
Tel: 08 259 5135 Fax: 08 259 5055
email: miller@lsod.dsto.gov.au
Primary field of interest: 6

Dr Clyde Joseph Mitchell
CSIRO DMS&T
PrivateBag 33
Clayton South MDC
Vic 3169
Tel: 03 9542 2942 Fax: 03 9544 1128
email: mitchell@mst.csiro.au
Primary field of interest: 8

Mr Valery Mogulsky
7/663 Inkerman Road
N. Caulfield
VIC 3161
Tel: 03 9509 9936 Fax: 03 9544 1128
email: mogulsky@mst.csiro.au
Primary field of interest: 8

Prof Anthony Moon
Univ of Technology Sydney
Department of Physics
PO Box 123
Broadway
NSW 2007
Tel: 02 330 2210 Fax: 02 330 1656
email: tonym@phys.uts.edu.au
Primary field of interest: 9

Dr Ian Moore
School of Physics
QUT
GPO Box 2434
Brisbane
QLD 4001
Tel: 07 3864 1583 Fax: 07 3864 1521
email: i.moore@qut.edu.au
Primary field of interest: 17

Mr. Amir Mostofi
Optical Communications Group
School of Electrical Engineering
UNSW
NSW 2052
Tel: 02 385 5394 Fax: 02 385 5993
email: amiro@cse.unsw.edu.au
Primary field of interest: 3

Prof Jeremy Mould
Mt Stromlo & Sidings Spring Observatories
Private Bag
Weston Creek Post Office
Canberra
ACT 2611
Tel: 06 249 0266 Fax: 06 249 0260
email: director@mso.anu.edu.au
Primary field of interest: 1

Mr D Muff
Balzers Australia Pty Ltd
3 Northcliff Street
Level 1
Milsons Point
NSW 2061
Tel: 02 954 1925 Fax: 02 954 1939
Primary field of interest: 4

Prof. Jesper Munch
Dept of Physics
University of Adelaide
ADELAIDE
SA 5005
Tel: 08 303-4749 Fax: 08 232 6541
email: jmunch@physics.adelaide.edu.au
Primary field of interest: 7

Dr. Roger Netterfield
CSIRO
Div of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7120 Fax: 02 413 7200
email: roger@dap.csiro.au
Primary field of interest: 12

Dr Michael P. Newell
CSIRO Div Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7771 Fax: 02 413 7200
Primary field of interest: 18 Surface Profiling

Dr Nicolae-Alexandru Nicorovici-Porumbaru
Dept of Theoretical Physics
School of Physics
The University of Sydney
NSW 2006
Tel: 02 351 5897 Fax:
email: nicolae@physics.su.oz.au
Primary field of interest: 9

Mr Gregory Joseph Noonan
Davies Collison Cave
1 Little Collins St
Melbourne
VIC 3000
Tel: 03 9254 2777 Fax: 03 9254 2770
Primary field of interest: 18 patent attorney

Prof. Keith Nugent
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 344 5446 Fax: 03 347 4783
email: kan@muon.ph.unimelb.edu.au
Primary field of interest: 1

Dr John O'Byrne
Department of Physical Optics
School of Physics
University of Sydney
Sydney
NSW 2006
Tel: 02 352 3184 Fax: 02 660 2903
email: obyrne@physics.su.au.oz
Primary field of interest: 1

A/Prof. Richard O'Sullivan
RMIT
Applied Physics Department
Box 2476V
GPO Melbourne
Vic 3001
Tel: 03 9660 3389 Fax: 03 9663 2764
email: ro'sullivan@rmit.edu.au
Primary field of interest: 16

Mr. Raymond Oermann
Box 935 P.O.
Gawler
SA 5118
Tel: 08 8259 5356 Fax: 08 8259 5938
email: ray.oermann@dsto.defence.gov.au
Primary field of interest: 10

Prof. Geoffrey Opat
University of Melbourne
School of Physics
Parkville
Vic 3052
Tel: 03 344 5121 Fax: 03 347 4783
email: opat@physics.unimelb.edu.au
Primary field of interest: 9

Dr Bob Oreb
CSIRO
Div Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7303 Fax: 02 413 7200
email: bfo@dap.csiro.au
Primary field of interest: 18 Optical profiling

Prof Brian Orr
School of Chemistry
Macquarie University
NSW 2109
Tel: 02 850 8289 Fax: 02 850 8313
email: brian.orr@mq.edu.au
Primary field of interest: 7

Dr. Francois Ouellette
Optical Fibre Technology Centre
P.O. Box 1716
Strawberry Hills
NSW 2012
Tel: 335 0919 Fax: 335 0910
email: f.ouellette@oftc.usyd.edu.au
Primary field of interest: 3

Prof Colin Pask
Department of Mathematics
Australian Defence Force Academy
University College
Canberra
ACT 2600
Tel: 06 268 8687 Fax: 06 268 8886
email: c-pask@adfa.edu.au
Primary field of interest: 3

## Regular Members:

Dr Helen Pask
19 Peacock St
Seaforth
NSW 2092
Tel: Home 9949 1256 Fax: 02 9850 8983
email: hpask@mpce1.mpce.mq.edu.au
Primary field of interest: 7

Mr Ian Pearson
CSIRO- Div. Building, Construction & Eng.
PO Box 56
Highett
VIC 3190
Tel: 03 9252 6132 Fax: 03 9252 6240
email: ian.pearson@dbce.csiro.au
Primary field of interest: 11

