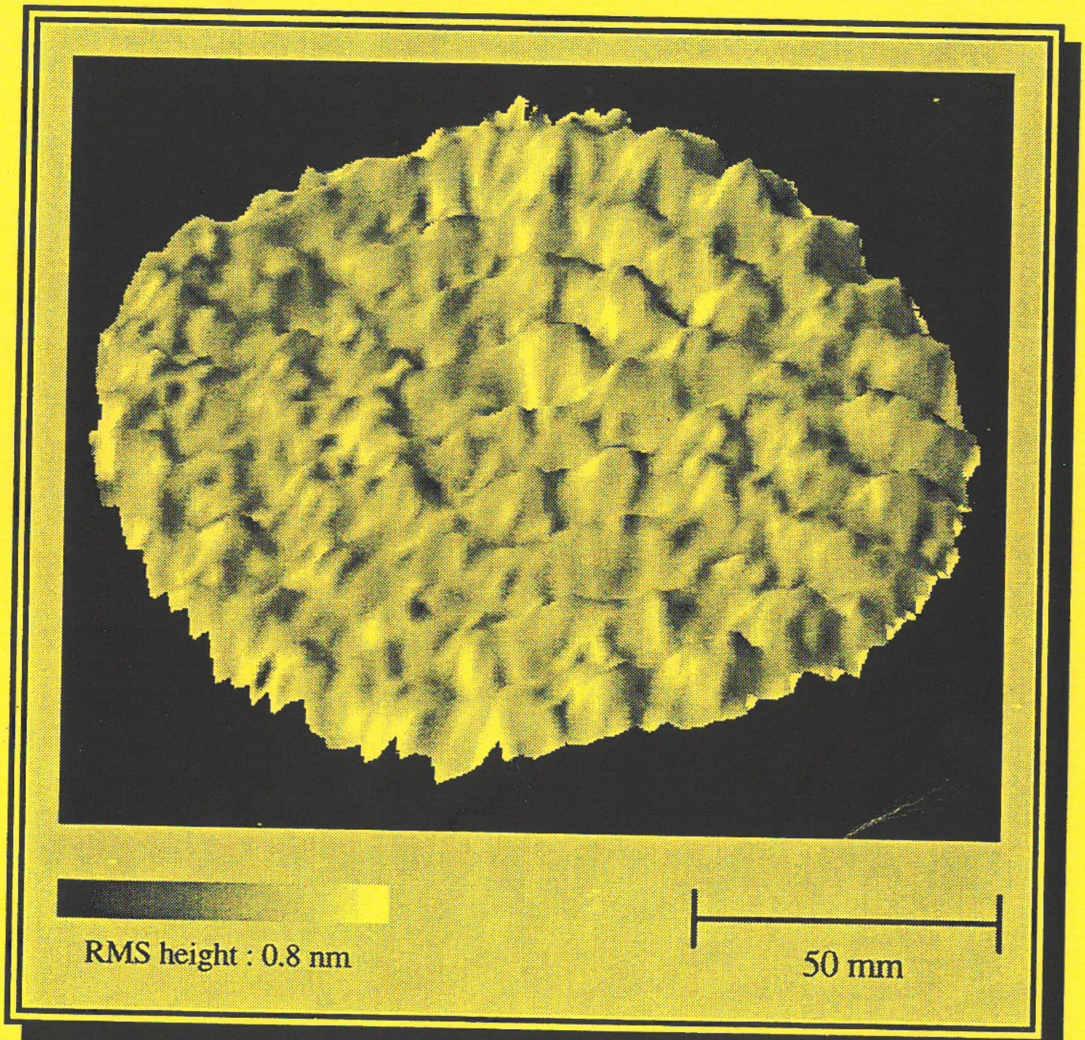
Australian Optical Society

NEWS



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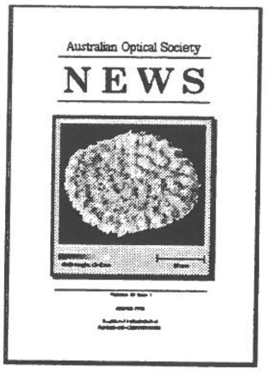

COVER :
This height map of a pitch polished silica flat was obtained using a Wyko 6000 phase shifting interferometer. The height profile is shown in perspective, exaggerating the 0.8 nm RMS roughness (3 nm peak-to-peak). The 0.1 nm vertical resolution of the instrument is easily sufficient to resolve the circular tracks left from the polishing process. For further information contact Mark Suchting. Email : masuch@dap.csiro.au

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AOS NEWS

ARTICLES

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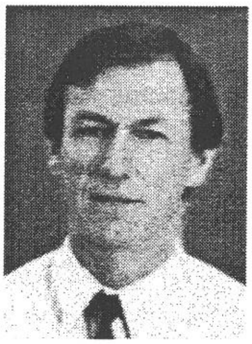
President's Report

by Chris Walsh



The activities of the Society have proceeded smoothly over the last few months, with little of note to bring to the attention of members. One of Council's more recent significant activities was to consider the applications for the annual Postgraduate Award, which provides a maximum of $1500 assistance to students studying optics in Australia to attend an international conference and present a paper. The recipient of the award is required to present an account of their trip in the AOS Newsletter.

As always, the standard of applications was very high and I think I can summarise the feelings of the Council when I say that it was difficult to limit the prize to just one person. It was necessary to do so, however, since dividing the $1500 prize would result in an insignificant contribution towards each of the winners' costs for their proposed trips.

I have mentioned previously that the Council plans to review the selection criteria for this award, and this process will be carried out over the next few months, leading to a ratification of new selection criteria at the next Council meeting which will be held during IQEC '96 in July. I am drawing up a discussion document for this review, and would be happy to provide copies to interested members should they request it. If members have any suggestions regarding selection criteria, please pass these on to one of the Councillors.

We also plan to review the conditions governing the Young Optical Worker Award. The suggestion has been made that the coverage of this award be broadened to make it similar to the OSA's David Richardson Medal, which 'recognises those who have made significant contributions to technical optics, but not necessarily in a manner manifested by an extensive publication record or traditional academic reputation'. The emphasis on youth would still remain, but the scope might include areas of applied optics in industry or academia such as optical design or instrument development. Again, we welcome your input to this discussion.

Readers will note the appearance of material in this issue from the Federation of Australian Scientific and Technological Societies (FASTS). The AOS is a member of FASTS, and our subscription payment, set at a level around $4+ per member, is a significant fraction of our budget. It is therefore timely and welcome to receive information on FASTS activities along with the opportunity to provide comments directly to the Executive of that Organisation on issues of interest to the AOS.

Editorial

Welcome to the first edition of *AOS News* in 1996. As the new editor, my first task is to thank the previous editors, Judith Dawes and Martijn de Sterke, for the excellent job they have done over the past two years. Over this period they produced a technically interesting and professionally laid out magazine which was an asset to the society. They have also been of great assistance in the production of this issue.

My aim as editor is to maintain the standard and style of the *AOS News* as it appeared under Judith and Martijn. I hope to bring about a slight reduction in the production costs (one of the significant expenditures of the AOS) by laying out the magazine on a personal computer, but without compromising quality at any stage.

I would like to point out that the success of this magazine depends on the contributions of AOS members. Please give some thought to writing an article for this forum, whether it be about your latest research results, a review of some field of optics, a report on a conference you have attended, or a review of software or a book. News of members' achievements, or significant events in optics, is always welcome.

This publication also provides a rather untapped resource to readers when it comes to publicising meetings or job vacancies. There is no charge for such advertisements and the feedback from previous advertisers has been very positive.

Duncan Butler

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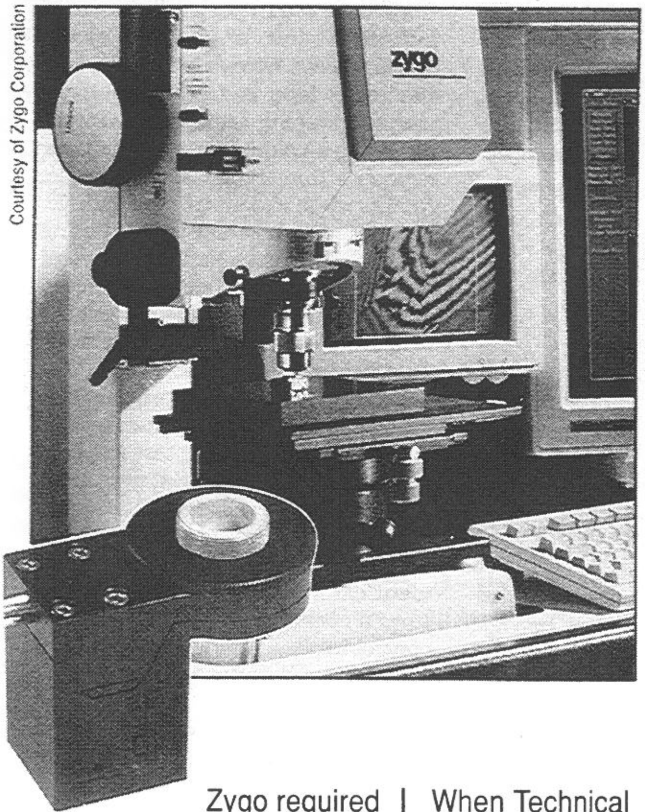
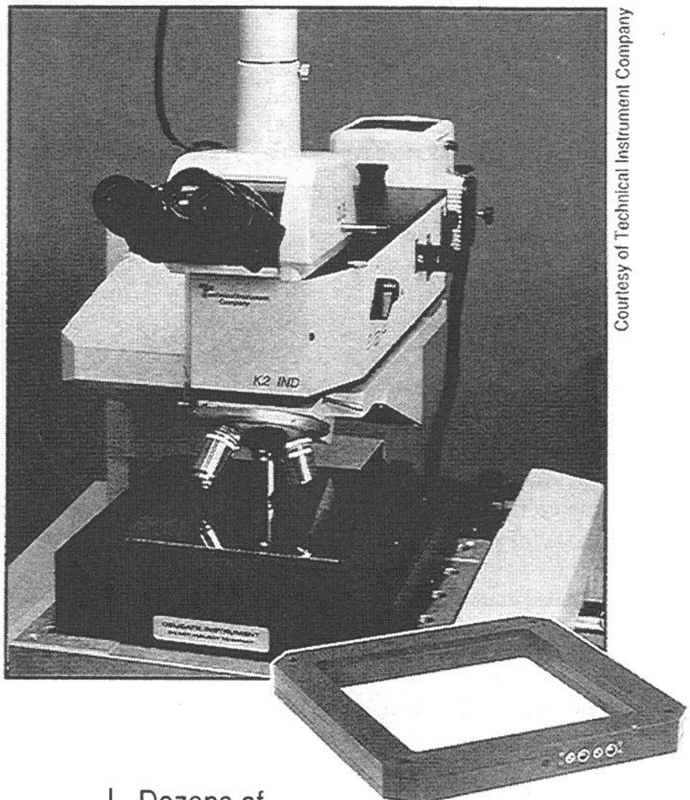


Courtesy of Zygo Corporation



Courtesy of Technical Instrument Company

Zygo required a compact device to focus microscope objectives to subnanometer accuracy over a 100 µm range. They chose a Physik Instrumente PIFOC, off-the-shelf from PI. The result? The NewView 100 3D Imaging Surface Structure Analyzer, Photonics Circle of Excellence and R&D 100 Award Winner.

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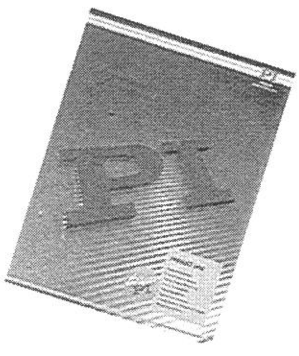

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Lenses for Demonstrating Aberrations

W. H. Steel
School of MPCE, Macquarie University, NSW 2109

A set of lens designs for the purpose of demonstrating aberrations are offered to teachers of optics.

To test a simple optical design program, I designed a series of Cooke triplets, one well corrected, the others each with one of the primary Seidel aberrations. Only distortion was not provided by a Cooke triplet since it seemed impossible to find one with enough distortion to be interesting. Although the design that shows distortion has three components, it is derived from an eyepiece design, not a Cooke triplet. The triplet designs were presented as a poster at the Ninth Conference of the AOS.

The designs have since been used to test another program aimed at deriving ray aberrations of a lens from its measured wave aberration. Since actual lenses of known design will be required for the final tests for this project, the designs have been fitted to radii of curvature available in Australia and four systems have been made by Francis Lord Optics. These lenses have since been used demonstrations for students of Opto-electronics at this University. They have proved so successful that I am offering the designs to optics teachers who would like to have sets of these lenses. Francis Lord Optics can make the lenses, which would need to be mounted in a mechanical workshop. The radii of curvature have been fitted to those held by the CSIRO Division of Applied Physics but I should be able to make equivalent fits to other sets of radii, provided these are extensive enough.

For the monochromatic aberrations, other than distortion, which is best shown by using the distorting eyepiece to view graph paper, the best demonstrations use a point source illuminated by a green He-Ne laser, the image being viewed by a low-power microscope. The triplet is turned off-axis to show the aberrations at different field angles. We also use as source a row of pinholes in front of a white-light fluorescent lamp. This is better for showing how the aberrations vary across the field and white light is required to demonstrate the chromatic aberrations. But this source does not show the aberrations in as much detail since the image is now viewed by an eyepiece only which, because it must cover at least the half field of 10 mm, has a limited magnification. The lenses we have at present show: negligible aberration, spherical aberration, coma, and astigmatism and their success has encouraged us to obtain the others. If we are forced to cut out any, distortion is obviously one that requires a different demonstration to the others and, from the spot diagrams given by the design, Petzval curvature is less spectacular than the other aberrations. But those for the two chromatic aberrations look very promising.

Acknowledgement. The lenses are a spin-off from a project supported by an ARC Grant.

