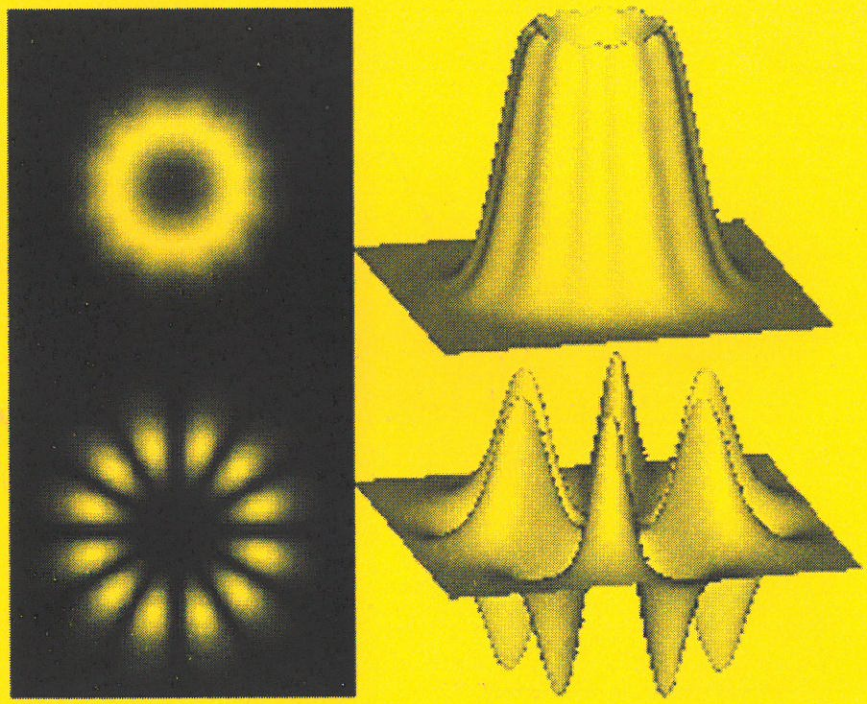
Australian Optical Society

NEWS



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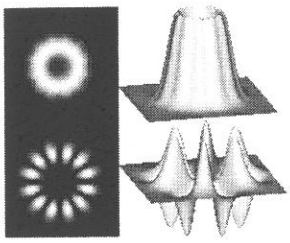

AOS NEWS

COVER :
Wave-particle duality insists that there are always analogies between light and matter. The cover of this edition shows the structure of a dodecagon multipole vector soliton, which in many ways acts a "molecule of light". See the article on page 7 for more details.

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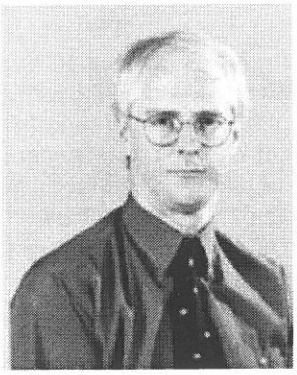
ARTICLES

DEPARTMENTS

President's Report



I have just returned from the ACOLS conference held at the University of Queensland. This conference was chaired by the AOS past-president, Halina Rubinsztein-Dunlop, and the program committee was chaired by another past AOS president, Bill MacGillivray. I would like to take the opportunity to congratulate them on an extremely professional job. It was an excellent conference, with speakers of the highest quality, excellent contributed papers and it ran like clockwork.

I have always found ACOLS to be an excellent conference series and one of the pleasures it offers is to welcome the President-Elect of both the Optical Society of America and of the SPIE. This year Anthony Johnson, an expert on ultra-short pulse lasers and also Editor-in-Chief of *Optics Letters*, from the New Jersey Institute of Technology, represented the OSA. The SPIE was represented by James Harrington, an expert on Infra-red optical fibres from Rutgers University, also in New Jersey. It is always productive and enjoyable to meet one's counterparts overseas, although the comparison is perhaps a bit pretentious as both of these US based professional organizations dwarf the AOS by roughly two orders of magnitude. Nevertheless, we have an excellent relationship with them and this years Presidents-Elect were good speakers describing interesting science and were tremendous ambassadors for the USA.