Dr. Gang-Ding Peng
School of Electrical Eng.
UNSW
Kensington
NSW 2033
Tel: 02 9385 4014 Fax: 02 9385 5993
email: g.peng@unsw.edu.au
Primary field of interest: 3

Dr David Phillips
DSTO
Microwave Radar Division
GPO BOX 1500
SALISBURY
SA 5108
Tel: 08 259 5603 Fax: 08 259 5200
email: philldm@mrd.srl.dsto.gov.au
Primary field of interest: 2

Dr. Philip Picone
DSTO
SRL HQ2
PO Box 1500
Salisbury
SA 5108
Tel: 08 259 7155 Fax: 08 259 5055
email: piconep@oed.dsto.gov.au
Primary field of interest: 2

Dr. C. Martin Platt
47 Koetong Pde
Mt Eliza
VIC 3930
Tel: 03 586 7666 Fax: 03 586 7600
email: cmp@larry.dar.csiro.au
Primary field of interest: 2

Dr Leon Poladian
Optical Fibre Technology Cntr
Building G05
University of Sydney
NSW 2006
Tel: 02 692 3241 Fax: 02 692 4671
email: leon@physics.su.oz
Primary field of interest: 3

Mr Colin Porter
Colin Porter Consulting Scientist Pty Ltd
9 Moselle St
Box Hill Nth
VIC 3129
Tel: 03 9890 3872 Fax: 03 9890 3872
Primary field of interest: 8

Dr David Pulford
36 Rossarden St
Fisher
ACT 2611
Tel: 06 265 0743 Fax: 06 265 0925
email: davidp@defcen.gov.au
Primary field of interest: 3

Dr Roger Reeves
Department of Physics and Astronomy
University of Canterbury
PB4800
Christchurch
New Zealand
Tel: 64 3 364 2572 Fax: 64 3 364 2469
email: r.reeves@phys.canterbury.ac.nz
Primary field of interest: 11

Dr Mark Riley
Department of Chemistry
University of Queensland
St. Lucia
QLD 4072
Tel: 07 3365 3932 Fax: 07 3365 4299
email: riley@chem.chemistry.uq.edu.au

Dr Aftab Rizvi
4/46 Provincial St
Auburn
NSW 2144
Tel: 02 646 4884 Fax:
Primary field of interest: 18 optical signal processing

Dr Ann Roberts
School of Physics
Melbourne University
Parkville
VIC 3052
Tel: 03 9344 5038 Fax: 03 9347 4783
email: roberts@optics.ph.unimelb.edu.au
Primary field of interest: 3

Dr Andrew V Rode
Laser Physics Centre
Australian National University
CANBERRA
ACT 0200
Tel: 06 249 4637 Fax: 06 249 0029
email: avr111@rsphy1.anu.edu.au
Primary field of interest: 18 pulsed laser deposition of thin films

Mr M.W. Rossiter
Optis
The Stables
9 Pepper Avenue
Stirling
S A 5152
Tel: 08 339 4981 Fax:

Mr David Rowlands
Aeronautical & Maritime Research Labs
Structures Division
PO Box 4331
Melbourne
Vic 3001
Tel: 039 6267343 Fax: 039 626 7089
Primary field of interest: 17

A/Prof. Halina Rubinsztein-Dunlop
Department of Physics
The University of Queensland
Brisbane
QLD 4072
Tel: 07 365 3412 Fax: 07 365 1242
email: halina@physics.uq.oz.au
Primary field of interest: 11

Dr Stuart Rumble
153 Olinda-Monbulk Rd
Olinda
VIC 3788
Tel: 03 558 0344 Fax: 03 558 0252
Primary field of interest: 4

Dr Wayne Sainty
CSIRO
Div of Applied Physics
PO Box 218
LINDFIELD
NSW 2070
Tel: 02 9413 7119 Fax: 02 9413 7161
email: wayne@dap.csiro.au
Primary field of interest: 12

Prof Rowland Sammut
School of Mathematics and Statistics
University College
ADFA
Canberra
ACT 2600
Tel: 06 268 8892 Fax: 06 268 8886
email: r.sammut@adfa.edu.au
Primary field of interest: 3

Dr. Marek Samoc
Laser Physics Centre
RSPhysSE
ANU
Canberra
ACT 0200
Tel: 06 249 4611 Fax: 06 249 0029
email: mjs111@rsphy1.anu.edu.au
Primary field of interest: 15

Dr Anna Samoc
Laser Physics Centre
RSPhys SE
Aust Nat Uni
Canberra
ACT 0200
Tel: 06 249 4611 Fax: 06 249 0029
email: asa111@rsphy1.anu.edu.au
Primary field of interest: 15

Dr. David Sampson
Dept. of Electrical & Electronic Engineering
University of Western Australia
Nedlands
WA 6907
Tel: 09 380 7112 Fax: 09 380 1065
email: dsampson@eeserver.ee.uwa.edu.au
Primary field of interest: 3

Emeritus Prof R. John Sandeman
Australian National University
Dept Physics & Theoretical Phy
PO Box 4
CANBERRA
ACT 2601
Tel: 06 249 0784 Fax: 06 249 0741
email: john.sandeman@anu.edu.au
Primary field of interest: 9

Dr. Barry Sanders
Macquarie University
School of MPCE
Macquarie University
NORTH RYDE
NSW 2109
Tel: 02 9850 8935 Fax: 02 9850 8115
email: barry@mpce.mq.edu.au
Primary field of interest: 14