OPTICS GRAPEVINE

News from the World of Optics

Message from the Treasurer

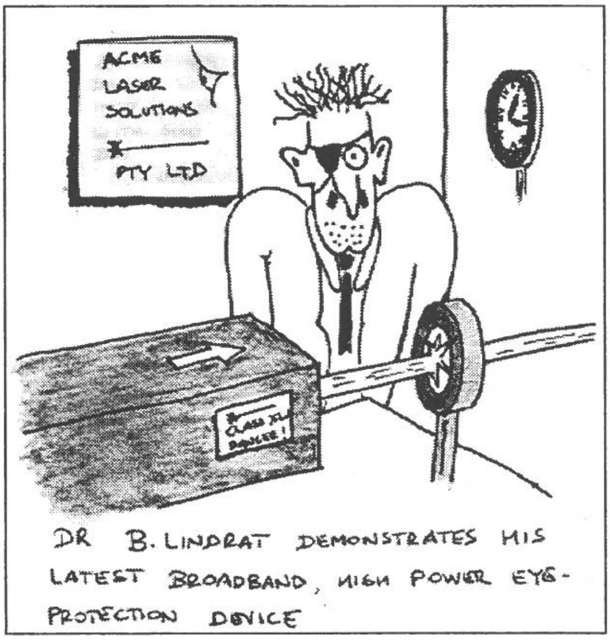
You are reminded that AOS membership subscriptions for 1996 are now due.

Please fill in the membership form inside the back cover of this issue and forward it with your payment to Esa Jaatinen

Thanks to everyone who has already subscribed for this year!

Congratulations!

☛ Past AOS secretary **Professor Keith Nugent** has been promoted to head of the School of Physics at the University of Melbourne. Well done Keith!



DR B. LINDRAT DEMONSTRATES HIS LATEST BROADBAND, HIGH POWER EYE-PROTECTION DEVICE

Atoms guided through hollow optical fibres

Laser light guided through hollow optical fibre has been shown to trap atoms at the centre of the fibre. The fibre is thus a flexible tube which can be used as an atomic source. [M.J.Renn et al, Phys.Rev.Lett **75** p3253 1995]

Novel aspects of Sonoluminescence

Sound waves of a high frequency travelling in some liquids can cause bubbles of gas in the liquid to emit light ("sonoluminescence"). The frequency of this light has recently been found to depend strongly on the isotope of hydrogen used in the water. [K.Weninger *et al*, J.Phys.Chem, **99** p14 195, 1995 and R.A.Hiller *et al*, Phys. Rev. Lett. (to be published)]

IQEC '96

This year ACOLS will be subsumed by the 20th International Quantum Electronics Conference to be held at Sydney's Darling Harbour, July 14-19.

The abstract and summary deadline has already elapsed, but the postdeadline paper submission date is May 8, and the advance registration deadline is May 17.

A Challenge for Atom Trappers...

Antihydrogen has been created at CERN in Geneva using their Low-Energy Antiproton Ring. Most researchers believe that anti-atoms will soon provide a fundamental test of our theories of matter and cosmology. However, the CERN antimatter, travelling at close to the speed of light, lasted only 40 billionths of a second. A team at Harvard University hopes to create antihydrogen by combining trapped antihydrogen with trapped antiprotons, thus achieving stable antimatter.

✈ AOS Prize Winner ✈

☛ The 1996 AOS Postgraduate Student Prize was won by Andrew White of the Australian National University. Andrew will receive $1,500 towards travel expenses to enable him to attend an overseas conference.

PS. Contributions to this forum are welcome!

FASTS - Ten Top Policies

for Australian science and technology in the 21st century

The FASTS Board and Executive has selected ten policies it would particularly like the Government and the Opposition to address in their policy statements on science and technology. AOS Members are invited to send any comments by email to the AOS President, Chris Walsh, or any of the AOS council (email addresses are listed on p2).

1. National forum to help direct scientific directions of the country.
FASTS urges the next Government to organise a multilateral national summit to determine a national vision for Australia and national priorities for Australia's sustainable development.

2. Set a percentage of superannuation funds for investment in R&D.
The next Government should build on the ideas of the Innovation Statement by earmarking a percentage of superannuation fund income for R&D investment. This would create a pool of patient venture capital to assist industry to develop Australian ideas.

3. Provide more secure career paths for scientists and technologists
Too many young scientists face uncertain careers on short term funding. They need productive opportunities for long-term employment, and FASTS urges scrutiny of the present granting system together with initiatives to boost employment prospects.

4. Improve protection for Australia's intellectual property
Protection of our intellectual property is as vital as its discovery and development. Patent costs should be allowable R&D expenditure for tax purposes.

5. Improve the supply of qualified mathematics and science teachers
Mathematics and science at all levels should be taught by appropriately qualified people, and the issue of teacher supply and the dwindling number of people studying to be secondary mathematics and physical science teachers needs to be addressed.

6. Support for infrastructure in research organisations
The quality of education and research is being compromised by inadequate support for equipment, libraries, computer facilities and buildings. FASTS urges the next Government to tackle the problem of crumbling infrastructure.

7. A clear role for CSIRO
Government should set broad directions for CSIRO, and allow it (and other national agencies such as AIMS and ANSTO) to determine the balance between strategic research and short term contract research.

8. Tax concessions for private and syndicated R&D
Public and private tax-exempt research bodies should be allowed to participate in R&D syndicates; and the tax concession for private sector R&D should be set at 150%.

9. Quality science education at the tertiary level
The Government should encourage best practice in tertiary science and mathematics education by supporting the Professional and Learned Societies in the evaluation and assessment of academic courses.

10. Science Minister in Cabinet
FASTS believes that the science portfolio should be at Cabinet level.

FASTS Response to Innovation Statement and to the Prime Minister's Speech of 6 December

Joe Baker
President FASTS

There is much to read and much to communicate among FASTS member societies before we can give a comprehensive response to all aspects of the Innovation Statement. That is no great cause for concern because the Government will be progressively developing several of the concepts in this broad statement.

However it is clear that many of the new initiatives of the Innovation Statement are consistent with the recommendations in the FASTS document launched mid year 1995 "A Science Policy for Australia in the 21st century", especially when one recognises that "Innovation is only one part of the continuum from excellence in all steps from education through

research, through communication and to commercialisation."

Minister Peter Cook has stressed this point - that the Innovation Statement necessarily concentrates on the application on the results of scientific research for the benefit of society, rather than on the support necessary to ensure excellence in scientific and technological training in fundamental research. Those aspects will be covered in other policy statements, and FASTS will continue to work with industry, commerce and Government to maintain awareness of the benefits of enhancing excellence in teaching, training and research.

Perhaps the biggest single message from the statement is that the whole of Government and particularly the Prime Minister now acknowledge the role of science and technology in sustainable economic, environmental and social well-being. The 'tone' of the Innovation Statement and the Prime Minister's speech provide a clear basis for further interaction of scientists and technologists with policy makers in Government, industry and commerce. We will strive to have scientists and technologists appointed to industry Boards of Directors.

When one combines the message of the Innovation Statement with other initiatives such as strengthening regional Australia, this is clearly an opportunity for scientists and technologists to be involved in local, regional, state/territory and national levels, in communicating the results of their research for the benefit of society. I think we must continue to link many of the aspects reflected in the Innovation Statement to generate a National Science and Technology Policy.

FASTS is particularly pleased that several initiatives relate directly to our recommendations and priorities eg. the

- Seven high priority visionary projects in such Major National Research Facilities.
- Continuation of the CRC concept with 5 new CRC's to be established.
- Continuation of the 150% R & D tax concession
- Competitive grants scheme for industry R & D.
- Signs of banks and superannuation fund schemes being accessible as sources of funds for R & D, the missing aspect of "patient money".
- Re-establishment of Syndicated Research Systems.
- Enhancement of Technology support systems to assist small to medium enterprises.
- Enhanced international science and technology linkage.
- Short term placement of experts in industry (improving the industry university partnerships).
- research agency
- Research Commercialisation Program.
- Protection of Intellectual Property.

We will continue to work with Government, industry and commerce on these and other issues.

FASTS sees opportunities for further discussions with Government on the challenging issues of rural Australia and of the "1994 - declared" marine Exclusive Economic Zone (EEZ).

The Prime Minister has emphasised the APEC initiatives and the role Australia will play. Innovations in rural productivity and sustainability and in a vast range of marine and maritime applications must be a feature of Australia's development towards 2010 and beyond. Both rural and marine areas could be essential to the Prime Minister's objective of "food security" for the APEC region.

Underpinning this new -found (or at least newly publicised) political recognition of the role of Science and Technology in innovative economic development is the need to ensure appropriate levels of infrastructures in our universities and resource institutions, and communication of the benefits of high quality science and mathematics education throughout Australia.

The Government commitment to improve national information systems should lead to opportunities for national high quality science and mathematics curricula, accessible to all.

One is always drawn back to the Prime Minister's emphasis on the APEC initiatives and his desire to have Australia "APEC-ready" Science and Technology are very real roles to play in achieving that readiness and we must communicate our capabilities in all parts of Australia.

We, in FASTS, agree with the Prime Minister's evaluations that

Australia already has the ingredients of a dynamic and effective innovation system, ranging from the tremendous national assets of our excellence in science, to our very own propensity to take up new technology, to the surge of companies including the crop of export-oriented small and medium enterprises - towards best practice and commitment to quality.

The "quality" can not be built in at the end. It must be there from the outset. That means maintaining "our excellence in science" (and technology), and ensuring that the resources are there to guarantee best training and best research in Science and Technology.

FASTS will endeavour to be a partner in all the ways the Prime Minister has identified to strengthen Australia's capacity for innovation viz.

- generating ideas
- commercialising and using new ideas
- linking Australia even more closely into ideas elsewhere in the world.
- encouraging new ideas in business and the work place.
- accelerating the application of ideas by using the information super highway, and promoting access to information technology for all Australians, including people with disabilities, those in remote areas, people on low incomes and women.

We look forward to Minister Cook's speech today, where we expect further details in the Science and Technology role.

Dr Joe Baker,
President,
FASTS

Nonlinear Switching and Spatial Solitons in $\chi^{(2)}$ Materials

Yuri S. Kivshar
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Recent achievements in nonlinear optics have demonstrated a potential use of the cascaded second-order nonlinearity for all-optical switching in materials with quadratic response, the so-called $\chi^{(2)}$ materials. Here I present a brief overview of the exponentially growing activity in this field with special attention to the results obtained in Australia.

1. Introductory Remarks

The study of nonlinear effects in optics has offered new possibilities for all-optical signal processing as well as optical communications. A large spectrum of all-optical switching devices has been demonstrated experimentally in a variety of optical materials (see, eg., a recent review paper [1]). Up to now the concepts of nonlinear switching have been based on the main assumption that an input light beam creates an intensity-induced change in the refractive index which, in turn, leads to an intensity-dependent change of the wave phase. The simplest optical material which demonstrates such a property is a nonlinear Kerr material, where the refractive index change is linear in the light intensity.

The phenomenon of the intensity-dependent phase change of light as it propagates through a nonlinear medium has a much broader context; for example, this is the main physical mechanism responsible for the compensation of beam diffraction, or dispersion-induced pulse broadening, leading to a stable propagation of *optical solitons*. The fundamental concept of soliton-based pulse transmission in optical fibres [2] is well known and now attracts the attention of many theoretical and experimental research groups internationally. Another fundamental idea is to use self-guided beams (spatial solitons) as steerable and multipurpose waveguides for all optical switching and processing. Nonlinear all-optical switches are a photonic analog of the electronic transistor with light controlling light itself within a bulk nonlinear material.

However, a serious problem to be solved for the practical realisation of all-optical switching is the development of materials in which a large nonlinear change of the refractive index can be achieved at realistic laser intensities. One possible way is to develop suitable (eg., organic) nonlinear optical materials with a large non-resonant third-order optical nonlinearity. The results already obtained (in particular, by the group of Prof. B. Luther-Davies at the Laser Physics Centre, ANU) are very promising, but it has also been revealed that in such materials a large nonlinearity is always accompanied by large nonlinear losses. At the same time, experimentalists believe that other novel and significant ideas coming from theory may help to resolve the serious problem of achieving low switching energy which would make all-optical processing quite practical.

Indeed, the pioneering work over the past few years has led to the realisation that the so-called $\chi^{(2)}$ materials may well suit the needs of all-optical switching. This is another previously unexpected approach to the practical realisation of low-power switching devices.

2. Cascaded Nonlinearities

Second harmonic generation (SHG) is one of the fundamental and first observed nonlinear effects in optics. It usually occurs when, due to a quadratic, i.e. $\chi^{(2)}$, response of a dielectric material, light of the fundamental harmonic with the frequency, $\omega_1 = \omega$, interacts *resonantly* with its second harmonic, and generates a double frequency $\omega_2 = 2\omega$ (see Fig. 1).

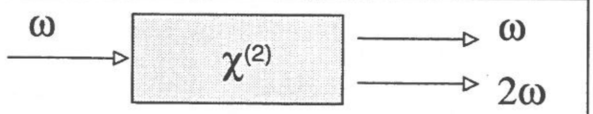


***Figure 1:** Schematic presentation of the generation of the second harmonic in a slightly mismatched configuration. The fundamental wave ω undergoes a phase shift.*

Such an interaction becomes effective provided the so-called phase matching condition $\Delta k = 0$ is satisfied, where $\Delta k = 2k_1(\omega) - k_2(2\omega)$ and k_1 and k_2 are the propagation constants of the fundamental and second harmonics, respectively. Physically, the reason a phase matched interaction leads to intense output of the doubled frequency is the following: The nonlinear dipole moment exhibits the spatial variation $\exp(2ik_1z)$ due to the second-order nonlinearity. If we consider two small regions of space separated by the distance *D*, the phase difference between the dipoles in each responsible for generating the second harmonic radiation is thus $2k_1D$. The radiation emitted by each set of dipoles has the frequency $\omega_2 = 2\omega_1$, and will propagate through the medium with the propagation constant k_2. If $k_2 = 2k_1$,

the radiation field emitted from the set of dipoles in the first volume is exactly in phase with that emitted by the dipoles in the second. Thus, the fields reinforce coherently. If we add up the fields radiated by all the dipoles in the strip of the length L, the intensity of the second harmonic is proportional to L^2.

If $\Delta k \neq 0$, the dipole radiation is not exactly matched and as the length of the strip of dipoles L increases beyond the characteristic length L_c, where $L_c = (\Delta k)^{-1}$ is the coherence length of the nonlinear parametric interaction, the interference becomes destructive. For this slightly mismatched interaction the fundamental harmonic still excites the field of the second harmonic but then, due to destructive interference, the energy comes back. As a result of such conversion, first to the second harmonic and then back, the fundamental wave undergoes a nonlinear phase shift $\Delta\Phi^{NL}$ proportional to $\chi^{(2)}(\omega;2\omega,-\omega):\chi^{(2)}(2\omega;\omega,\omega)$. In the small conversion efficiency regime, this phase shift is found to be [3]

$$\Delta\Phi^{NL} \approx -\frac{\Gamma^2 L^2}{\Delta k L}$$

where

$$\Gamma = \frac{\omega d_{eff}|E_0|}{c\sqrt{n_{2\omega}n_\omega}}$$

and $d_{eff} = |\chi^{(2)}(2\omega;\omega,\omega)|/2$, and E_0 is the incident fundamental field. As the optical Kerr effect is described by the refractive index $n = n_0 + n_2 I$, where I is the light intensity, we can, by analogy, introduce an *effective nonlinear index of refraction*, n_2^{eff} through the Kerr-type relation $\Delta\Phi^{NL} = (2\pi L/\lambda)n_2^{eff} I$. This indicates directly that, under the condition of *slightly mismatched* SHG, traditional materials for SHG can be used for all-optical switching and processing due to the phenomenon of cascaded nonlinear phase shift.