The two US based societies very kindly agreed to annually donate a generous prize of $US2,500 to recognise the best student presentation at the AOS conference. The standard of the student presentations was extremely high and the competition for the award was intense. In the week preceding the meeting, I had chaired an Asia-Pacific Workshop on near-Field Optics for which a student prize was donated by the Japanese Society for Applied Physics. In my role as part of the selection committee, it was apparent that the average quality of the student presentations was well above the average quality for the hardened professionals. I suspect that the same was true for ACOLS. I was not able to be present at the awards ceremony at the close of ACOLS, but the recipient(s) could not help but have been extremely deserving.

There is little dispute anywhere in the community that scientists are undervalued. Even Federal politicians will admit that academics are underpaid, but until recently no funding has been released to improve the personal lot of scientists. With the release of *Backing Australia's Ability*, things may slowly be changing. This policy recommended that the funding allocated to the Australian Research Council be doubled over time, and part of this funding was allocated to the establishment of the "Federation Fellowship" scheme. This aims to pay scientists an "internationally competitive" salary so as to retain key scientists here as well as to bring some of our ex-patriot talent home. It is intended that there will ultimately be 125 of these positions, and 15 were announced in September this year. I was fortunate enough to be awarded one. This was part of a very good set of outcomes for the physical sciences generally, and optics in particular. Other recipients included Dr Ben Eggleton, returning to Australia from Lucent Technologies in the USA, who will join the University of Sydney to work on photonics. On a less obviously optics area, Bob Clark, working on Quantum Computer Technology and Martin Green, working on solar cell technology, were also offered fellowships.

There was a clear priority on research with an identified national interest. The AOS is convinced of the importance of optics in the development of Australian industry and so it is entirely appropriate that its practitioners would be well represented. However, more broadly than this, I think we should be encouraged that there is recognition that scientists should be better remunerated and that these fellowships are an important first step in that direction. I have no doubt that many more AOS members will receive fellowships and I am happy to share my experience with AOS members.

I am of the view that the critical issue is now the lack of support for education in this country. While I am now in a position to concentrate on research for a few years, I still have concerns about returning to a stressed environment with unrealistic expectations on teaching loads. This is the problem that now needs to be fixed and the signs are not yet very good. I live in hope.

Finally, I would like to wish all AOS members a very happy Christmas and a prosperous new year.

Keith Nugent
President of the Australian Optical Society

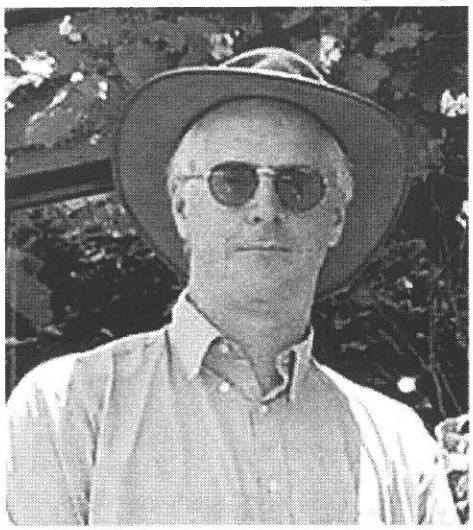
December 2001

Federation Fellowship Awarded to Prof Keith Nugent

Professor Keith Nugent has been awarded one of the most prestigious and richest publicly-funded Fellowships ever offered in Australia: the Federation Fellowship. This is an extremely significant acheivement, and indicates the highest regard with which Keith's scientific prowess is held, within Australia and around the world. The AOS Council request that the entire membership of the Society join with them in offering sincere congratulations to Keith.