**Regular Members:**

Prof Weston Sandle
Dept. of Physics
University of Otago
PO Box 56
Dunedin
New Zealand
Tel: +6434797807 Fax: +6434790964
email: sandle@maxwell.otago.ac.nz
Primary field of interest: 15

Dr. Robert T Sang
Max-Planck-Institut fur Quanten Optik
Hans-Kopfermann Str1.
D-85748 GARCHING
MUNICH
Germany
Tel: (49) 089 32905245 Fax: (49) 089 32905200
email: rts@sat.ipp-garching.mpg.de
Primary field of interest: 11

Dr Craig Savage
Physics, Faculties
ANU
Canberra
ACT 0200
Tel: 06 249 4202 Fax: 06 249 0741
email: craig.savage@anu.edu.au
Primary field of interest: 14

Dr Christine Scala
GPO Box 4331
Melbourne
VIC 3001
Tel: 03 9626 7087 Fax: 03 9626 7087
email: christine.scala@dsto.defence.gov.au
Primary field of interest: 18 laser ultrasonics

Dr. Mark Sceats
University of Sydney
Australian Photonics CRC
NSW 2006
Tel: 02 9351 1905 Fax: 02 9351 1910
email: m.sceats@photonics.crc.org.au
Primary field of interest: 3

Dr Robert Schaeffer
A.G. Thompson and Co.
17 Synagogue Place
Adelaide
SA 5000
Tel: 08 223 2466 Fax: 08 232 2594
Primary field of interest: 12

Dr Robert E. Scholten
School of Physics
University of Melbourne
PARKVILLE
VIC 3052
Tel: 03 9344 5457 Fax: 03 9347 4783
email: scholten@tauon.ph.unimelb.edu.au
Primary field of interest: 18 (Atom Optics)

Mr Jeffrey Seckold
CSIRO
Div of Applied Physics
PO Box 218
LINDFIELD
NSW 2070
Tel: 02 413 7078 Fax: 02 413 7200
email: jeffs@dap.csiro.au
Primary field of interest: 5

Mr. Brian See
7 Lyn Court
WYNN VALE
SA 5127
Tel: Home O8 263 1179 Work 08 343 0435
Fax: 08 349 7420
Primary field of interest: 7

Dr Robert Seymour
DSTO
Land, Space & Optoelectronics Division
PO Box 1500
Salisbury
SA 5108
Tel: 08 259 6563 Fax: 08 259 5055
email: bob.seymour@dsto.defence.gov.au
Primary field of interest: 7

John Shaw
PO Box 230
Petersham
NSW 2049
Tel: 02 560 8367 Fax:
Primary field of interest: 10

Mr Greig Small
CSIRO
Division of Telecomm. & Industrial Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 9413 7736 Fax: 02 9416 7902
email: greig@dap.csiro.au
Primary field of interest: 3

Dr. Raymond Smartt
National Solar Observatory
Sacramento Peak
Sunspot
New Mexico
USA 88349
Primary field of interest: 1

Dr Barnaby Smith
WSD
DSTO
PO Box 1500
SALISBURY
SA 5108
Tel: 08 259 5246 Fax: 08 259 5688
email: bws@gwd.dsto.gov.au
Primary field of interest: 4

A/Prof George Smith
Department of Optometry
University of Melbourne
Parkville
Vic 3052
Tel: 03 9349 7400 Fax: 03 9349 7498
email: u6554416@ucsvc.ucs.unimelb.edu
Primary field of interest: 13

Prof. Allan Snyder
Optical Sciences Centre
RSPhysSE
Australian National University
Canberra
ACT 0200
Tel: 06 249 2626 Fax: 06 249 5184
email: a.snyder@anu.edu.au
Primary field of interest: 15

Prof M C Standage
Griffith University
Div of Science and Technology
Nathan
QLD 4111
Tel: 07 875 7120 Fax: 07 875 7656
email: mstandage@sct.gu.edu.au
Primary field of interest: 14

Dr Andrew John Stevenson
Department of Applied Physics
Faculty of Science. Victoria University
PO Box 14428
MCMC Melbourne
VIC 8001
Tel: 03 9688 4913 Fax: 03 9688 4698
email: andrews@cougar.vut.edu.au
Primary field of interest: 3

Mr G.F. Stroot
26 Castle Rd
Warrandyte
Vic 3113
Tel: 03 9905 4964 Fax:
email: greg.stroot@eng.monash.edu.au
Primary field of interest: 5

Mr Toshiyuki Takatsuji
Optical Technology Group
CSIRO Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 413 7798 Fax: 413 7200
email: toshi@dap.csiro.au
Primary field of interest: 17

Dr. William Tango
Astronomy Department
School of Physics
University of Sydney
NSW 2006
Tel: 02 692 3953 Fax: 02 660 2903
email: tango@physics.usyd.edu.au
Primary field of interest: 1

Dr Brendan Tarte
School of Physics
Qld Uni Tech
PO Box 2434
Brisbane
QLD 4000
Tel: 07 3864 5232 Fax: 07 3864 1521
email: b.tarte@qut.edu.au
Primary field of interest: 7

David Thorncraft
49 Narara Creek Rd
Narara
NSW 2250
Tel: 02 335 0920 Fax: 02 335 0910
email: davidt@oftc.su.oz.au
Primary field of interest: 3

Mr Eric Thwaite
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7193 Fax: 02 413 7161
Primary field of interest: 4