The idea to generate an effective $\chi^{(3)}$ nonlinearity using cascading is, in fact, not new. It seems that one of the first works in this area which demonstrated the generation of an effective cubic nonlinearity due to cascading was published in 1967 by Lev Ostrovsky [4]. Professor Ostrovsky, who is working now in Boulder (USA) visited Australia last year and gave a talk at the Optical Science Centre (ANU) on the qualitative theory of nonlinear dynamical systems. He remembers that, after the theoretical idea of cascading was proposed at the end of the 1960's and beginning of the 1970's, several efforts to observe the self-trapping of light in $\chi^{(2)}$ materials were made in Moscow and Nizhnii Novgorog (formerly Gorki), but these efforts were unsuccessful. According to Lev Ostrovsky, the very special conditions used in the theoretical analysis (large phase mismatch) made experimental verification impossible because of the significant scattering losses for imperfectly matched configurations.

Interest in the experimental study of switching and self-focusing properties of $\chi^{(2)}$ materials was renewed in 1992 when the group led by Professor G. Stegeman from Florida measured the nonlinearity-induced effective shift of the propagation constant as a function of the phase mismatch in a KTP crystal with the result $n_2^{eff} \approx \pm\ 2\times10^{-14} cm^2/W$. After that experimental demonstration many physicists realised that the large phase shift may be of great use for all-optical switching, because optical $\chi^{(2)}$ materials provide one of the fastest nonlinearities among those which are currently available. This has stimulated efforts to take advantage of cascaded second-order effects.

Many examples of possible optical devices based on cascaded nonlinearities have been suggested (see, eg., [5]). Only very recently, however, has the first all-optical switching, resulting from a cascaded second-order nonlinearity in a hybrid Mach-Zehnder interferometer, been demonstrated [6]. The work on a $\chi^{(2)}$ directional coupler is also very promising [7]. This is very important because the switching power in cascading varies inversely as $|\chi^{(2)}|^2$, so that by using existing materials with larger nonlinear coefficients it should be possible to make integrated, cascaded, all-optical switching devices with operating powers reduced by orders of magnitude.

3. Spatial Solitons

After the experimental measurements of the nonlinear phase shift in KTP, it became clear that the necessary condition for such effects related to $\chi^{(3)}$ materials as nonlinear phase shift and self-trapping can be achieved due to a quadratic nonlinearity alone, so that self-refraction and the intensity-dependent light propagation in the form of parametric self-guided beams (spatial solitons) can be expected in $\chi^{(2)}$ materials for a rather wide range of the physical parameters.

The first effort to analyse solitons in quadratic materials was reported by a Russian group [8] more than 20 years ago. This topic was renewed after the successful experimental demonstration of cascaded nonlinearities. The group from the University of Queensland [9] reported some particular solutions describing beam self-trapping. A very important step in this direction has been made recently at the Optical Sciences Centre (ANU) where it has been demonstrated that wide classes of self-guided beams (spatial optical solitons) can be supported by purely parametric interactions in quadratic $\chi^{(2)}$ materials[10]-[13]. Preliminary numerical analysis confirmed this expectation, but a complete physical picture was not available until recently, when the general classification of the self-guided waves was completed. The results include a general family of the self-trapped beams (bright spatial solitons) in the (1+1) and (2+1) dimensions; dark solitons in a dispersive medium; gap solitons; and bound states of bright and

dark solitons. A few particular cases of the self-trapped beams known earlier have found their natural physical explanation in this general picture and I am pleased to mention that the greater part of this work was carried out as a project of the Australian Photonics Cooperative Research Centre.

This research created collaborative links between the OSC group and many other groups around Australia and the world, including Germany, Italy, the UK, and the USA. All the results obtained up to now indicate that these self-trapped beams can be used to write different switching configurations in bulk materials, and that solitons in $\chi^{(2)}$ materials are conceptually similar to those in a generalised Kerr medium with saturation of the refractive index.

It is interesting to note that mutual trapping of the fundamental and second-harmonic beams in a diffractive $\chi^{(2)}$ medium can support (2+1) dimensional two-component beams of circular symmetry, which, unlike the familiar case of collapsing beams in a medium with Kerr nonlinearity, are stable. Collisions between these beams are phase dependent and this property can be used for realising all-optical switching in bulk materials.

In response to the many analytical and numerical predictions, an experimental observation of spatial solitons due to cascaded second-order optical nonlinearities has been very recently demonstrated at the University of Central Florida [14]. It is quite surprising that successful experiments followed the theory almost immediately. This experimental demonstration strongly supports the expectation that by using materials with a higher quadratic nonlinearity, well known for generating the second harmonic and frequency doubling, it will be possible to lower the input power level to that required for practical soliton-based switching devices.

4. Nonlinear Theory of Soliton Stability

The extensive analysis of the solitary waves in $\chi^{(2)}$ finally led to the development of the nonlinear theory of soliton stability. As is well understood, stability is one of the most important issues of the theory of nonlinear guided waves and spatial optical solitons in non-Kerr materials. For writing the induced optical waveguides using solitons, mode stability is obviously required, as unstable modes play a key role in nonlinear all-optical switching. The standard approach to investigate the mode stability is based on a *linear analysis* which is known to lead to the Vakhitov-Kolokolov criterion, first proven for solitons of generalised nonlinearities [15] (see also [16] and references therein). This criterion shows that important information about the guided-wave instability can be extracted from the dependence of the beam power P on the nonlinearity-induced shift of the propagation constant β: The bound mode is unstable provided $dP/d\beta < 0$ [15,16]. However, such a linear stability analysis does not predict the *subsequent evolution* of the unstable solitons and guided waves when the corresponding linearised equations, describing small perturbations upon the solution profile, become invalid. In each particular case numerical simulations are a necessary tool to investigate the beam dynamics.

Recently, for the first time, a powerful *analytical approach* which allows us to describe not only linear instabilities but also the nonlinear long-term evolution of unstable (and stable) solitons and guided, waves has been developed [17]. This approach has already been applied to predict instabilities of $\chi^{(2)}$ solitons [18] and to investigate the oscillating and self-focusing regimes for the dynamics of bright and also dark solitons of generalised nonlinearities.

Standard perturbation theory analyses soliton dynamics under the action of (usually small) external perturbations [19]. The problem here is different and it investigates how an unstable soliton evolves under the action of its 'own' exponentially growing perturbation. As a result of the development of such an instability, the soliton propagation constant β becomes dependant upon the propagation distance z. Close to the instability threshold, when the growth rate is small, a remarkable result follows. The dynamics of optical solitons and guided waves is described by the following *generic* nonlinear equation :

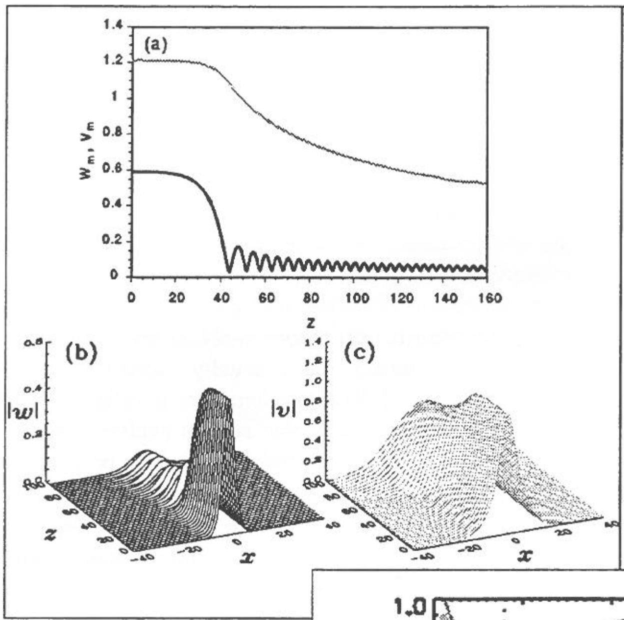
$$\frac{d^2\Delta}{dz^2}+\lambda^2\Delta+\gamma\Delta^2=0 \qquad (1)$$

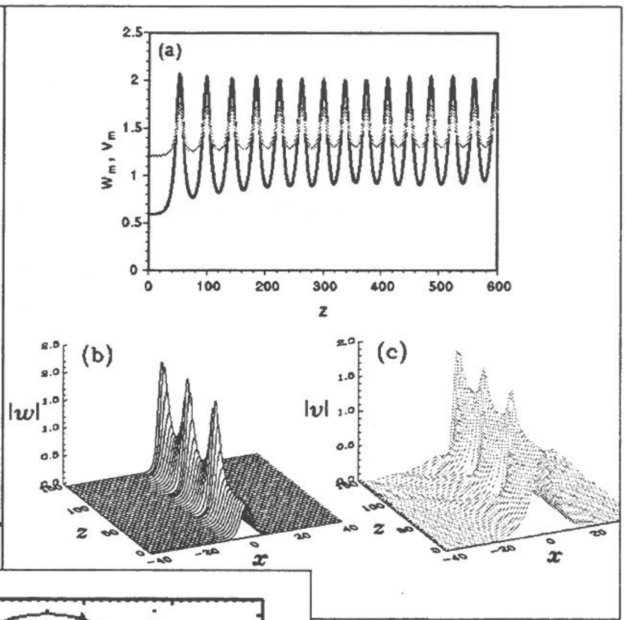
Here Δ is a deviation of the soliton propagation constant β from its unperturbed value β_0, λ^2 is proportional to the derivative $dP/d\beta$, and γ ($\gamma > 0$) can be found in an explicit form (see, eg., [18]). The first two terms in Eq.(1) give the result of the linear stability analysis [15,16], ie. a guided wave or soliton is exponentially unstable provided $dP/d\beta < 0$. The nonlinear term in Eq.(1) allows one to consider not only linear but also *nonlinear* regimes of unstable guided waves and, moreover, to identify all possible scenarios of the instability dynamics investigating the corresponding phase plane of the dynamical system (see Fig.2 inset).

Figure 2 presents the results of the application of this nonlinear theory to the case of $\chi^{(2)}$ solitons. If the amplitude of the initially perturbed two-component soliton is taken to be smaller than the amplitude of the (unstable) stationary solution [ie., $\beta < \beta_0$], the instability leads to a decrease of β (which is proportional to the soliton amplitude) and this process results in spreading of the soliton due to diffraction. This is indicated in the left side of Fig.2(a)-(c). On the other hand, if the initially perturbed soliton has the amplitude slightly larger than that of the stationary soliton solution (Fig.2,

right side), the exponentially growing perturbation 'pushes' the soliton into the stable domain where there is a *stable stationary* state with another β corresponding to the same value of the power. Near a stable equilibrium state, long-lived *oscillating optical solitons* are observed.

The nonlinear theory of soliton and guided wave stability, which has already led to the prediction of unexpected features of spatial solitons in $\chi^{(2)}$ materials, opens an intriguing new frontier, and also allows new opportunities in generation, switching, and control of guided beams and spatial solitons in novel, eg. photorefractive and $\chi^{(2)}$, optical materials.





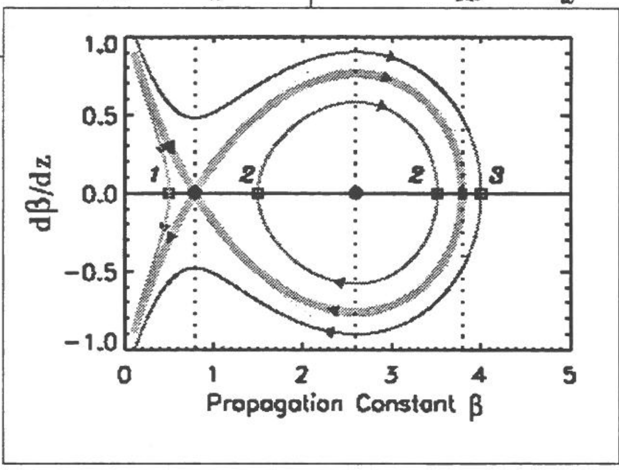


***Figure 2:** Nonlinear regimes of the soliton instabilities as calculated for two-wave $\chi^{(2)}$ solitons. In each case (a) depicts the change of the maximum amplitudes of the two harmonics, and (b) and (c) depict the evolution of the fundamental and second harmonic beams.*
***(left)** If the initial amplitude of the soliton is slightly decreased the beam spreads due to diffraction.*
***(right)** if the initial soliton amplitude is increased, the beam oscillates around a stable state.*

***Inset:** The results of the analytical nonlinear theory of soliton stability presented on the phase plane of the parameters* dβ/dz *and* β, *where* β *is the beam propagation constant. Unstable solitons correspond to a saddle point on this plane, so that after being initially perturbed, the two-wave soliton either diffracts (curves 1 and 3) or becomes trapped into an oscillating state (curve 2) in excellent agreement with the two regimes observed in simulations.*

References

[1] G.I. Stegeman and A. Miller, "*Physics of all-optical switching devices*", in *Photonics Switching*, J. Midwinter, ed. (Academic, Orlando, Fla., 1993), Vol. 1, pp. 81-146.

[2] A. Hasegawa, *Optical Solitons in Fibers* (Springer-Verlag, Berlin, 1989).

[3] R. De Salvo, D.J. Hagan, M. Sheik-Bahae, G. Stegeman, E.W. Van Stryland, and H. Vanherzeele, Optics Letters, **17**, 28 (1992).

[4] L.A. Ostrovsky, JETP Lett. **5**, 272 (1967).

[5] G. Assanto, G.I. Stegeman, M. Sheik-Bahae, and E. Van Stryland, IEEE J. Quantum Electron. **31**, 673 (1995).

[6] Y. Baek, R. Schiek, and G.I. Stegeman, Optics Letters, **20**, 2168 (1995).

[7] R. Schiek, private communication.

[8] Y.N. Karamzin and A.P. Sukhorukov, Pis'ma Zh. Eksp. Teor. Fiz. **20**, 734 (1974) [JETP Lett. **20**, 339 (1974)].

[9] M.J. Werner and P.D. Drummond, J.Opt.Soc.Am.B **10**, 2390 (1993).