The Federation Fellowships are a major initiative arising from the Government's January 2001 statement "Backing Australia's Ability: an innovation action plan for the future". Each Federation Fellow will receive a salary of $1.125 million over five years. The aims of the Federation Fellowships are to:

- attract and retain leading Australian researchers in key positions
- attract outstanding overseas researchers whose research is demonstrated to be of national benefit to Australia
- support research that will result in economic, environmental and social benefits for Australia
- expand Australia's knowledge base and research capability support excellent, internationally competitive research by individuals
- build and sustain world-class research teams and linkages



Applications were assessed by a special committee drawn from the Expert Advisory Committees of the ARC. Keith is one of only 15 recipients awarded in the first round of the scheme.

In addition to the personal honour, Keith's Federation Fellowship is also a recognition of the national importance of the field of optics, and the strengths that already exist in Australia.

The details of Keith's award are as follows:

Research project: Developments in Optical Sciences

Federation Fellowship institution: University of Melbourne

Personal details: Professor Nugent was born in 1959 and educated at the University of Adelaide and the Australian National University. Professor Nugent's interests are in x-ray and visible optics and he has published over 90 refereed papers in these areas. Professor Nugent was awarded an R&D100 award for one of the 100 most important inventions of 1988, the 1989 Pawsey Medal from the Australian Academy of Science and the 1991 Edgeworth-David Medal from the Royal Society of NSW for his contributions to Science. In 1997 he was awarded the Boas Medal from the Australian Institute of Physics, its highest award. He was elected to the Australian Academy of Science in 2000. Professor Nugent is currently the Head of the School of Physics at the University of Melbourne.

Professor Nugent has embraced the need to commercialise the intellectual property arising from his research. He has been awarded six patents and has been involved with two start-up companies. One of these, Iatia, was recently awarded a $1.8 million R&D Start Grant to develop Quantitative Phase Imaging based on Professor Nugent's pathbreaking research.

Research Program: Professor Nugent leads a highly motivated and successful group of young investigators doing internationally-leading work on complete recovery of phase information. This work is able to provide new approaches to fundamental research problems at the basis of quantum mechanics, as well as leading to important new applications in biomedical and industrial imaging. The proposed work has already led to one start-up company and it is expected that commercial development will continue.

The program will lead to an involvement in an international space project, enhance synchrotron-based research in Australia and lead to new developments in microfabrication technologies. Professor Nugent will continue his work on all the cutting-edge research areas of optics and photon-based science. He will also do significant work on the development of a new style x-ray telescope based on 'lobster eye optics' which will allow for the launch of a low-weight satellite capable of (a) capturing very faint signals and (b) focussing the x-rays and observing the whole sky. This will position Australia as a significant player in contributing instruments to astronomical observations and will strengthen Australia's scientific collaboration with the USA and the UK.

The research project will also be important for the development of x-ray microscopy through the use of the synchrotron and this has implications for both fundamental and applied research, with the scope for significant industrial applications.

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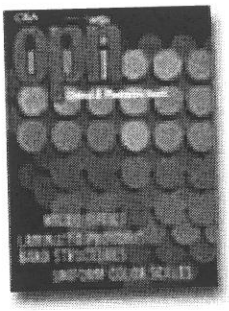

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Making "Molecules" from Light

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We discuss the physics and properties of composite (or vector) spatial optical solitons created by incoherent interaction of two optical beams in a bulk medium. Such stationary self-trapped beams include, in particular, vortex- and dipole-mode vector solitons, and also incorporate higher-order multipole spatial structures such as quadrupole and "necklace"-type beams. We overview our recent theoretical and experimental results on the structure, formation, and stability of these localized structures. These novel spatial solitons open the road for new ways to control the diffraction of optical beams, and they may play a significant role in novel concepts of optical switching and storage.