Dr Rod Tobin
Monash University
Department of Physics
Vic 3168
Tel: 03 565 3647 Fax: 03 565 3637
email: rod.tobin@physics.monash.edu.au
Primary field of interest: 7

## Regular Members:

Mr John Tobin
8 Culgoa Ave
EASTWOOD
NSW 2122
Tel: 02 890 1233 Fax: 02 890 1243
Primary field of interest: 17

Dr Graham Town
University of Sydney
Electrical Engineering (J03)
Sydney
NSW 2006
Tel: 02 9351 2110 Fax: 02 9351 3847
email: towng@ee.su.oz.au
Primary field of interest: 3

Dr. Hai Tan Tran
MRD, 180 Labs
PO Box 1500
Salisbury
SA 5108
Tel: 08 8259 6752 Fax: 08 8259 5200
email: hai.tran@dsto.defence.gov.au
Primary field of interest: 15

Prof Rod Tucker
Dept. of Electrical & Electronic Eng.
University of Melbourne
Parkville
VIC 3052
Tel: 03 9344 7688 Fax: 03 9344 7412
email: head@ee.mu.oz.au
Primary field of interest: 3

Mr Frederick Turvell
Microscope Department
53 Bishop St
Kelvin Grove
Brisbane
Qld 4059
Tel: 07 356 4043 Fax:
Primary field of interest: 7

Mr Tommy Chih-Hon Tzeng
9A 19/F Stage 7
Mei Foo
Kowloon
Hong Kong

Tel: 27410063 Fax: 27448222
Primary field of interest: 3

Dr Paul van Saarloos
Lions Eye Institute
2 Verdun Street
Nedlands
WA 6009
Tel: 09 346 2801 Fax: 09 346 1545
email: paulvs@uniwa.uwa.edu.au
Primary field of interest: 18 medical

Dr Roderick Vance
Unit 1, 14 Shelley Street
Elwood
VIC 3184
Tel: 03 9525 6821, 0419 378 334 Fax: 03 9525 6851
email: rodv@hypatia.com.au
Primary field of interest: 8

Dr. Peter Veitch
Dept. Of Physics
University of Adelaide
Adelaide
S.A. 5005
Tel: 08 303 5040 Fax: 08 232 6541
email: pveitch@physics.adelaide.edu.au
Primary field of interest: 7

Richard Walmsley
19 St Annes Place
Parkside
SA 5063
Tel: O8 274 1322 Fax: 08 460 1199
Primary field of interest: 4

Dr Christopher Walsh
CSIRO
Division of Applied Physics
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7156 Fax: 02 413 7200
email: cjw@dap.csiro.au
Primary field of interest: 5

Dr. Rod D. Watkins
Scan Optics Pty Ltd
35 Stirling St
Thebarton
SA 5031
Tel: 08 234 9120 Fax: 08 234 9417
Primary field of interest: 8

Dr. Fred Watson
Anglo-Australian Observatory
Coonabarabran
NSW 2357
Tel: 068 426312 Fax: 068 422288
email: fgw@aaocbn2.aao.gov.au
Primary field of interest: 1

Dr. Changjiang Wei
Laser Physics Centre
RSPhysSE
ANU
Canberra
ACT 0200
Tel: 06 249 4571 Fax: 06 249 0029
email: changjang.wei@anu.edu.au
Primary field of interest: 11

Dr. Lew Whitbourn
CSIRO
Division of Exploration and Mining
PO Box 218
Lindfield
NSW 2070
Tel: 02 413 7733 Fax: 02 413 7202
email: lbw@dap.csiro.au
Primary field of interest: 7

Mr Andrew White
Australian National University
Dept. of Physics
CANBERRA
ACT 0200
Tel: 06 247 2747 Fax: 06 249 0741
email: andrew.white@anu.edu.au
Primary field of interest: 14

Dr. Bruce Wielinga
School of MPCE
Macquarie University
New South Wales 2109
Tel: 850 8962 Fax:
email: wielinga@mpce.mq.edu.au
Primary field of interest: 14

Mr John Ernest Wilkinson
Dept of Applied Physics
Central Queensland University
Rockhampton
Qld 4702
Tel: 079 309 627 Fax: 079 309 209
email: j.wilkinson@cqu.edu.au
Primary field of interest: 9

Dr Philip Wilksch
RMIT
Applied Physics Department
GPO Box 2476V
Melbourne
Vic 3001
Tel: 03 9660 2145 Fax: 03 9660 3837
email: wilksch@rmit.edu.au
Primary field of interest: 17

Dr Geoffrey Williams
LSOD
DSTO
P.O.Box 1500
Salisbury
S.A. 5108
Tel: 08 259 5582 Fax: 08 259 5055
email: geoff.williams@dsto.defence.gov.au
Primary field of interest: 15

Mr Anthony Willing
AUSLIG
PO Box 2
Belconnen
ACT 2616
Tel: 06 235 7111 Fax: 06 235 7103
email: awilling@auslig.gov.au
Primary field of interest: 7

Dr. Howard Wiseman
Physics Department
University of Auckland
Auckland
New Zealand
Tel: 9 3737599 ext 5871 Fax: 9 37373445
email: hmw@phy.auckland.ac.nz
Primary field of interest: 14

Mr Micheal Withford
Maquarie University
Centre for Lasers & Applic.
NORTH RYDE
NSW 2109
Tel: 02 805 8911 Fax: 02 805 8983
email: withford@macadam.mpce.mq.edu.au
Primary field of interest: 7