[10] A.V. Buryak and Yu.S. Kivshar, Optics Letters **19**, 1612 (1994).

[11] A.V. Buryak and Yu.S. Kivshar, Phys. Lett. A **197**, 407 (1995).

[12] Yu.S. Kivshar, Phys. Rev. E **51**, 1613 (1995).

[13] A.V. Buryak, Yu.S. Kivshar, and V.S. Steblina, Phys. Rev. A **52**, 1670 (1995).

[14] W.E. Torruellas, Z. Wang, D.J. Hagan, E.W. Van Stryland, G.I. Stegeman, L. Torner, and C.R. Menyuk, Phys. Rev. Lett. **74**, 5036 (1995).

[15] M.G. Vakhitov and A.A. Kolokolov, Radiphys. Quantum Electron. **16**, 783 (1973).

[16] D.J. Mitchell and A.W. Snyder, J. Opt. Soc. Am. B **10**, 1572 (1993).

[17] Yu.S. Kivshar, D.E. Pelinovsky, V.V. Afanasjev, and A.V. Buryak, In: *Proceedings of the Interanational Symposium on Physics and Applications of Optical Solitons*, Ed. A. Hasegawa (Kluwer, Amsterdam, 1996), in press.

[18] D.E. Pelinovsky, A.V. Buryak, and Yu.S. Kivshar, Phys. Rev. Lett. **75**, 591 (1995).

[19] Yu. S. Kivshar and B.A. Malomed, Rev. Mod. Phys. **61**, 763 (1989)

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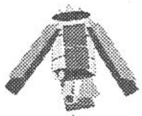

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Nonlinear Effects in Gratings

(or How Gratings Can Slow Down Light)

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Intuition suggests that an optical pulse travels in a medium with a velocity equal to that of the speed of light in that medium. Our recent experiments have shown, however, that this is not necessarily true when light of sufficient intensity to induce a nonlinear optical response propagates in a medium with a periodically modulated refractive index.

1. Introduction

Although the optical properties of periodic structures have been studied for well over a century, frequent innovations are keeping the field vigorous. Over the last decade or so, two exciting developments, one conceptual and one experimental, have drawn new contributors. The conceptual development is that of a photonic band gap, introduced by Yablonovitch [1]. He pointed out that because of the periodicity, many of the concepts developed for the study of crystalline (i.e. perfectly periodic) solids should carry over to the realm of optics. Indeed, the photonic gap, part of a photonic band structure, is an example of this. The key experimental development in optical fibres was an invention by Meltz *et al.* [2] allowing the practical use of the photosensitivity of germanium doped optical fibres, which until then was a laboratory curiosity (albeit a very interesting one!).

Meltz *et al.* showed that the refractive index of the core of an optical fibre changes permanently when it is exposed to ultra-violet light. They did so by exposing the fibre along its length to a sinusoidal intensity distribution obtained from a Mach-Zehnder interferometer. This gave rise to a periodic refractive index, i.e. a grating written in the fibre core. Many of the details of this experiment have been improved upon in the meantime. For example use of a phase masks to produce the exposure [3,4], rather than a bulky interferometer, and hydrogenation of the fibre [5], which leads to an increase in the sensitivity of the glass by three orders of magnitude.

The invention of Meltz *et al.* has spawned a multi-million dollar industry which is growing rapidly! For example, fibre Bragg gratings are now finding important applications in telecommunications as dispersion compensators and filters [6,7]. In this article we briefly describe a recent set of experiments in which these two key developments are combined with the phenomenon of optical nonlinearity, to show that a grating can slow down light [8].

2. Fibre Bragg Gratings

The fibre Bragg gratings of which we speak here are fabricated by placing a bare optical fibre behind a phase mask [3] while the mask is illuminated with intense ultraviolet light at a wavelength of around 240 nm. The +1 and -1 diffracted orders of the UV beam interfere at the fibre core with a period of half that of the phase mask itself. Through the photosensitive effect the periodic intensity variations are permanently imprinted as small, periodic variations of the refractive index along the core of the fibre. The grating used in our experiment had a period of about 350 nm, and was 55 mm long, so that there were over 150,000 periods, with a refractive index difference of only 0.0003.

To understand how light travelling along the core of the fibre responds to the grating, consider the propagation of light through the core. In the absence of the grating the light is unimpeded. However, with the grating present, each ruling reflects a fraction of the beam. The light reflected by the whole grating can be found by adding all these contributions vectorially and squaring to find the intensity. Clearly this intensity is largest when the contributions of all rulings are exactly in phase with each other. This condition of high reflectivity defines the resonant or *Bragg wavelength*, λ_B, given by

$$\lambda_B = 2n\Lambda$$

where Λ is the spatial period of the grating and n is the average refractive index. This is illustrated in Fig.1, which shows the reflection spectrum of our grating. This grating was designed to reflect light emitted by a Nd:YLF laser, and so its Bragg wavelength is around 1053 nm. Even though the refractive index varies by only 0.0003, the grating clearly reflects strongly thanks to the large number of periods.

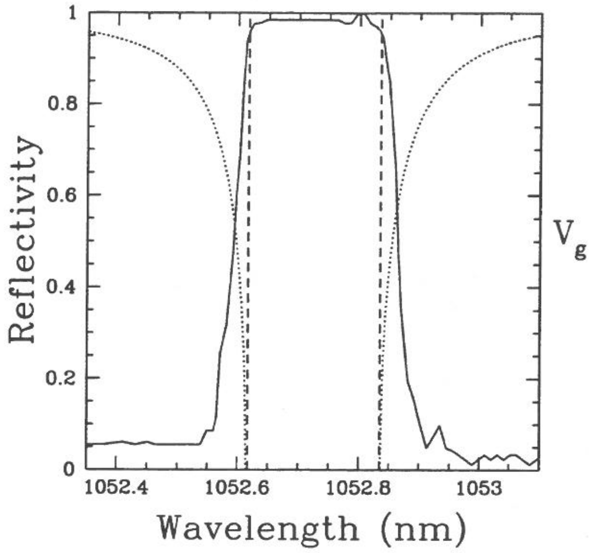

Figure 1: *The measured reflection spectrum of the actual grating used in the experiment. The grating length is 55 mm and the refractive index modulation is $\Delta n = 3\times 10^{-4}$. The dashed lines indicate the boundaries of the photonic bandgap. The dotted lines indicate the normalised group velocity $V_g = v_g/(c/n)$ as a function of wavelength around the Bragg resonance, λ_B.*

3. Photonic Band Gaps

Fig.1 also shows that our insight is not quite complete: the grating does not reflect just a single wavelength but a narrow range of wavelengths with a width of about 0.25 nm. This is the photonic band gap, the boundaries of which are shown approximately in Fig.1 by the dashed line. As discussed earlier, this term has been borrowed from solid state physics, where electronic band gaps, for example in semiconductors, are well known. Waves (electronic or optical) with wavelengths inside the bandgap cannot propagate within the periodic structure, and are therefore strongly (Bragg) reflected as indicated in Fig. 1. At wavelengths well away from the Bragg wavelength the waves travel essentially as if the grating were not there at all (although this point may be stretching things somewhat for a semiconductor; for the fibre gratings of interest here it is an excellent approximation).

If within the photonic band gap the light does not propagate at all, while far outside the gap waves propagate as if the grating weren't there, what happens for wavelengths in between? As illustrated in Fig.1 by the dotted line, the velocity at which the light propagates (the group velocity) increases smoothly from zero at the edge of the photonic band gap, to c/n away from it (here c is the speed of light in vacuum, and $c/n \approx 2\times10^8$ m/s is the light velocity in the fibre in the absence of the grating). The range of wavelengths over which this occurs is of the same order as the width of the photonic bandgap; for the grating we are considering this is a few tenths of a nanometre. Within this very narrow wavelength range the group velocity of the light increases from zero to c/n; thus the group velocity varies very rapidly as a function of wavelength. The grating dispersion is therefore enormous, and in fact is about 10,000 times larger than the dispersion of virgin fibre.

Now consider a low intensity (transform limited) pulse, at a wavelength just outside the photonic bandgap, travelling through the grating. Due to the small group velocity of light near the band edge, the average velocity of the pulse can be substantially less than the speed of light in the uniform medium. This offers the possibility of tailor made slow energy transport which could have important applications, for example in optical delay lines. However, at these wavelengths the grating dispersion is also very large, and it thus quickly rips the pulse apart.

4. Bragg Grating Solitons

This is not the full story, because the propagation of a pulse in the high intensity regime where the *optical nonlinearity* plays a role can be dramatically different. In effect, the nonlinearity acts as a "glue," which holds the pulse together in spite of the strong dispersion. To understand this we must first consider intense pulses travelling in a uniform medium without a grating but with an optical nonlinearity. In particular we consider a Kerr-type nonlinearity in which the refractive index is intensity dependent,

$$n = n_0 + n_2 I$$

where I is the optical intensity and n_2 is the nonlinear component of the refractive index. In glass this is equal to $n_2 = +2.3\times10^{-16}$ cm²/W. Thus the refractive index of a directly sun-illuminated window is larger during the day than in the night, albeit by only one part in 10^{17}. However, even under laboratory conditions this is a small effect. For example, in the experiments we describe below I = 14 GW/cm² and thus the refractive index changes by a few parts per million.

The effect of the Kerr nonlinearity on a light pulse is to distort the otherwise sinusoidal electromagnetic wave so as to generate new frequencies not initially present in the pulse. For a positive Kerr nonlinearity ($n_2 > 0$) the result is an accumulation of red-shifted light on the leading edge, and blue-shifted light on the trailing edge of the pulse. Such a pulse, the frequency of which varies continuously from one end to the other, is said to be "chirped", by analogy with the smoothly rising pitch of some bird calls.

In a non-dispersive medium, a chirped pulse travels with a constant shape. However, in a suitably dispersive medium the redder wavelengths on the pulse's leading edge are retarded, and the blue wavelengths advanced so that the blue end of the pulse catches up with the red, and the pulse is compressed. It is clear from Fig.1 that in a fibre grating this occurs for wavelengths below the photonic band gap. In fact, it has been shown that the

dispersion and nonlinearity can exactly balance [9,10] to give a soliton, a narrow pulse travelling through the grating without changing its shape. Because this particular soliton only exists inside a Bragg grating we refer to it as a "Bragg grating soliton". The argument used here is identical to that for the "standard" solitons that have been demonstrated in uniform optical fibre. However, Bragg grating solitons live off the grating dispersion, rather than the weak material dispersion, and thus can travel at any velocity between zero and the speed of light.

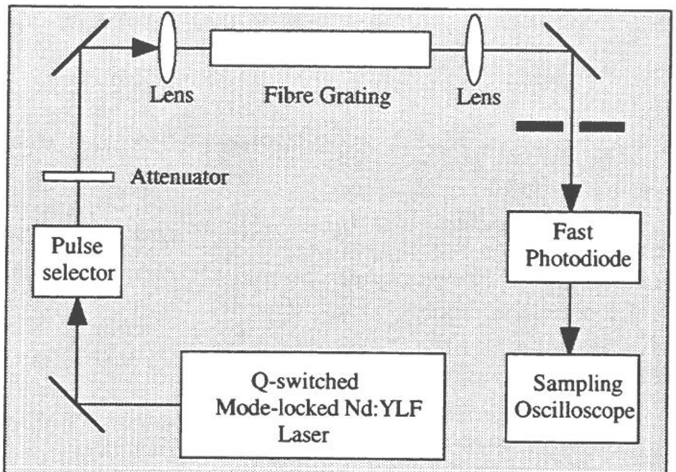

Figure 2: Schematic diagram of experiment to observe Bragg grating solitons

5. Experiment

The existence of Bragg grating solitons was recently demonstrated in a series of experiments performed as a part of a collaboration between the authors and members of AT&T Bell Laboratories in the USA [8]. This collaboration brought together the expertise in fibre grating technology and the theory of nonlinear gratings developed at the University of Sydney in the Optical Fibre Technology Centre and the School of Physics, and the expertise in pulse propagation experiments at AT&T. The two principal ingredients for this experiment are long fibre gratings described above and a source of intense short pulses. The pulses were generated by a mode-locked Q-switched Nd:NLF laser which allowed efficient coupling of more than 100GW/cm^2 into the single-mode optical fibre containing the Bragg grating. The pulses were then detected with a fast photodiode. A schematic diagram of the experiment is shown in Fig.2.

The pulses were first tuned such that their frequency spectrum was just outside the photonic bandgap, where the grating is highly dispersive. We first interrogated the linear properties of the fibre Bragg grating by attenuating the beam to ensure that the peak intensities were very small. The pulses were then substantially retarded in time and also broadened by approximately 40%. The retardation is due to the reduced velocity, while the broadening is due to the strong dispersion.

The peak intensity of the laser pulses was then increased to approximately 14 GW/cm^2 where the optical nonlinearity plays a role. The solid line in Figure 3 shows the transmitted pulse having a FWHM of approximately 80 ps when the pulse is detuned far from the Bragg wavelength (so that there is no interaction with the grating). This should be compared to the transmitted intensity at the same high input intensity,

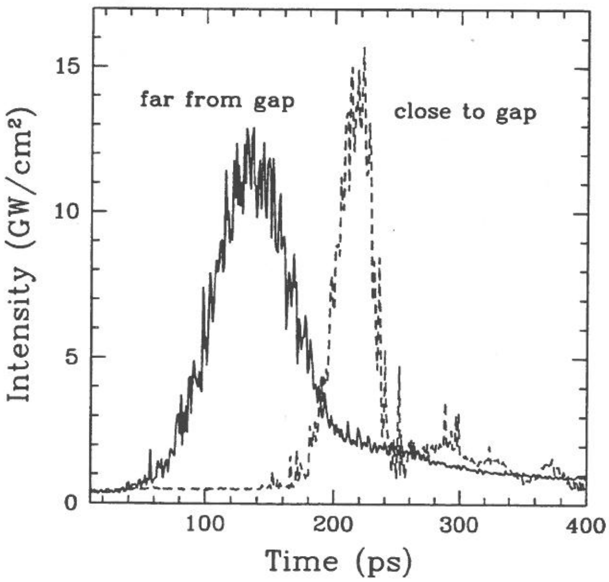

Figure 3: Transmitted pulse, having a FWHM ≈ 80 ps, when the grating is tuned far from the resonance, and the transmitted pulse having FWHM ≈ 15 ps when the grating is tuned such that the pulse is centred on 1052.55 nm where the grating reflectivity is only 25%

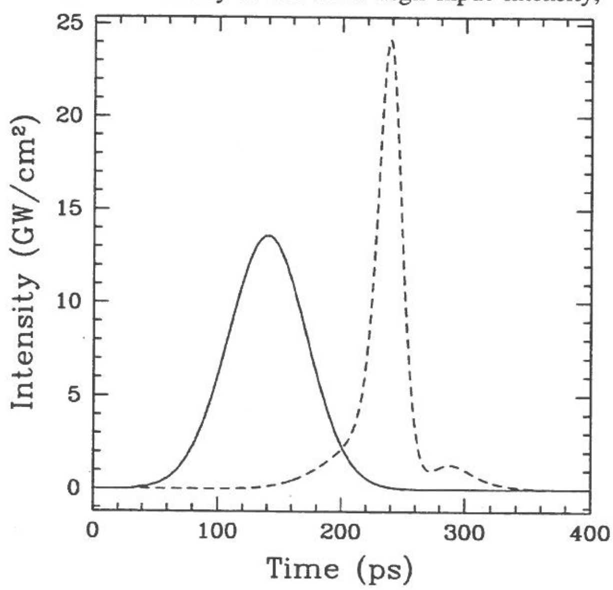

Figure 4: Numerical simulations of transmitted pulse when the pulse is centred on 1052.55 nm where the grating reflectivity is 25%.

but when the grating is tuned, by straining, such that the pulse is just outside the photonic bandgap where the grating is highly dispersive. It is clear from the figure that a compressed pulse leaves the grating approximately 85 ps later than the pulse propagating without dispersion.