1. Introduction

One of the goals of modern nonlinear optics is the development of fast all-optical devices where light can be used to control light. The unique possibilities of reconfigurable circuits in nonlinear bulk media without any fabricated optical waveguide can be achieved with the help of the fundamental concept of *light guiding light* based on so-called *spatial optical solitons* [1,2]. Spatial solitons, self-trapped and self-guided light beams that do not spread owing to diffraction when they propagate, are expected to be the units carrying information, and the process of all-optical switching is associated with the evolution of different types of spatial optical solitons and interactions between them.

Recent progress in the experimental generation of spatial solitons in different types of nonlinear media [1,3] opens new perspectives for using rich and exciting nonlinear soliton-bearing effects such as soliton fusion, fission, annihilation, and three-dimensional spiraling. More importantly, the working powers when all those nonlinear effects become important have been reduced to a few milliwatts and, in optical materials with photorefractive nonlinearity, even light of microwatts power can cause strong nonlinear effects. Thus, nonlinear optics becomes a very attractive area for realising all-optical processing and all-optical switching devices.

The general physical interest to the study of solitons and soliton phenomenology is stimulated by a deep equivalence between solitons and particles, first suggested back in 1965 [4]. Solitons interact like real particles, displaying "forces" between them. Additionally, the de-Broglie wave representation of real particles has many common properties with self-trapped wave-packets (namely, solitons). A deeper development of this analogy recently led to the concept of *"light molecules" [5-7]: multi-component spatial solitons which can be regarded as more complex composite objects consisting of coupled states of simpler, scalar solitons (or "atoms").* This concept has been confirmed experimentally by the realisation of the so-called dipole-mode vector solitons [8,9]. The universality of soliton properties manifests itself in other actively developing areas of nonlinear physics such as the study of the coherent excitations of Bose-Einstein condensates or the dynamics of "braided light" [10] in plasmas, so that the results obtained for optical solitons may be also useful in other fields.

2. Self-trapping of light and spatial solitons

To introduce the basic concepts of spatial solitons, first we recall the main principles of the light self-focusing and self-trapping phenomenon, well known after the discovery of lasers. When a laser beam propagates in a nonlinear medium, a variety of interesting effects can be observed. Nonlinear optical media are characterized by the electromagnetic response that depends on the strength of the propagating light. The total polarization, P, of such a medium can be described as

$$P = \chi_1 E + \chi_2 E^2 + \chi_3 E^3$$

where E is the amplitude of the light wave's electric field, and the coefficients characterize both the linear and nonlinear response of the medium. The χ_1 coefficient describes the linear refractive index of the medium. When χ_2 vanishes (as happens in the case of centrosymmetric nonlinear media), the main nonlinear effect is produced by the third term which can be presented as an intensity-induced change of the medium refractive index proportional to $\chi_3 E^2$. An important consequence of such an intensity-dependent nonlinearity is the spontaneous focusing of a beam due to the lensing property of a self-focusing ($\chi_3 > 0$) medium. This focusing action of a nonlinear medium can exactly balance diffraction of a laser beam. As a result of this balance, spatial optical solitons – self-trapped light beams that do not change shape during propagation – can be created [1-3].

The self-trapping mechanism responsible for creating spatial solitons is the key process for the light guiding light concept. The light beam locally changes the refractive index because of the strong interaction with a nonlinear medium, and it induces the effective waveguide that supports a mode that creates it. This self-induced waveguide traps the light and produces the beam with uniform shape, the spatial soliton. Usually the sequence of interactions light – matter – light is shortened to the term "self-action" when there

is only one light beam, and for the case when two or more self-trapped light beams propagate simultaneously the same physical phenomena is called "interaction" of solitons.

Two main types of soliton interactions are distinguished depending upon the way the light interacts with the medium. A coherent interaction occurs for all nonlinearities with an instantaneous or extremely fast time response (the optical Kerr effect and the quadratic nonlinearity) so that the nonlinear medium can respond to interference effects that take place when the beams overlap. The character of interaction (attraction or repulsion) is determined by phase difference and can be very complex because of the power transfer between solitons [1]. An incoherent interaction occurs when there are no interference effects (waves with orthogonal polarisation states) or the relative phase between solitons varies sufficiently faster than the response time of the medium (photorefractive and thermal). In this case the interaction is always attractive, it does not depend on the soliton relative phase, and it does not allow energy exchange between solitons. The incoherent interaction may lead to the mutual trapping of interacting solitons, thus producing a composite, or *vector* soliton, consisting of two (or more) components.