Dr Chris Woodruff
B-2-17
Department of Defence
Canberra
ACT 2600
Tel: 06 265 2729 Fax: 06 265 2223
email: chris.woodruff@dsto.defence.gov.au
Primary field of interest: 6

Dr Weiping Zhang
School of Mathematics, Physics,
Computing & Electonics
Macquarie University
NSW 2109
Tel: 02 9850 8951 Fax: 02 9850 8115
email: weiping@osiris.mcpe.mq.edu.au
Primary field of interest: 14

## Student Members:

Mr Miguel Angel Alonso
School of MCPE
Macquarie University
North Ryde
NSW 2109
Tel: 02 850 8909 Fax: 02 850 8983
email: alonso@mpce.mq.edu.au
Primary field of interest: 18 Hamiltonian Optics

Miss Awdah Arraf
Dept of Theoretical Physics
School of Physics, A29
University of Sydney
NSW 2006
Tel: (02) 351 5896 Fax: (02) 660 2903
email: arraf@physics.usyd.edu.au
Primary field of interest: 15

Nicole Astridge
29/203 Waterloo Rd
Marsfield
NSW 2122
Tel: 02 9868 5658 Fax:
email: s3026967@macmouth.btech.mq.edu.au
Primary field of interest: 7

Mr David Balaic
School of Physics
University of Melbourne
Parkville
Melbourne
VIC 3052
Tel: 344 5465 Fax: 344 4783
email: dxb@tauon.ph.unimelb.edu.au
Primary field of interest: 8

Mr Glenn W. Baxter
School of Chemistry
Macquarie University
Ryde

NSW 2109
Tel: 02 850 8267 Fax: 02 850 8313
email: gbaxter@laurel.ocs.mq.edu.au
Primary field of interest: 15

Mr Justin Laurence Blows
71 Arcadian Circuit
Carlingford
NSW 2118
Tel: 02 630 2288 Fax:
Primary field of interest: 7

Mr Glenn C Bowkett
Optical Technology Research Lab
Victoria University
PO Box 14428
MMC Melbourne
VIC 3001
Tel: 03 9688 5064 Fax: 03 9688 4698
Primary field of interest: 7

Mr Steven John Cavanagh
Laser Atomic Physics Laboratory
School of Science
Griffith University
Nathan
QLD 4111
Tel: 07 343 7590 Fax:
email: s.cavanagh@sct.gu.edu.au
Primary field of interest: 4

Mr Yew Tai Chieng
Hewlett Packard (Singapore) Pte. Ltd.
Singapore Components Operation
1150 Depot Road
SINGAPORE
109673
email: chieng@ee.usyd.edu.au
Primary field of interest: 7

Mr Peter Dekker
Maquarie University
Centre for Lasers & Applic.
NORTH RYDE
NSW 2109
Tel: 850 7764 Fax: 850 8983
email: dekker@macadam.mpce.mq.edu.au
Primary field of interest: 7

Vladimyros Devrelis
26 Chambers Ave
Richmond
SA 5033
Tel: 08 303 3106 Fax: 08 232 6541
Primary field of interest: 7

Mr Hassan Fatemi
14/12 Union Street
Meadowbank
NSW 2114
Tel: 02 692 3047 Fax: 02 692 0923
email: fatemi@physics.su.oz.au
Primary field of interest: 18 Near-field microscopy

Ms Marlies Friese
Dept of Physics
Uni of Queensland
St Lucia
Qld 4072
Tel: 07 365 1361 Fax:
email: friese@physics.uq.oz.au
Primary field of interest: 7

Mr Hugo Giordano
Australian National University
Laser Physics Centre RSPS&E
GPO Box 4
CANBERRA
ACT 2601
Tel: 06 249 3613 Fax: 06 249 0029
email: hag111@rsphy4.anu.edu.au
Primary field of interest: 15

Mr Ron Gordon
School of MPCE
Macquarie University
North Ryde
NSW 2109
Tel: 02 850 8909 Fax: 02 850 8983
email: rlgordon@mpce.mq.edu.au
Primary field of interest: 18 Diffraction Theoy

Mr S. Griffin
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 344 5465 Fax: 03 349 2183
email: griffin@muon.ph.unimelb.edu.au

Mr Stephen Craig Guy
Dept of Electrical Engineering
Maze Crescent, J03
University of Sydney
SYDNEY
NSW 2006
Tel: 02 351 3170 Fax: 02 351 3847
email: guy@ee.su.oz.au
Primary field of interest: 11

Mr Rodney Stephen Hall
4 Alt Crescent
Davidson
NSW 2085
Tel: 02 452 4826 Fax: 02 452 4826
email: rhall@hardy.ocs.mq.edu.au
Primary field of interest: 7

Joseph Hope
Physics Department
Faculty of Science
ANU
Canberra
ACT 0200
Tel: 06 249 4253 Fax: 06 249 0741
email: joseph.hope@anu.edu.au
Primary field of interest: 14

Mr Allan Kenneth Horsfall
Optics Group
School of Physics
University of Melbourne
Parkville
VIC 3052
Tel: 03 344 5465 Fax: 03 347 4783
email: akh@muon.ph.unimelb.edu.au
Primary field of interest: 18 Near Field Opt. Microscopy

David Hunter
Dept. of Electrical Engineering
The University of Sydney
NSW 2006
Tel: 02 351 3008 Fax: 02 351 3847
email: d.hunter@ee.usyd.edu.au
Primary field of interest: 3