Since the length of the grating is 5.5 cm, and light in a bare optical fibre travels approximately 1cm in 50 ps, the compressed pulse travels at an average velocity corresponding to 76% of the speed of light in the uniform fibre. Also note that the transmitted pulse now has a pulse width of 15 ps which corresponds to a compression factor greater than 5. So at low intensity the pulse is broadened due to the grating dispersion, while at high intensity the pulse is compressed.

Shown in Figure 4 is the calculated transmitted intensity for the case when the pulse is detuned far from the gap (solid line) and when it is tuned close to the gap (dashed line), for parameters similar to those in the experiment. Our simulations suggest that the formation of Bragg grating solitons can explain the observed compression. The predicted formation length of the soliton is approximately 2 cm and as our grating was 5.5 cm there was clearly plenty of distance over which the Bragg grating soliton could form. The simulations also show that the incident pulse initially undergoes compression followed by evolution into a Bragg grating soliton which then propagates without changing shape.

A class of Bragg grating soliton which has attracted much theoretical attention in the past is the "gap soliton" whose frequency spectrum lies almost entirely within the photonic bandgap and thus at low intensities is strongly reflected [10]. To understand this we need to consider an intense pulse whose frequency spectrum lies within the photonic bandgap, where at low powers most of the energy is reflected. If, however, the peak intensity is high enough, then because of the intensity dependent refractive index, the photonic bandgap is shifted. As a result, the peak of the pulse effectively tunes itself out of the photonic bandgap to a region where the grating is transmitting. However, the wings of the pulse which are lower in intensity are not detuned in this way and are reflected. Thus the energy in the pulse is now confined and the pulse propagates along the length of the grating without changing shape.

6. Future Work

It is not clear that Bragg grating solitons will find immediate applications in optical communications, especially considering that the presently required intensities are within a factor of ten of the damage threshold for the input facet of the fibre. The development of new, highly nonlinear glass fibre compositions, with correspondingly lower thresholds for Bragg grating soliton formation, may eventually lead to applications such as variable optical delay lines.

Questions presently under investigation include the effects of even higher pulse intensities than those mentioned above, and the consequences of intentional nonuniformities in the Bragg grating. Irrespective of the practicality of Bragg grating solitons, it is clear that a whole range of new optical phenomena has been opened up by the experiments described here, and many more intriguing phenomena stand to be discovered and studied.

Acknowledgements

The authors thank Michael Steel, Neil Broderick and R. E. Slusher for fruitful conversations. B. J. Eggleton acknowledges the support of an Australian Postgraduate Award and an Australian Telecommunications Electronic Research Board scholarship. The Optical Fibre Technology Centre is a member in the Australian Photonics Cooperative Research Centre.

References

[1] E. Yablonovitch, *Phys. Rev. Lett.*, **58**, pp. 2059-2062, (1987).

[2] G. Meltz, W. W. Morey and W. H. Glenn, *Opt. Lett.*, **14**, pp. 823-825, (1989).

[3] K. O. Hill, B. Malo, F. Bilodeau, D. C. Johnson and J. Albert, *Appl. Phys. Lett.*, **62**, pp. 1035-1037, (1993).

[4] J. Martin and F. Ouellette, *Electron. Lett.*, **30**, pp. 812-813, (1994).

[5] P. J. Lemaire, R. M. Atkins, V. Mizrahi and W. A. Reed, *Electron. Lett.*, **29**, pp. 1191-1193, (1993).

[6] P. A. Krug, T. Stephens, G. Yoffe, F. Ouellette, P. C. Hill and G. Dhosi, *Electron. Lett.*, **31**, pp. 1091-1093, (1995).

[7] R. J. Campbell and R. Kashyap, *International Journal of Optoelectronics*, **9**, pp. 33-57, (1994).

[8] B. J. Eggleton, R. E. Slusher, C. Martijn de Sterke, P. A. Krug and J. E. Sipe, *Phys. Rev. Lett.*, in press.

[9] A. B. Aceves and S. Wabnitz, *Phys. Lett. A*, **141**, pp. 37-42, (1989).

[10] C. M. De Sterke and J. E. Sipe, in *Progress in Optics XXXIII*, E. Wolf, ed., (Elsevier, Amsterdam, 1994), Chap. III-Gap Solitons.

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- ☐ **NEAT (New England Affiliated Technologies)** - *ball slides, etc.*
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Serving Australian Scientific Research & Industry

The Need for Project Management Skills in Research Laboratories

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Electrical & Electronic Engineering Building,
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Cooperative Research Centres are an important method of overcoming geographical and financial obstacles in applied research. The need for project management and its implementation are discussed here.

Background

Around the world, and especially in Australia, it seems there is a basic change in high technology research and development enterprise. The nature of this change is the emergence of an ever-increasing number of collaborative research and development (R&D) efforts. These efforts, although mostly domestic, are often international in scope and consist of: collaborations between corporations that may be competitors in other areas, between corporations and academic institutions, and between government institutions and private-sector institutions of many types.

There are several reasons for these R&D alliances. Budgetary constraints are forcing corporations to find ways of getting a "bigger bang for their buck", and joint undertaking of competitive research may save money for the alliance partners by reducing duplication of effort without foregoing the right to compete vigorously when the R goes to D and products are marketable. As well, larger corporations are looking to Universities for their bigger R&D programs, allowing closer cooperation between Industry R&D groups and Universities. Cooperative Research Centres provide an excellent framework for this to happen.

This environment of Industry and University collaboration has led to a need for University researchers to become more focussed with some of their more applied research work, and to provide industry partners with schedules detailing time, quality, cost and deliverable's. Researchers have typically been conditioned to estimating in broader, less detailed terms showing person-years, equipment costs and laboratory space required, within the constraints of a research grant application. To deliver R&D in this environment project management is needed.

Project Management is Needed

Nowadays engineers and, indeed, engineering researchers, are faced with the need for project management of their research and development projects. A considered and well planned approach is called for when the stakes are high and time is pressing. Designs suitable for manufacture are essential if the end products are to reach international markets before the window of opportunity has passed. Product life cycles are decreasing whilst the complexity of new technologies is growing with technical innovations.

All this means researchers are having to adopt engineering project management to deliver the outcomes of their research on time and within budget especially for the more applied projects.

What is Project Management?

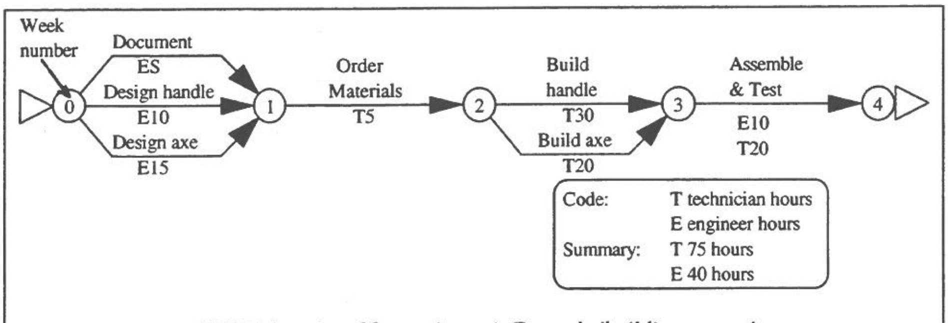
A project is an organised endeavour aimed at completing a specific task or number of tasks. Teams of people with different talents are needed to accomplish the completion of a number of tasks within an agreed time frame. These teams are pulled together on an ad hoc basis from people who have duties in other parts of the organisation. After the project is complete the team may be disbanded. A plan is needed to assemble the tasks and complete them in a structured fashion.

The major processes are to:

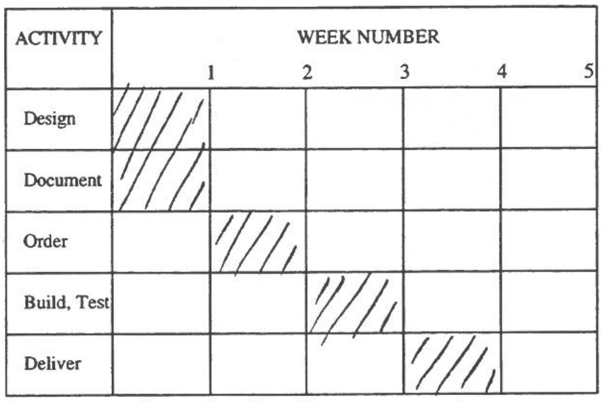
- o identify the need for a product or service
- o define the project goals
- o select appropriate performance measures
- o develop the technological concept
- o develop a schedule and budget
- o integrate into a project plan
- o implement the plan
- o monitor and control the project
- o evaluate the project success

Some History and Planning Methods for Project Managers

Project planning methods as we know them today originated mainly from the defence industry with PERT (Program Evaluation and Review Technique) charts developed in 1958 at the US Navy Special Projects Office and CPM (Critical Path Method) developed at DuPont in 1957. These network methods identify and communicate the planned activities and their



PERT chart (used by engineers). Example 'building an axe'.



Gantt chart (used by management).

interrelationships. Their value has been demonstrated time and time again on projects. As well, Gannt charts (a version of a bar chart) developed during World War 1 by Henry L Gannt are used to represent activities on the vertical axis and corresponding duration on the horizontal axis. Activities are scheduled usually for an early start and initiated as early as possible without violating the precedence relations.

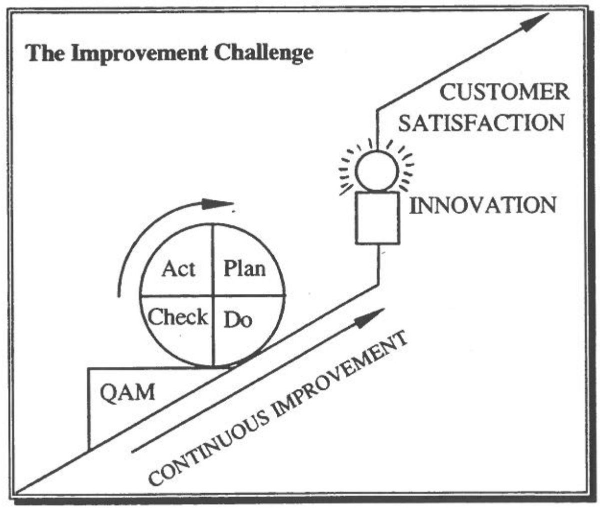
Using a simple example one might develop a Pert chart and a Gantt chart for designing developing and building an axe. The Pert chart shows more detail and is used by engineers whereas the Gantt chart is usually used by managers, gives a broader picture and often includes budgetary information.

The activities for this example are:
Design handle, design axe head, document the design, order materials, build the handle, build the axe head and assemble and test.

Of course there are many computer programs available off the shelf that use these methods in a more effective way, for example Microsoft Project.

A Summary and Word of Warning

There is no doubt project management methods help deliver results of research and engineering projects on time and within budget. The management of projects however requires an attitude of continuous improvement, supported by quality assurance management and combined with innovation to be world competitive. Quality Assurance Management involves the documentation and formalisation of system needs, various testing methods, test set up and other tasks that need to be repeated. This may all be represented on the illustration shown below using the analogy of pushing a wheel up an incline. The spokes of the wheel are *act*, *plan*, *do*, and *check*. It is hard to push this wheel up the continuous improvement incline so a rest is needed. This rest is provided by the QAM (quality assurance management) chock which prevents the wheel (the project) from rolling backwards down the incline. The chock represents the documentation of your system as the project proceeds, allowing others to help using the documentation. Then further up the incline, every so often, innovation comes along to provide a step change improvement and this helps the work to gain a competitive advantage.



Laws of Project Management

Finally the American Production and Inventory Control Society has fashioned the following laws to explain the uncertainty in project management.

1. No major project is ever installed on time, within budget or with the same staff that started it. Yours will not be the first.
2. Projects progress quickly until they become 90% complete, then they remain at 90% complete forever.
3. One advantage of fuzzy project objectives is that they let you avoid the embarrassment of estimating

the corresponding costs.

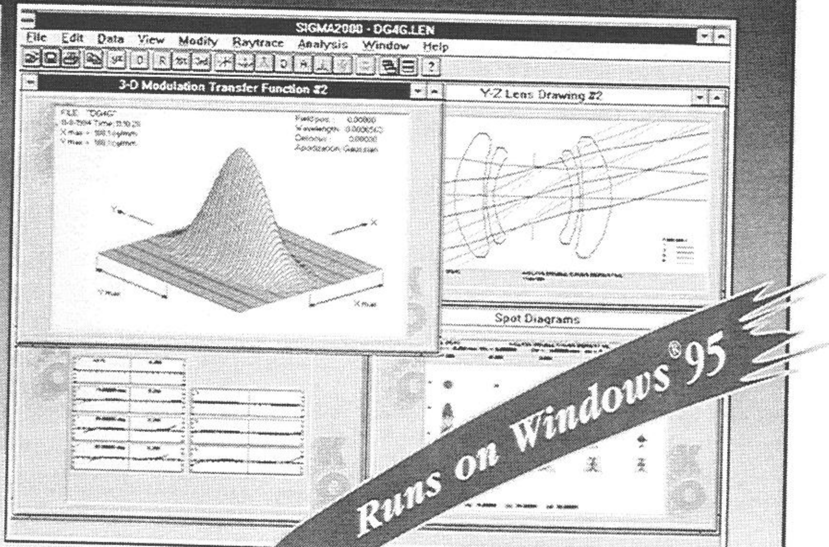
4. When things are gong well, something will go wrong.
5. When things just cannot get any worse, they will.
6. When things appear to be going better, you have overlooked something.
7. If project content is allowed to change freely, the rate of change will exceed the rate of progress.
8. No system is ever completely debugged. Attempts to debug a system inevitably introduce new bugs that are even harder to find.
9. A carelessly planned project will take three times longer to complete than expected; a carefully planned project will take only twice as long.
10. Project teams detest progress reporting because it vividly manifests their lack of progress.