3. Multimode composite spatial solitons

As described above, vector solitons can be viewed as composite states where one of the components induces an effective waveguide that supports other components as the guided modes of different orders. The physics of soliton-induced waveguides applied for two-component (bimodal) system leads to the idea of so-called *multipole spatial vector solitons* [11], which include, as a special case, previously studied vortex- and dipole-mode composite solitons [5-9] (see Fig. 1) associated with the idea to create a self-trapped beam that has an angular momentum (or "spin") carried by a vortex beam.

In the nonlinear regime, self-trapped optical vortices exist on a broad background beam (in a self-defocusing medium) or decay because of azimuthal instability (in a self-focusing medium). Stabilization of a beam with a finite extension carrying angular momentum may occur if the optical vortex co-propagates with a bright soliton in a self-focusing nonlinear medium. Through a nonlinear change of the medium's refractive index, the soliton beam creates an effective waveguide which can trap and guide a co-propagating beam. As follows from the linear waveguide theory which is applicable when a trapped beam is weak, guided modes of different shapes can be trapped by such a soliton-induced radially symmetric waveguide. However, as the intensity of the trapped beam grows, the guided mode can no longer be considered linear, affecting the waveguide itself because of nonlinear interaction with the soliton beam. As a result, both beams form a composite (or vector) soliton with mutually trapped components of a complex shape. The existence of such composite soliton structures carrying angular momentum (the "spin" of the beam) would allow observation of an optical version of the spin-orbital interaction of light waves [5].

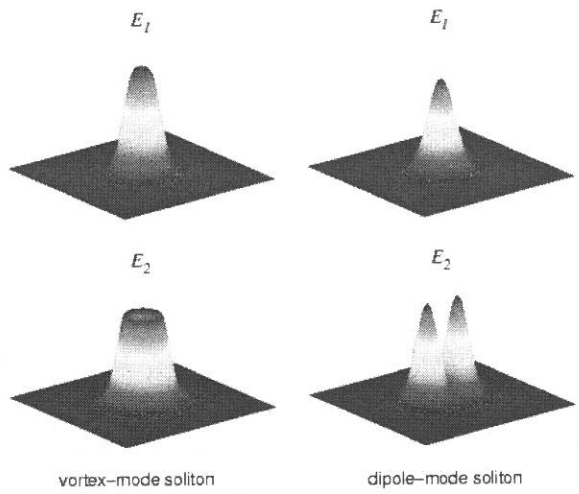

Fig. 1. *Left*: intensity components of a composite vortex-mode soliton in self-focusing medium (the second beam carries a vortex phase). *Right*: intensity components of a composite dipole-mode soliton.

Two examples of such composite solitons are shown in Figure 1. The first example features a component with the doughnut-shaped structure characteristic of the Laguerre-Gaussian (LG_0^1) vortex-like mode of a linear radially symmetric optical waveguide; it carries angular momentum [5]. The second type of vector soliton originates from using a soliton-induced waveguide to trap a dipole-like Hermite-Gaussian (HG_{01}) mode [6]. The two lobes of the dipole-mode component have a relative phase difference of π. Contrary to what might have been expected, the radially asymmetric dipole-mode soliton is more stable than the radially symmetric vortex-mode soliton; the latter, in fact, undergoes a non-trivial symmetry-breaking instability and transforms into a rotating dipole-like structure that resembles two spiraling solitons. This rotation is caused by the angular momentum imparted by the decaying vortex mode to its residuals. In contrast to its unstable counterpart, a dipole-mode soliton is a very robust - albeit complex - object that can be likened to a molecule of light. It may preserve its structural integrity in collisions with other "molecules" and "atoms" - scalar soliton beams, or display more complicated dynamics that involves "molecular" degrees of freedom.