Mr Victor Karaganov
Department of Physics
The Flinders University
GPO Box 2100
Adelaide
SA 5001
Tel: 08 201 2883 Fax: 08 201 3035
email: phvlk@cc.flinders.edu.au
Primary field of interest: 9

Weijian Lu
Laser Physics Centre
The Australian National University
Canberra
ACT 0200
Tel: 06 249 4244 work 06 241 9026 home Fax:
email: weijian.lu@anu.edu.au
Primary field of interest: 18 - Atom Optics

Miss Karen McNally
School of MPCE
Macquarie Uni
North Ryde
NSW 2109
Tel: 02 850 8964 Fax: 02 850 8115
email: karen@macadam.mpce.mq.edu.au
Primary field of interest: 18 - lasers in microsurgery

## Student Members:

Ms Dragana Milic
Laser Physics Centre
Aust Nat Uni
Canberra
ACT 0200
Tel: 06 249 3626 Fax: 06 249 2452
email: dom111@rsphys.anu.edu.au
Primary field of interest: 18- atom optics

Ms Tanya Mary Monro
Theoretical Physics
School of Physics
University of Sydney
NSW 2006
Tel: 02 9351 3241 Fax: 02 9351 7726
email: tanya@physics.su.oz.au
Primary field of interest: 15

Mr David J Paterson
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 9344 5465 Fax: 03 9349 2183
email: paterson@optics.ph.unimelb.edu.au
Primary field of interest: 11

Mr Andrew Peele
Optics Group
School of Physics
University of Melbourne
Parkville
VIC 3052
Tel: 03 344 5465 Fax: 03 347 4783
email: agp@muon.ph.unimelb.edu.au
Primary field of interest: 18 X-ray Optics

Mr Bill P. Petreski
30 Allison St
Ardeer
VIC 3022
Tel: 03 9688 4277 Fax: 03 9688 4698
email: petbp@cougar.vut.edu.au
Primary field of interest: 9

Mr David Psaila
University of Sydney
OFTC
LG2 Madsen Bld (F09)
NSW 2006
Tel: 02 692 3241 Fax: 02 692 4671
email: d.psaila@oftc.usyd.edu.au
Primary field of interest: 3

Mr Stephen Rhodes
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 9344 5465 Fax: 03 9347 4783
email: rhodes@optics.ph.unimelb.edu.au
Primary field of interest: 9

Mrs Maitreyee Roy
Dept. Physical Optics
School of Physics
University of Sydney
NSW 2006
Tel: 02 351 3941 Fax: 02-692 0923
email: mroy@physics.usyd.edu.au
Primary field of interest: 6

Mr Chris Russell
La Trobe University
Theoretical Space Physics
Physics Dept
BUNDOORA
Vic 3083
Tel: 03 479 2640 Fax: 03 479 1552
email: tspcjr@lure.latrobe.edu.au
Primary field of interest: 1

Mr Arjang Salamat
32 Oakes Road
West Pennant Hills
NSW 2125
Tel: 02 9872 1627 Fax: 02 9872 1627
Primary field of interest: 7

Mr. Farin Sanaei
260 Malabar Rd
Maroubra
NSW 2035
Tel: 02 9385 5534 Fax: 02 9385 5993
email: f.sanaei@unsw.edu.au
Primary field of interest: 15

Mr Max Shurgalin
School of Science
Griffith Uni
Nathan
Qld 4111
Tel: 07 875 7588 Fax:
email: m.surgalin@sct.gu.edu.au
Primary field of interest: 11

Mr Benedict Gregory Smith
3 Henley Street
Lane Cove
NSW 2066
Tel: 02 427 2538 Fax:
Primary field of interest: 7

Mr Michael James Steel
Department of Theoretical Physics
School of Physics
The University of Sydney
NSW 2006
Tel: 02 351 3241 Fax: 02 660 2903
email: mikes@physics.su.oz.au
Primary field of interest: 15

Kannan Venkatachalam
4/37 Balcombe Road
Mentone
7/16 Rodd Street
VIC 3194
Tel: 03 9585 2397 Fax: 03 584 1741
Primary field of interest: 4

Mr Mark L. von Bibra
Optics
School of Physics
University of Melbourne
Parkville
VIC 3052
Tel: 03 9344 5465 Fax: 03 9349 2183
email: mvb@mozart.ph.unimelb.edu.au
Primary field of interest: 5

Mr Miroslaw Walkiewicz
School of Physics
University of Melbourne
Parkville
Vic 3052
Tel: 03 9344 5465 Fax: 03 9349 2183
email: mirek@muon.ph.unimelb.edu.au
Primary field of interest: 18 Atom optics

Ms Kylie Waring
AMPL
RSPhysSE
Australian National University
Canberra
ACT 2601
Tel: 06 249 3075 Fax: 06 249 0390
email: KZW121@ampl1.anu.edu.au
Primary field of interest: 11

Ms Margaret Wegener
Dept of Physics
Uni of Queensland
St Lucia
Qld 4072
Tel: 07 3365 3715/3365 1134 Fax: 07 3365 1242
email: wegener@physics.uq.oz.au
Primary field of interest: 17

*The names that appear in this list are of all members who had paid their 1996 AOS fees by the 14th of October 1996, who had also provided a current contact address. If you feel that your name was incorrectly left off this list or the contact details that appear are incorrect, please contact the AOS Treasurer, Esa Jaatinen to rectify the situation.*

*All information that appears in this article was obtained from the 1996 Subscription Renewal Form completed by members.*

*The treasurer and editor apologise for any typographical errors and omissions that may have occurred in the compiling and printing of this list.*