Final Note

In my experience most project managers are given full responsibility without authority to match. This means that progress is often inhibited whilst decisions from higher authority are being sought. Project managers should expect this and provide contingencies.

Do not despair: the use of project management techniques will allow your project team to improve performance greatly. Clear, focussed objectives with achievable targets arrived at by the project team and progress reviews combined with working extra hours will result in success.

(Terry is a graduate electronics engineer with a Graduate Diploma in Manufacturing Technology and a Masters Degree in Enterprise and Innovation and has over 25 years of experience in the research, design, development, manufacture and commercialisation of high technology products both domestically and internationally into world markets).



Optics on the World Wide Web

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The Internet is a rapidly-growing source of information on almost any topic. The nature of the information relevant to optics is discussed here and illustrated with examples.

Introduction

The first building blocks of the much anticipated 'information superhighway' are already in place. One of these building blocks, the Internet, has recently undergone rapid growth in popularity due to the development of the World Wide Web (WWW), a system which makes using the Internet very simple. This article is intended to inform readers about what is already available on the Internet as far as optics is concerned, and offer a few starting points for people to explore this information for themselves. As well, a brief introduction to the Internet is given for the benefit of readers who do not have Internet access, and may be considering such a connection.

We also hope that this article will encourage members of the optics community in Australia to contribute to the Web by setting up their own pages. Despite its shortcomings, the Web can be a valuable source of information, and its importance will most likely increase in the future.

The World Wide Web

Computers communicate over data networks, which generally consist of cables, optical fibres or microwave links in some combination. The Internet is a giant 'network of networks' which spans the globe, enabling a personal computer in a someone's office to access information from thousands of sites from around the world. These sites are simply other computers on the Internet which have the permissions on certain areas set so that they can be read by anyone. Each local network decides exactly what information can be read from outside, making it possible to access this information from any machine on the Internet.

The WWW is a system of storing information on the Internet so that it can be retrieved using a web browser. This web browser is a program, usually with a simple graphical interface, which makes the nuts and bolts of the Internet transparent to the user. Using only a mouse the WWW can be searched, files down loaded, images viewed and sounds played.

The WWW can be used to access information of almost any kind. The latest weather information, television guides, newspaper articles, etc, are within the click of a mouse button. Indeed, one of the difficulties of using the web effectively is the rejection of irrelevant data.

In the field of optics, there are several types of information readily available. For instance, advance journal article titles and abstracts, in particular the OSA journals, can be searched and downloaded. Several companies can be contacted through the web, and many have product information that is easily accessible in multimedia format. Tables of constants and optical data can be found online. Powerful shareware and demo software is available and easy to locate using the Web's search routines. Several optics magazines have home pages, often containing either articles from the magazines or information about coming issues (this is particularly useful for those of us who get these magazines by sea mail). If you plan to visit a laboratory or company for the first time, you can consult the relevant home page to obtain a profile of the institution, local travel information, or to search the staff list for contact information. Many institutions have a database of the staff email addresses, which can be particularly useful. Conference organisers are also taking advantage of the WWW and you can find calls for papers, advance information and the like for several major conferences in optics.

The WWW is also a place to search for a job and to advertise a vacant position. Many employers, in addition to advertising in the traditional media, advertise through their home pages or through a society such as the OSA. Some job advertisements have application forms which can be filled out from your web browser, allowing for an entirely electronic submission of an application.

Getting Started on the Web

To use the WWW you need an Internet connection (hardware) and a web browser (software). If you work in an institution which possesses one or more mainframe Unix machines, chances are the system administrators can set you up quickly. If you do not have a network

which is connected to the Internet, you will need to go through a modem to a machine which has such a connection. Although only a local call is required, there is usually a monthly fee for this service. You can find out about this option from most dealers selling personal computers.

Once Internet access has been established you can obtain the popular web browser, Netscape, via anonymous ftp from several sites, one such Australian site being *ftp://ftp.adelaide.edu.au/pub/WWW/Netscape /netscape/* There are versions for Mac, Unix or Windows, the latest version being v1.22.

Searching the 'Net

The following list of WWW pages is intended to give an outline of the type of information available on the WWW. If you have a web browser installed, you can use the rest of this article as a starting point or reference for optics information on the web. If you do not have a web browser, some of the information below may help you decide if an Internet connection is worthwhile.

These examples are meant as starting points only; many contain a multitude of links to other sites and information. Also, please remember that the URL's (the Web addresses) for each site are CAse SeNsiTiVe, and will not work unless you pass them to your web browser exactly as written. If you don't like typing in URL's, try passing some of the keywords to a search routine which will most likely return these sites as hot links. Alternatively, all these links can be found at *http://www.dap.csiro.au/OPTECH/Optics-Radiometry/ sitelist.html*

OPTICS IN GENERAL
OSA OpticsNet *http://www.osa.org/* is one of the best starting points for general optics information. OpticsNet features searchable contents for the soon-to-be-released issues of OSA journals, conference information, some optics articles and employment listings. It also has links to the SPIE and IEEE. Good sets of optics links can also be found at *http://www.uml.edu/Dept/EE/ RCs/CEMOS/optics.html* and *http://www .physics.mcgill.ca/physicsservices/physc is_optics.html* These are web pages consisting solely of lists of links to other optics information on the web.

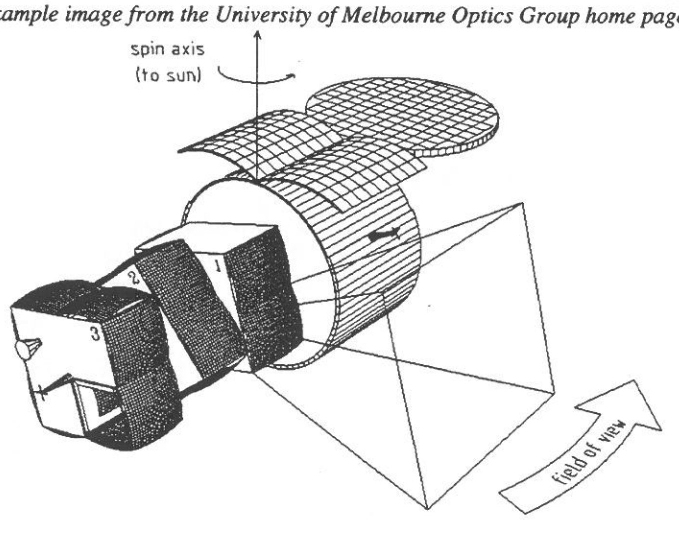
OPTICAL DATA
For an example of optical data which can be perused on the 'net, visit NIST Physics Laboratory Physical Reference Data *ttp://physics.nist.gov/PhysRefData/ contents.html* This includes links to atomic spectroscopic data and values for the fundamental physical constants.

OPTICAL ENGINEERING
Yahoo hyperlinks *http://www.yahoo.com/text/Science/ Engineering/Optical_Engineering/Institutes/* is a list of optics-related sites with an optical engineering slant.

OPTICS IN AUSTRALIA
Listed below are some pages about optics research in Australia. This list is only meant to be a representative sample. The sites usually contain a summary of the work being carried out, lists of staff and their involvement, as well as links to other sites dedicated to the relevant field. The coming AOS page will eventually contain a more complete list of Australian optics sites.

University of Melbourne Optics Group
http://optics.ph.unimelb.edu.au/
The ANU Laser Physics Centre
http://rsphy1.anu.edu.au/~bld111/brochure-word.html
ANU Photonics
http://laserspark.anu.edu.au/photonics.html
Theoretical Quantum Optics Group (UQ)
http://www.physics.uq.oz.au:8001/qo.html
The Department of Astrophysics & Optics (UNSW)
http://www.phys.unsw.edu.au/astro.html
CSIRO Applied Physics Optical Technology Program
http://www.dap.csiro.au/OPTECH/
University of Sydney Department of Physical Optics
http://www.physics.su.au.oz/physopt/
University of Adelaide Optics Group
http://www.physics.adelaide.edu.au/optics/home.html

Example image from the University of Melbourne Optics Group home page:



A schematic of a possible satellite, incorporating 3 modules of lobster eye telescopes. Each half side of each module is a portion of a spherical lobster eye telescope. (The eye of a lobster uses a lens consisting of approximately square microchannels, which reflect light onto the lobster retina. The Optics Group has borrowed this concept to design a prototype imaging X-ray telescope, and research is underway to model the performance and investigate the feasibility, in collaboration with groups at Los Alamos, NASA and the University of Leicester).

SPECTROSCOPY
Optical data (see entry under NIST Physics Laboratory Physical Reference Data) and products (see under Optima Research or Oriel Instruments for examples).

SOFTWARE
Software available on the Internet comes in a variety of types, ranging from free software to demonstration versions of powerful commercial packages. For example, a demo of the ZEMAX optical design program by Focus Software, Inc can be found at *http://www.focus-software.com/fsi/* along with other products. For a full Windows ray tracing package you can try IRT, available at *ftp://ftp.creol.ucf.edu/pub/optics/* (latest version irt52.zip). This ftp site also contains many other optics-related programs. For optical design beyond geometric optics, LightPipes (*http://guernsey.et.tudelft.nl/*) is a toolbox for numerical simulation of optical devices, taking into account diffraction.

COMMERCIAL SITES
Several companies provide information about their products on the web. These are a few examples chosen to reflect the different companies you can find. Australian Holographics, a local manufacturer, can be found at *http://www.camtech.com.au/~austholo/index.html* Laser Focus World magazine has a page (including links to several companies, such as Melles Griot) at *http://www.lfw.com/www/home.html* Optical Research Associates (makers of CODE V, an optical design program) are at *http://www.opticalres.com/* Oriel Instruments (manufacturers of optical components) are at *http://www.oriel.com/WWW/adv/oriel.html* , and Optima Research (suppliers of optical components) are at *http://www.optima.co.uk*

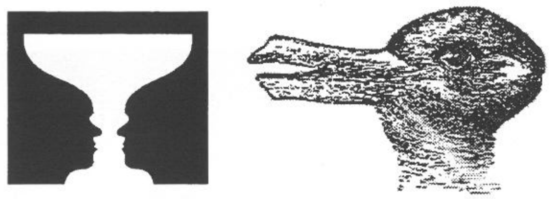
ASTRONOMY
There is a vast amount of information concerning astronomy in general, from a complete pictorial guide to the solar system, to information for amateur astronomers. Here's one of many links to some of the images taken by the Hubble Space Telescope: *http://www.ast.cam.ac.uk/HST/press.html* The optics of astronomy is less well represented, but you might find something from the list of well over 100 astronomy-related sites contained in: *http://fits.cv.nrao.edu/www/yp_optical.html* There's also plenty on adaptive optics. For example, a site at the University of Hawaii *http://queequeg.ifa.hawaii.edu/Welcome.html* enables you to download PostScript versions of the group's latest publications.

OPHTHALMOLOGY
The American Academy of Ophthalmology *http://www.eyenet.org/* has articles on topics such as corneal surgery. The National University of Singapore has ophthalmic information and links as part of its Cyberspace Hospital *http://ch.nus.sg/CH/eye.html*

EDUCATIONAL
Questacon (The National Science and Technology Centre in Canberra) *http://actein.edu.au/Questacon/index.html#00* Not a lot of optics here, but some interesting material for schools. Contains an overview of the Science Centre and some puzzles from all areas of science. The commercial site, Optical Research Associates, *http://www.opticalres.com/* contains some good introductory optics articles (look under 'Optics for Kids').

EMPLOYMENT IN OPTICS
Monster Jobs on the Web allows you to search and apply for a job, advertise a position, or post your resumé: *http://www.monster.com/home.html* See also the OSA and SPIE sites.

OPTICS FOR FUN
Several WWW pages offer an educational and entertaining selection of optical effects. There are a few sites devoted to optical illusions; images which confuse our perception of reality. For example: *http://lainet3.lainet.com/~ausbourn/* You can also find software to generate 3D random dot stereograms (often called SIRDS) and display them on your computer screen. This site also contains a link to a virtual art gallery devoted to raytraced images: *http://www.comlab.ox.ac.uk/archive/3d.html*



Optical illusions which demonstrate the image recognition capability of the brain. Each image has two interpretations which cannot be held simultaneously.

Newsgroups

Usenet is a public bulletin board system consisting of over 8,000 public discussion groups (newsgroups). When someone posts a message to one or more discussion groups, the message may be read and replied to by anyone else reading the group.

sci.optics is a newsgroup devoted to the discussion of optics. You may ask almost any optics-related questions, although students looking for answers to their latest assignment are usually frowned upon! The quality of the answers you receive depend upon the level of specialisation of the question. This is a great place to ask about areas of optics outside your own. *news:sci.optics*

Other newsgroups which have some optics content are:

sci.med.vision (medical optics and vision), *sci.image.processing* (digital imaging), *comp.ai.vision* (a moderated forum for digital imaging and vision), *sci.astro* (astronomy), and *sci.techiques.spectroscopy* (guess).

Miscellaneous Tips.

- Switch off Netscape's *Auto Load Images* option to speed-up a slow link. If you decide a link is too slow while the page is still loading, press the *Stop* sign, switch off *Auto Load Images* and then press *Reload.*
- The last few letters in the machine name of a site indicate the country the site is in. For instance, Australian sites end in *.au* while French sites end in *.fr*. The address for the United States has no country suffix, and most likely ends in .edu or .com. In general, the nearer a site the faster the link.
- There are several databases of WWW pages which you can search using keywords. All of these are very good, but have different methods to indicate the strength of the keyword match. If you create a new web site you can submit its URL to these databases.
- If you need to ftp a large file, it *may* be quicker to login to the server via anonymous ftp rather than use a web browser.

Glossary

ftp : File Transfer Protocol. A program which enables files to be transferred between two machines on the Internet.

html : Hypertext Markup Language. Web pages are ASCII documents written in html. Graphics and sounds etc. are included by placing references to the graphics or sound files, which are read by the web browser and inserted at the appropriate points.

http : Hypertext Transfer Protocol.