Thus, the vortex- and dipole-mode composite solitons are the simplest types of complex multi-component soliton structures in a bulk medium that can be associated with the concept of "molecules of light". More complicated structures are also possible [11]. In particular, if the soliton-induced waveguide guides a higher-order mode, it gives birth to some of the complicated multi-peak structures shown in Fig. 2, e.g.

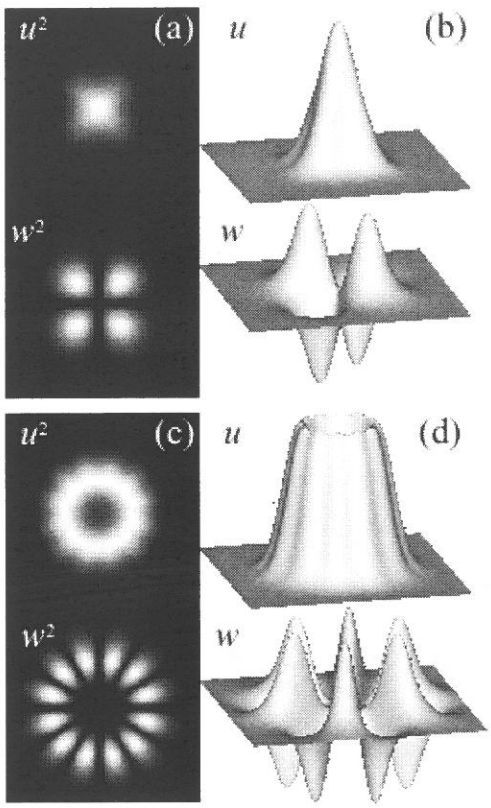

Fig. 2. Examples of two-component composite solitons in a saturable self-focusing nonlinear medium: (a,b) a quadrupole vector soliton, and (c,d) dodecagon multipole vector soliton (see details in Ref. [11]).

a quadrupole vector soliton [Figs. 2(a,b)] and a dodecagon multipole vector soliton [Fig. 2(c,d)].

One of the components of such a multipole vector soliton consists of several humps (light beams) trapped by a single beam of the second component. Although the only linearly stable composite object found so far is the dipole-mode vector soliton, many of the lower-order multipole vector solitons are quasi-stable (i.e. their instability growth rate is small), so that it is possible to experimentally generate those weakly unstable structures as well.

4. Experimental observations

Experimental observation of the dipole-mode vector solitons, the simplest molecules of light, was recently reported by Krolikowski *et al.* [8] and Carmon *et al.* [9] who used a photorefractive nonlinear crystal biased with a dc field. In the experiments reported by Krolikowski et al. [8], a strontium barium niobate crystal (SBN) was used. When biased with the dc field of 1.5-2 kV, the crystal produced an effective saturable nonlinearity that supported the soliton formation. Krolikowski et al. [8] employed two different methods of producing the dipole component: phase imprinting, and a symmetry-breaking instability of a vortex-mode soliton. Observation of dipole-mode vector soitons in SBN crystal was also reported by Carmon *et al.* [9].

Figure 3 shows the formation of the dipole-mode soliton consisting of two different components [Fig. 3(a-c)], and the scattering of the dipole-vector soliton with a scalar soliton [Fig. 3(d)]. Figure 3(a) shows the intensities of the input beams before their propagation in a nonlinear medium. When the beams propagate in a nonlinear medium independently (i.e. uncoupled), the first beam create a fundamental soliton, whereas the second beam creates a pair of solitons that strongly repel each other due to the imposed phase difference of π. However, when the beams are launched simultaneously being mutually incoherent, they couple together and form a two-component structure, a dipole-mode vector soliton, that does not display a break-up, even for larger propagation distances [Fig. 3(c)]. When such a composite dipole state collides with a scalar (one-component) soliton, the interaction depends on the relative phase between the self-trapped beams. If the scalar soliton has a π phase difference with the dipole, the dipole experiences rotation and repels the scalar soliton, changing its propagation direction [see Fig. 3(d)].