# Meetings Calendar at a Glance

| Date | 1997 Meetings | Contact | Location |
|---|---|---|---|
| Jan | International Conference on Quantum Optics and Laser Physics | OSA | Hong Kong |
| Jan 26 | Advanced Solid-state Lasers Topical Meeting | OSA | Orlando, Florida |
| Feb 8 or 14? | Photonics West '97 (Inc. Optoelectronics,LASE '97,BiOS'97,EI'97)<br>- Optoelectronics, High-Power Lasers (LASE '97)<br>- International Biomedical Optics (BiOS '97)<br>- Electronic Imaging Science and Technology (EI '97) | SPIE | San Jose, California |
| Feb 9 | Winter Topical Meetings<br>- Optical Remote Sensing of the Atmosphere<br>- Light and Color in the Open Air<br>- Fourier Transform Spectroscopy<br>- Chemistry and Physics of Small-Scale Structures<br>- Vision Science and Its Applications (Jan 30) | OSA | Santa Fe, New Mexico |
| Feb 16 | Optical Fiber Communication (OFC '97) | OSA | Dallas, Texas |
| Feb 22 | Medical Imaging '97 | SPIE | Newport Beach, California |
| Mar 2 | The 10th meeting on Optical Engineering in Israel | EOS | Jerusalem, Israel |
| Mar 2 | Smart Structures and Materials | SPIE | San Diego, California |
| Mar 3 | EUROPTO : Optics and Optoelectronics for Environmental Safety | SPIE | Wiesbaden, Germany |
| Mar 10 | Microlithography | SPIE | Santa Clara, California |
| Mar 18 | Spring Topical Meetings<br>- Spatial Light Modulators<br>- Ultrafast Electronics and Optoelectronics<br>- Quantum Optoelectronics | OSA | Lake Tahoe, Nevada |
| Mar 19 | Applications of High Field and Short Wavelength Sources | OSA | Santa Fe, New Mexico |
| April 2 | 8th European Conference on Integrated Optics | OSA | Stockholm, Sweden |
| April 20 | AeroSense : Aerospace/defence sensing and controls | SPIE | Orlando, Florida |
| April | 3rd Int. Conf. on Optical Fiber Submarine Telecomm. Systems | OSA | t.b.a |
| April | European Symposium on Space Optics II | EOS | t.b.a. |
| April | Photomask Japan | SPIE | Kawasaki City, Japan |
| May 18 | Lasers and Electro-Optics (CLEO '97) | OSA | Baltimore, Maryland |
| May 18 | Quantum Electronics and Laser Science (QELS'97) | OSA | Baltimore, Maryland |
| June 4 | Pattern Recognition in Practice V | IAPR | Vlieland, Netherlands |
| June 16 | LASER MUNICH'97<br>- European Symposium on Environmental Sensing III<br>- European Symposium on Lasers and Optics for Research and Man. III<br>- European Symposium on Microelectronics Manufacturing I | EOS | Munich,Germany |
| July | Materials for Nonlinear Optics | EOS | Capri, Italy |
| July 7 | Topical Meeting on Diffractive Optics | EOS | Savonlinna, Finland |
| July 20 | Optical Amplifiers and their Applications | OSA | Victoria, Canada |
| July 27 | SPIE Annual Symposium | SPIE | San Diego, California |
| Aug 26 | OIST'97 | EOS | Moscow, Russia |
| Sept 9 | EUROPTO Series: BiOS Europe V (Biomedical optics) | SPIE | Italy |
| Sept 17 | Photomask Technology and Management | SPIE | Santa Clara, California |
| Sept 22 | EUROPTO Series: Satellite remote sensing IV | SPIE | France |
| Sept 22 | 11th Int. Conf. on Integrated Optics and Optical Fiber Comm. | OSA | Edinburgh, UK |
| Sept 22 | 23rd European Conference on Optical Communication | OSA | Edinburgh, UK |
| Sept 28 | Photonics East | SPIE | Philadelphia, Pennsylvania |
| Oct | Micromachining and microfabrication | SPIE | Austin, Texas |
| Oct | Microelectronic Manufacturing | SPIE | Austin, Texas |
| Oct | Applied Imagery Pattern Recognition Workshop | SPIE | Washington, DC |
| Oct 11 | OSA'97 Annual Meeting<br>- Interdisciplinary Laser Science Conference (ILS-XIII)<br>- Organic Thin Films for Photonics Applications | OSA | Long Beach, California. |
| Oct 18 | Fall Topical Meetings<br>- 12th International Conference on Optical Fiber Sensors<br>- Photosensitivity and Nonlinearities in Guided Wave Optics<br>- Glass and Optical Materials Division (GOMD) Meeting | OSA | Williamsburg, Virginia |
| Dec 10-12 | AOS Bi-Annual Conference | AOS | Adelaide, SA |

| | | | |
|---|---|---|---|
| **1998** | | | |
| Feb 22 | **Optical Fiber Communication Conference (OFC'98)** | OSA | San Jose, C |
| Mar 23 | **European Symposium on Advanced Networks and Imaging Technologies II** | EOS | United Kingdom |
| May 3 | **CLEO** | OSA | San Francisco, CA |
| June 8 | **European Symposium on Environmental Sensing IV** | EOS | Lyon, France |
| Sept 11 | **Biomedical Optics Europe VI** | EOS | t.b.a. |
| Sept 21 | **European Symposium on Satellite Remote Sensing V** | EOS | Florence, Italy |
| Oct ? | **Photonics Europe'98** | EOS | Paris, France |
| Oct 3 | **OSA Annual Meeting** | OSA | Baltimore, MD |
| **1999** | | | |
| May 16 | **CLEO** | OSA | Baltimore, MD |
| Feb 21 | **Optical Fiber Communication Conference (OFC'99)** | OSA | San Diego, CA |