Hypertext : Text that contains links.

Internet : Global network of networked computers.

Link : short for "hot link". Just click on one of these in your web browser and the browser loads the document pointed to by the link.

Newsgroup : Public bulletin board system on the Internet. Post and read questions, arguments, replies, etc, and upload and download software.

Page : Or home page. A document in the WWW consisting of text, graphics and/or sounds which can be viewed using a web browser.

URL : Uniform Resource Locator. A URL includes the type of resource being accessed, the address of the server, and the location of the file. Think of it as a world-wide path name.

Web browser : Software capable of interpreting documents on the WWW.

WWW : World Wide Web. System of storing documents (text/pictures/sounds) on the Internet so that the document may be read by a web browser running on any machine which is a part of the Internet.

1996-1997 Meetings Calendar at a Glance

Detailed information concerning major optics conferences is now accessible on the World Wide Web. For example:
OSA (*http://www.osa.org/*)
SPIE (*http://www.spie.org/*)
The principle sponsors of many of these conferences, OSA and SPIE, can be contacted at the following addresses.

OSA
2010 Massachusetts Ave
NW Washington DC 20036, USA
Tel: +1 202 223 0920
Fax: +1 202 416 6100

SPIE, PO Box 10
Bellingham
WA 98227-0010, USA
Tel: +1 206 676 3290
Fax: +1 206 647 1445
Email : spie@mom.spie.org

ICO conferences, as well as being listed here, are featured overleaf.

Date	Meeting	Contact	Location
April 18	**Photomask Japan '96**	SPIE	Kanagawa, Japan
April 21	**Optical Computing (OC '96)**	OSA	Sendai, Japan
April 21	**Photonics in Switching (PS '96)**	OSA	Sendai, Japan
April 28	**Spring Topical Meetings**	OSA	Boston, Massachusetts
May 6	**Photonics in Manufacturing II**	SPIE	Paris, France
May 12	**Optical Systems Design and Production II**	SPIE	Glasgow, UK
May 21	**Optical Fiber Sensors (OFS-11)**	OSA	Sapporo, Hokkaido, Japan.
May 28	**Ultrafast Phenomena**	OSA	San Diego, California
May 29	**Optical Telescopes of Today and Tomorrow**	SPIE	Landskrona, Sweden
June 2	**Lasers and Electro-Optics (CLEO '96)**	OSA	Anaheim,Calif.
June 2	**Quantum Electronics and Laser Science (QELS '96)**	OSA	Anaheim, Calif.
June 9	**Multiphoton Gordon Conference**	OSA	New London, NH
June 10	**Lasers and Optics for Productivity in Manufacturing I**	SPIE	Besancon, France
June 17	**Optical Instrument and Systems Design**	SPIE	Glasgow, UK
June 24	**Airborne Remote Sensing**	OSA	San Francisco, Calif.
July 1	**12th Australian Institute of Physics Congress**	AIP	Hobart, Australia
July 7	**Summer Topical Meetings**	OSA	Maui, Hawaii.
July 10	**Optical Amplifiers and their Applications.**	OSA	Monterey, California
July 14	**International Quantum Electronics Conference (IQEC '96)**	OSA	Darling Harbour, Sydney
July 29	**Applications of Photonic Technology (ICAPT'96)**	OSA	Montreal, Canada
Aug 4	**Symposium on Optical Science, Engineering, and Instrum.**	SPIE	Denver, Colorado
Aug 19	**International Commission for Optics (ICO XVII)**	ICO	Taejon, Korea.
Aug 22	**Photon Correlation and Scattering**	OSA	Capri, Italy
Aug 25	**Organic Thin Films for Photonic Applications**	OSA	Orlando, Florida
Aug 26	**ICHOIP '96, Holography and Optical Inf. Proc.**	OSA	Nanjing, China
Aug 27	**IWI '96, Internat. Workshop on Interferometry**	ICO	Wako, Japan
Sept ?	**Nonlinear Guided Waves and Their Applications**	OSA	United Kingdom
Sept 9	**CLEO/EUROPE**	OSA	Hamburg, Germany
Sept 7	**Biomedical Optics IV**	SPIE	Vienna, Austria
Sept 15	**Optical Communication**	OSA	Oslo, Norway
Oct 7	**Imaging Sciences and information Services**	OSA	Berlin, Germany.
Oct 15	**Optoroute'96-Photon'96 (Information highways)**	OSA	Grenoble, France
Oct 20	**OSA `96 Annual Meeting**	OSA	Rochester, N.Y.
Oct 20	**Optical Fiber Communication (OFC '97)**	OSA	Dallas, Texas
Oct 20	**Interdisciplinary Laser Science (ILS-XII)**	OSA	Rochester, N.Y.
Oct 22	**Ocean Optics XIII**	SPIE	Nova Scotia, Canada
Oct 27	**High Speed Photography, Videography, and Photonics**	SPIE	Sanat Fe, New Mexico
Nov 4	**Photonics China '96**	SPIE	Beijing, China
Nov 18	**Photonics East**	SPIE	Boston, Massachusetts
Dec 10	**Photonics and Fibre Optics (Photonics India 96)**	SPIE	Madras, India
	1997		
Feb 16	**Optical Fiber Communication (OFC '97)**	OSA	Dallas, Texas
May 18	**Lasers and Electro-Optics (CLEO '97)**	OSA	Baltimore, Maryland
May 18	**Quantum Electronics and Laser Science (QELS'97)**	OSA	Baltimore, Maryland
Oct 11	**OSA'97 Annual Meeting**	OSA	Long Beach, California.
Oct 11	**Interdisciplinary Laser Science (ILSC-XIII)**	OSA	Long Beach, California

Forthcoming meetings with ICO participation

Responsibility for the correctness of the information on this page rests with ICO, the International Commission for Optics.
President : Prof. A. Consortini, Dipartimento di Fisica, Università degli Studi, Via Santa Marta 3, I - 50139 Firenze, Italy
Secretary : Dr P. Chavel, Institut d'Optique (CNRS), B.P. 147, F - 91403 Orsay cedex, France
e-mail Pierre.Chavel@iota.u-psud.fr

January 6-14, 1996
4th Internat. Workshop on the Physics and Modern Applications of Lasers *(ICO cosponsored)*
Khartoum, Sudan. Contact : Prof. Farouk Habbani, Dept of Physics, Faculty of Science, Univ. Khartoum, P.O. Box 321, Khartoum, Sudan. Fax (249) 11 80539, telex 22113 SD GAMA

April 21-25, 1996
1996 Internat. Topical Meeting on Optical Computing, OC'96 *(ICO cosponsored)*
Sendai, Japan. Contact : Prof. T. Yatagai, Univ. of Tsukuba, Inst. of Applied Physics, Tsukuba, Ibaraki 305, Japan, fax (81)298-53-5205, e-mail yatagai@optlab.bk.tsukuba.ac.jp

August 19-23, 1996

ICO XVII

General Meeting of the International Commission for Optics "Optics for Science and New Technology"

ICO General Meeting

Contact : Sang Soo Lee, Department of Physics, KAIST, 373-1, Kusung-dong, Yusong-Gu, Taejon 305-701, Korea.
Fax (82)42 869 5527,
e-mail yoonkim@sorak.kaist.ac.kr

August 26-28, 1996
ICHOIP'96, Internat. Conf. on Holography and Optical Information Processing *(ICO endorsed)*
Nanjing, China. Contact :Prof. Hsu Dahsiung, Beijing Univ. of Posts & Telecom., Beijing 100088, China, fax (86)1 202 8561

August 27-29, 1996
IWI'96, Internat. Workshop on Interferometry, *(ICO endorsed)*
Wako, Japan. Contact : Dr Ichirou Yamaguchi, Optical Eng. Lab., RIKEN, Wako, Saitama 351-01, Japan, fax (81)48 462 46453, e-mail yamaguch@optsun.riken.go.jp

December 10-14, 1996
Photonics 96, *(ICO cosponsored)*
Madras, India. Contact : Prof. J.P. Raina, Dept Elect Engin., IIT, Madras 600 036, India. fax (91) 44 235 1405, e-mail eedpt1@iitm.ernet.in

Summer of 1997
Optics Education and Training, ICO 50th Anniversary Meeting ***(ICO Topical Meeting)***
Delft, the Netherlands. Contact : Dr C.H.F. Velzel, Philips CFT, building SAQ, P.O. Box 218, 5600 MD Eindhoven, the Netherlands, fax +31 40 736024

August 26-30, 1997
OIST'97, Optical Information Science and Technology, *(ICO endorsed)*
Moscow, Russia. Contact : M. Politov, Inst. for Optical Neural Technologies, No44/2 Vavilov Street, Moscow 117333, Russia, fax (7) 95 925 5972 fax box K-03, e-mail iont@glas.apc.org

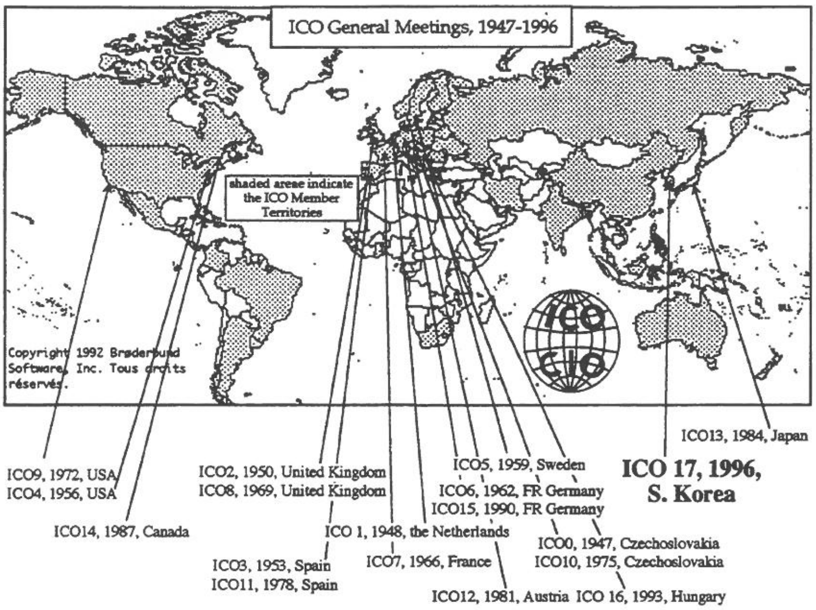
Summer of 1998
Optics for Industry, ***(ICO Topical Meeting)***
Tianjin, China. Contact : Prof. G.G. Mu, Nankai Univ., 94 Weijin Road, Tianjin 300071, China, fax (86) 22 350 4853

ICO NEWSLETTER

Commission Internationale d'Optique ◆ International Commission for Optics ◆ January 1996

ICO XVII, Taejon

The 17th General Assembly and General Scientific Meeting of the International Commission for Optics will be held in Taejon, South Korea, August 19-23, 1996. Announcement flyers, complete announcements, and posters are available from all ICO Territorial Committees, the Optical Society of America, and SPIE—the International Society for Optical Engineering. The contact point for submitting communications, for registration and accommodations, for the associated exhibition, and for all inquiries is the ICO XVII Secretariat, Prof. B.Y. Kim, Department of Physics, KAIST, 373-1 Kusong- dong, Yusong-gu, Taejon 305-701, Korea, +82 42 869 2527, fax +82 42 869 5527, yoonkim@sorak.k-aist.ac.kr. The next ICO Newsletter will cover the project in more detail. While ICO XVII will cover the whole field of Optics in its broadest sense, the International Commission for Optics has endorsed two more topical meetings that are coordinated with ICO in space and time: the 1996 International Conference on Holography and Optical Information Processing, Nanjing, China, August 26-28, 1996 and the 1996 International Workshop on Interferometry, Wako, Japan, August 27-29, 1997. Contact points for these two meetings are listed on page 2 of this newsletter.



ICO Prize 1995 Winner: Tony F. Heinz

The 1995 Prize of the International Commission for Optics has been awarded to Tony Frederick Heinz. Heinz is recognized for his seminal contributions to the development and application of laser spectroscopic techniques for surface and interface analysis from the experimental standpoint.

The prize is awarded annually to an individual who has made a noteworthy contribution to optics before reaching the age of 40, and consists of a citation, a cash award of $1,000(US), and the Ernst Abbe Medal. It will be presented, along with the 1993 and 1994 Prizes, during the ICO XVII General Meeting, that will be held in Taejon, Korea, August 19-23, 1996. The ICO Prize Committee consists of K. Chalasinska-Macukow (Poland), J.W. Goodman (USA), A.W. Lohmann (Germany), D. Malacara (Mexico), and T. Asakura, Chairperson (Japan).

Tony Heinz was born in 1956 in Palo Alto, California, USA. He attended Stanford University, where he received a B.S. degree (with Distinction) in Physics in 1978. At Stanford, Heinz was awarded the Levine Prize for Physics. Heinz continued his studies at the University of California, Berkeley. There he was the recipient of fellowships from the National Science Foundation and the IBM Corporation.

Heinz was awarded a Ph.D. in Physics in 1982 based on thesis work on surface nonlinear optics carried out under the guidance of Prof. Y.-R. Shen. After leaving Berkeley, Heinz joined the IBM Research Division at the T. J. Watson Research Center in Yorktown Heights, New York. In addition to the research program described below, starting in 1987 Heinz served in various management positions in IBM. In 1995, he joined Columbia University in New York City as Professor of Electrical Engineering and Physics.

Heinz has played a pivotal role in the development and application of an entirely new area of laser spectroscopic studies for surface and interface analysis. His investigation of nonlinear and time-resolved optical techniques has led to the demonstration of powerful new experimental tools that have been widely adopted in laboratories throughout the world.

Of particular note has been Heinz's contribution to the development and application of surface second harmonic generation,

Continued on last page

ICO Territorial Committees: News and History

The Finnish Territorial Committee of ICO: History, Organization, and Activities

Finland was accepted as a member of ICO at the ICO-11 General Meeting in Madrid on September 14, 1978. Before this, Finnish scientists had already participated in ICO meetings. In Finland, the international activities of scientists and scientific societies are coordinated by the Delegation of the Finnish Academies of Science and Letters. From the beginning, this body has also been providing funds for the participation of Finland in ICO.

The representative of Finland in ICO from 1978 through 1993 was Professor Eero Byckling, who was replaced in 1993 by Dr. Ari Friberg. The ICO Topical Meeting on "Image Science" was organized in Helsinki in August 1985. Eero Byckling served as a Vice-President of ICO in 1984-87. The number of participants from Finland in ICO meetings has grown rapidly over the period of membership and has been quite substantial in the recent years when compared to the size of the country.