This list of optics related conferences is compiled from several sources and should be used as a guide only. Further information can be obtained from :

**OSA** 2010 Massachusetts Ave
NW Washington DC 20036,USA
Tel: +1 202 223 0920
Fax: +1 202 416 6100
OSA (*http://www.osa.org/*)

**SPIE**, PO Box 10, Bellingham
WA 98227-0010, USA
Tel: +1 360 676 3290
Fax: +1 360 647 1445
Email : spie@mom.spie.org

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# Corporate Membership Address List

**Australian Holographics Studios Pty Ltd**
PO Box 160
Kangarilla
SA 5157
Tel: (08) 383 7255
Fax: (08) 383 7244
austholo@camtech.net.au

**AVIMO Electro-Optics Pty Ltd**
14 Fifth Lok Yang Road
Singapore, 2262
Tel: +65 265 5122
Fax: +65 265 1479

**British Aerospace Australia**
PO Box 180
Salisbury SA 5108
Head Office:
14 Park Way
Technology Park
The Levels, SA 5095

**Coherent Scientific Pty Ltd**
116 Burbridge Road
HILTON, SA, 5033
Tel: (08) 352 1111
Fax: (08) 352 2020
100351.1471@compuserve.com

**Electro Optic Systems**
55A Monaro St
Queenbeyan, NSW, 2620
Tel: (06) 299 2470
Fax: (06) 299 2477

**Electro Optics Pty Ltd**
PO Box 67
Kenthurst, NSW, 2156
Tel: (02) 9654 1873
Fax: (02) 9654 1539

**Francis Lord Optics**
33 Higginbotham Rd
Gladesviile, NSW, 2111
Tel: (02) 9807 1444
Fax: (02) 9809 7136

**Hadland Photonics Pty Ltd**
19A Hampsbire Road
Glen Waverley, Vic, 3150
Tel: (03) 560 2366
Fax: (03) 560 8402

**Jung Precision Optics**
Bld 186, Contractors Area
Salisbury, SA, 5108
Tel: (08) 287 2422
Fax: (08) 287 2706

**Kidger Optics Limited**
9a High Street
Crowborougb, East Sussex
TN6 2QA, UK
Tel: +44 1892 663555
Fax: +44 1892 664483
sales@kidger.demon.co.uk

**Laser Electronics (operations) Pty Ltd**
PO Box 359
Southport, QLD, 4215
Tel: (075) 96 0177
Fax: (075) 96 3530

**Lastek Pty Ltd**
GPO Box 2212
Adelaide, SA, 5001
Tel: (08) 438 668
Fax: (08) 438 427
gjones@wattle.itd.adelaide.edu.au

**OptiScan Pty Ltd**
27 Normanby Road
Notting Hill, Vic, 3168
Tel: (613) 9562 7741
Fax: (613) 9562 7742

**Raymax Applications Pty Ltd**
16 Ross Street
Newport Beach, NSW, 2106
Tel: (02) 9979 7646
Fax: (02) 9979 8207

**Rofin Australia Pty Ltd**
Unit 4 42-44 Garden Boulevard
Dingley, VIC, 3172
Tel: (03) 558 0344
Fax: (03) 558 0252

**Spectra-Physics Pty Ltd**
25 Research Drive
Croyden, VIC, 3136
Tel: (03) 761 5200
Fax: (03) 761 5600

**Warsash Pty Ltd**
PO Box 1685
Strawberry Hills, NSW, 2012
Tel: (02) 9319 0122
Fax: (02) 9318 2192

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- Fast tip/tilt of mirrors & optics, ∅ 10 - 300 mm
- Sub-μrad resolution
- Response: 0.1 to 3 ms
- Tilt range up to 5 mrad
- Step and scan operation

### 5. Capacitive Displacement Sensors & Electronics

➢ Applications: *sub-nm accuracy distance measurement...*

- Ultra-high resolution: ≤ 0.1 nanometre
- Measurement ranges: 15 - 300 μm
- Linearity ≤ 0.05%
- Bandwidth up to 10 kHz

### 6. Linear/Rotary Micropositioners

➢ Applications: *semiconductor manufacturing, micro-machining, micro-mechanics...*

- Manual, DC-& stepper driven stages
- Travel ranges 6 - 300 mm
- Resolution: 0.01 μm, $V_{max}$ :100 mm/s
- Rotary stages: resolution ≤ 0.001°, $V_{max}$ : 45° /s
- Hexapod: six degrees of freedom
- Ultra-fast Voice Coil Scanning Stages (250 mm/s)

### 7. Piezoelectric Ceramics

➢ Applications: *micropositioning, ink jet printers, ultrasonic transducers, sonar, medical diagnostics, buzzers, resonators, filters...*

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- Shear actuators, multilayer stacks and benders
- PZT linear- and rotary motors
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| OPTICAL TABLES - | TMC CleanTop™ |
| MINIATURE SPECTROMETERS - | Ocean Optics |
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## SPIE and Working Group Membership Application

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❑ *Journal of Biomedical Optics,* quarterly
❑ *Journal of Electronic Imaging,* quarterly

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# 1997

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