At present, there are plans to reorganize the optical community in Finland under a new Finnish Optical Society. The ICO contact person for Finland is Dr. Ari Friberg, Helsinki University of Technology, Department of Technical Physics, Rakentajanaukio 2C, FIN-02150 Espoo, Finland; +358 451 3150; fax +358 451 3164; ari.friberg@hut.fi.

France

Elections for the French Optical Society (SFO) Executive Committee were held at the last General Meeting of SFO at Palaiseau in November 1995. The composition of the Committee for 1995-97 is as follows:

- President: Dr J.C. Fontanella, Thomson TTD Optronique, Guyancourt.
- Past-President: Prof. S. Huard, Ecole Nationale Superieure de Physique de Marseille.
- Vice-President: Dr J.M. Maisonneuve, ONERA/CERT,
  -Treasurer: Prof. A. Brun, Institut d'Optique, Orsay.
  -Secretary: Mr G. Corbasson.

-Members: Drs. D. Dolfi, Thomson CSF LCR; M. Druetta, Univ. St Etienne and SFP; E. Giacobino, Laboratoire Kastler-Brossel; C. Gorecki, Univ. Franche Comte, Besancon; J.P. Goure, Univ. St Etienne; D. Laroche, SFIM ODS; M. Lequime, Bertin; J.L.Mercier, Essilor; M. Sirieix, SAT and GIFO. M. Andre Masson serves as the appointed observer from Club Nanotechnologies.

The SFO Executive Committee serves as the French Territorial Committee of ICO.

Italy

In June 1995, the Italian National Research Council appointed the new ICO Territorial Committee, Commissione Italiana di Ottica, which consists of seven members:

- President: Dr. Giancarlo Righini of IROE (Istituto di Ricerca sulle Onde Elettromagnetiche) "Nello Carrara," CNR, Via Panciatichi 64, 50127 Firenze, Italy, fax +39 55 412 878, righini@iroe.fi.cnr.it
- Secretary: Dr. Giuseppe Molesini
- Members: Dr. Pier Alberto Benedetti, Prof. Anna Consortini, Ing. Gabriele Emiliani, Dr. Paolo Saraceno, Prof. Alberto Sona.

The Italian Territorial Committee of ICO, while appointed by the Consiglio Nazionale delle Ricerce, works in close coordination with the Societa Italiana di Ottica e Fotonica.

Japan

In March 1995, the ICO Territorial Committee in Japan appointed its new president, Prof. Toshimitsu Asakura, Research Institute for Electronic Science, HokkaidoUniversity, Sapporo, Hokkaido 060, +18 11 706 2877, fax+81 11 758 3173, asakura@hikari.hokudai.ac.jp.

The Netherlands

Ir. Tom Nuijs, stepped down as a Board Member of the Dutch Society for Optics and Photonics and contact person for ICO in the Netherlands. His task has now been transferred to Dr. G.W.R. (Wouter) Leibbrandt, Philips Natuurkundig Laboratorium/WY32, Prof Holstlaan 4, 5656 AA Eindhoven, the Netherlands, +31 40 743641, fax +31 40 744335, leibbran@prl.philips.nl.

Switzerland: News, History, Organization, and Activities

The Swiss Society for Optics and Electron Microscopy (SGOEM/SSOME) has installed its new board for the period 1995-1997. President: Dr Karl Knopp, Paul Scherrer Institut, Zurich. Treasurer: Mr Guido Luond, Ciba-Geigy AG, Basel; Bulletin Editor: Dr Kurt Pulfer, Ciba-Geigy AG, Basel. The Secretary for the Optics Section is Dr Peter Seitz of Paul Scherrer Institut, Zurich (fax +41 1 491 00 07), and its members are Dr H.P. Herzig, Univ. Neuchatel, Prof. F. Marquis Weible, EPFL, Dr. E. Mathieu, Leica AG, Dr. M.W. Sigrist, ET H, and Prof. H.P. Weber, Univ. Bern. The delegates to ICO are Dr. Hans Peter Herzig, Institut de Microtechnique, Rue A.L. Breguet 2, CH2000 Neuchatel, +41 38 23 42 51; fax +41 3825 4276; HansPeter.Herzig@imt.unine.ch and Prof. Dr. Heinz P. Weber, Institut fur angewandte Physik, Sidlerstrasse 5, CH 3012 Bern, +41 31 631 89 31, fax +41 31 631 37 65, HWeber@iap.unibe.ch.

The Swiss Society for Optics and Electron Microscopy (SSOEM/SGOEM/SSOME) was founded in 1949, as the Swiss Committee for Optics. In its present form, combining the Swiss national interests in optics and electron microscopy, it has existed since 1969. At the end of 1994, the SSOEM had 565 individual and 71 corporate members. 45% of the members are from trade and industry, 40% are from universities, and 15% are from research institutes. In even years, *i.e.*, 1996, 1998, the optics section organizes meetings devoted to topics of interest especially to the optics section. Since 1985, the optics section organizes every second year "EngelbergerFachkurse," covering relevant topics in optics, which are of interest to a wide audience from university and industry. More information about the SSOEM and its present activities can be found on the WWW: http://www.sgoem.ch/

International Commission for Optics

International Commission for Optics. Bureau members: President: A. Consortini; Past-President: J.P. Dainty; Treasurer: R.R. Shannon; Vice-Presidents: T. Asakura, K. Chal-asin' ska-Macukow, S.S. Lee, F. Merkle, G.G. Mu, G.T. Sincerbox, C.H.F. Velzel, M.J. Yzuel; Secretary: P. Chavel.

International Commission for Optics, secretariat: B.P. 147, 91403 Orsay cedex, France, phone (33)1 69 41 68 44, fax (33)1 69 41 31 92, e-mail: Pierre.Chavel@iota.u-psud.fr

Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036; 202/223-8130; fax 202/223-1096; e-mail: postmaster@osa.org

Precision Fabrication of Fine Ground Single-Crystal Silicon Spheres

*Ron Bulla**
CSIRO Division of Applied Physics
PO Box 218, Lindfield, NSW 2070

Single-crystal silicon spheres serve to redetermine Avogadro's constant and may replace the standard kilogram. Starting with a cylinder of pure silicon, successive cycles of grinding and measurement are used to create the sphere which is round to within 100 nm.

***Ron received the 1995 AOS Young Optical Worker of the Year Award for this work**

Introduction

A macroscopic object made entirely from a pure, single-crystal provides an important link to the atomic world. The regular arrangement of silicon atoms inside a well characterised geometrical shape enables quantities, such as density and mass, to be expressed in multiples of atoms.

Silicon is an ideal material for such objects because it is chemically inert and large quantities can be manufactured in pure, single-crystal form. Spheres made from single-crystal silicon are used by researchers in Germany, Italy, Japan and Switzerland as volume and density standards. They are also being used in experiments for re-determination of Avogadro's constant. Research is under way to use the spheres to define the standard kilogram. If the kilogram can be defined in terms of the atomic mass of silicon, a new standard will be achieved which can, theoretically at least, be reproduced anywhere in the world.

The accuracy of any measurement with the sphere is limited by, among other factors, its sphericity. This article concentrates on the optical grinding process which is used to generate the sphere.

Coarse Grinding

The Avogadro experiment requires the ball to have a mass close to one kilogram, which corresponds to minimum diameter of 93.6 mm, with an allowable tolerance of only 15 μm. This requires a rigid program of coarse and fine grinding to remove a fixed and finite amount of silicon with each grit size, leaving very little room for mishaps such as scratches.

The raw material is usually supplied in the form of a cylindrical ingot, approximately 100 mm in length and diameter. Initially, the silicon ball is shaped using a model 2VSLG "Adcock and Shipley" universal glass grinding machine, manufactured. It is used to generate two hemispherical surfaces of 47.8 mm radius of curvature, on the 100 mm long ingot. The generated surface is then checked against a template.

After generation is completed, however, there is still a ring of silicon which could not be generated away around the "equator" of the ball. This ring remains as a result of our most suitable diamond cutting tool being slightly less than the most effective size. This excess material is removed as the first step of the rough grinding process, using silicon carbide 120 grade grit.

To enable us to rough grind the silicon ball, a mild steel tool of conical cross-section, is rotated at high speed on a "roughing" spindle (Fig.1). The silicon ball is carefully turned by hand in the tool. Fresh abrasive slurry is used otherwise the ball becomes too slippery from the mixture of old abrasive and silicon waste.

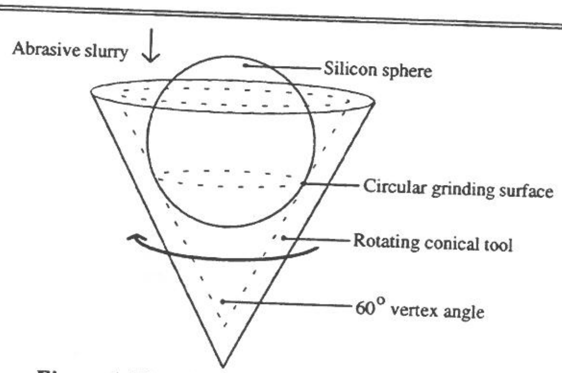


***Figure 1.** The silicon sphere is ground in a rotating conical tool. The sphere is turned by hand to grind the entire surface.*

The reason behind using a conical section tool for grinding the sphere is its ability to constantly and completely adjust to the ever decreasing diameter of the ball. The ring shaped spherical grinding surface produced by the ball on the inside of the conical grinding tool is maintained, on average, 15 mm wide, and is constantly reshaped by the ball's diminishing diameter. The relatively small ring-shaped grinding tool surface, compared to the large surface area of the ball, makes grinding in this was a very time consuming operation, particularly with material as hard and tough as single-

crystal silicon.

An efficient "cleaning up" procedure is essential throughout the entire grinding process. In between successive grades of abrasive all work surfaces must be thoroughly cleaned of coarser grade abrasive to prevent contamination.

Rough grinding is completed when sufficient material has been removed with 220 and 400 grade silicon carbide grit. In between changes of abrasive, the diameter of the ball is measured and recorded. Furthermore, the entire surface of the sphere is inspected for scratches with a stereo microscope of 20X magnification. At this stage the sphericity error of the ball will be between 1 and 4 μm peak-to-valley. This must be considered a combination of out-of-roundness and surface roughness. Measurements of roundness are made using a Talyrand 73 [1]

Fine Grinding

To begin the fine grinding process, a brass conical grinding tool identical in size and shape to the steel tool used for rough grinding, is used with aluminium oxide abrasives of 25 and 15 μm. Brass is used in preference to mild steel as it does not corrode, thus reducing the chance of scratching the surface of the silicon sphere.

The process of grinding single-crystal silicon spheres becomes progressively more critical with the use of successively finer abrasives. As the particle size gets smaller the slurry can no longer prevent the ball from contacting the surface of the brass tool, where the sphere picks up brass causing scratches. For this reason, when grinding with abrasive smaller than 15 μm particle size, the brass tool is replaced with a pyrex glass-ring grinding tool which is submerged in a plastic bowl containing a suspension of treated abrasive slurry to provide continuous feed.

The remainder of the fine grinding process is carried out on a grinding machine operated by a knee-switch. This has the advantage of leaving the operator with both hands free, to securely hold and roll the sphere, while the spindle speed is varied by moving the knee-switch to the left or right.

The glass tool assembly is driven at approximately 50 RPM for the 15 μm abrasive, and is gradually reduced to 10 RPM when grinding with 1 μm abrasive, while the silicon sphere is carefully and randomly rotated by hand.

Correct abrasive slurry consistency is essential to maintain an efficient fine-grinding action. The sphere should "feel" that it is turning with just a little resistance from the pyrex glass tool. The initial white abrasive slurry will soon change to a brown/grey colour as silicon is abraded from the sphere.

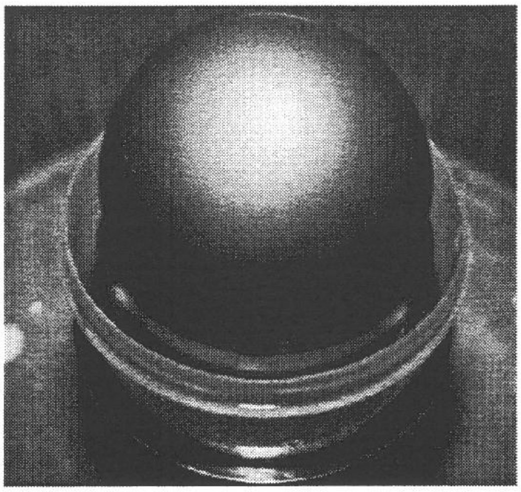


Figure 2 : *Fine ground silicon sphere sitting in the pyrex glass-ring grinding tool*

Approximately 3 hours of actual grinding time is needed with each of the four grades of suspension treated aluminium oxide abrasives. These abrasives, when used with the glass ring grinding tool, reduce the diameter of the silicon ball by 0.10 mm. A ground sphere is shown in Fig 2.

Provided that a sufficiently slow spindle speed and correct slurry consistency are maintained this procedure will reliably achieve a total sphericity error of between 100 nm and 180 nm peak-to-valley. As long as the diameter of the sphere lies within the required tolerance; roundness measurements are satisfactory, and the sphere surface remains clean, polishing of the single-crystal silicon sphere can now begin. The polishing process is a chemo-mechanical one, further refining the surface quality and improving the roundness of the sphere. The final product is shown in Fig 3 beside a silicon ingot.

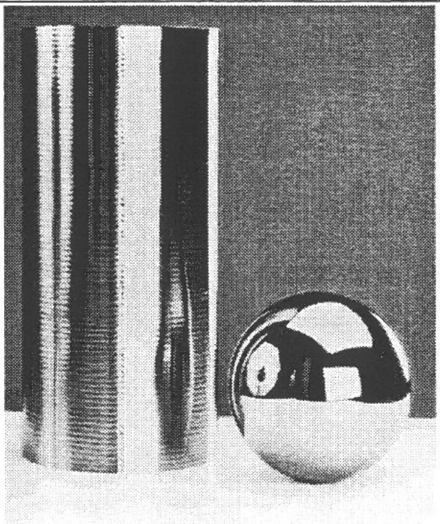


Figure 3 : *Cylinder of pure silicon crystal beside a finished sphere after grinding and polishing.*

References

[1] A. J. Leistner and W. J. Giardini, *Fabrication and sphericity measurements of single-crystal silicon spheres.* Metrologia **31**, p231-245 (1994)

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