The linear stability analysis [6] demonstrated that only dipole-mode vector solitons are stable, in a rigorous mathematical sense. However, many of the lower-order multipole vector solitons are quasi-stable (i.e. their instability growth rate is small) and, indeed, it is possible to generate experimentally those weakly unstable structures as well. Figure 4 shows one such examples, recently presented by Desyatnikov et al.[11],

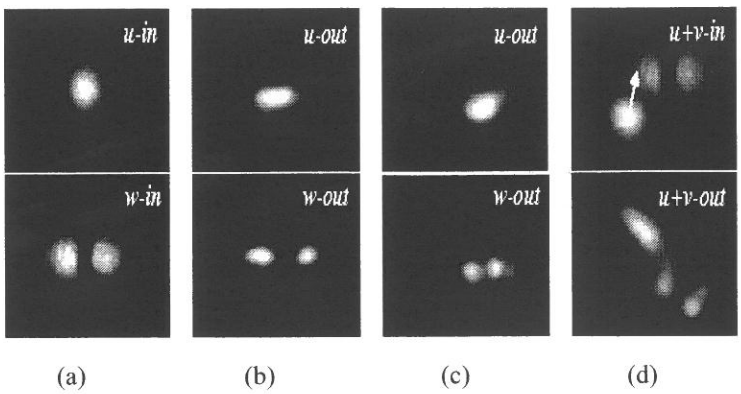

Fig. 3. Experimental demonstration of the formation of the dipole-mode vector soliton and its collision with a scalar soliton with the transformation of the linear-angular momentum [7].

a quadrupole composite vector soliton. Initially, two beams are launched, as shown in Fig. 4 ("in").

One of the beams, a Gaussian beam, is similar to the fundamental mode of the composite soliton and it has no nodes. The second beam is passed through a phase mask that creates a phase difference π between the adjacent beamlets, so that when such a quadrupole beam propagates independently, it forms four individual spatial solitons which strongly repel each other. However, being launched together with the fundamental beam that interacts incoherently, the second beam creates a quasi-stationary structure that resembles the stationary soliton solution shown above in Fig. 2(a,b).

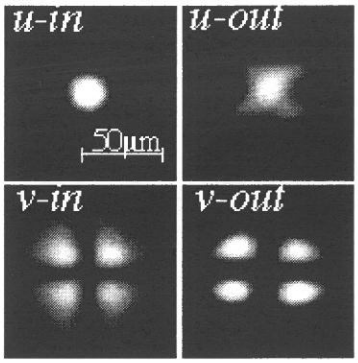

Fig. 4. Experimental generation of the quadrupole vector soliton in a photorefractive nonlinear crystal [11].

5. Concluding remarks

The concept of composite solitons is closely connected with other important concepts of modern nonlinear physics, and other types of multi-soliton localized states which can be observed in Nature. The recently found *necklace-ring vector solitons* [12] represent another example of the stationary self-trapped structures consisting of azimuthally modulated components. The most simple solution of this class has a radially symmetric total intensity which coincides with the intensity of a vortex. However, this solution, unlike the vortex, has a planar wave front and zero angular momentum (spin). Such a difference determines new features of the spatial solitons and a novel scenario of the symmetry-breaking instability. In general, the spin of necklace-ring solitons can have any fractional value that transforms, in the process of the soliton instability, into the linear momenta of the splitters appearing after the soliton break-up.

Acknowledgments

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Optical Fibre Bragg Grating Packaging

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Fibre Bragg Gratings (FBGs) are temperature sensitive due to the change in refractive index with variations in temperature. Packaging of FBGs requires design considerations to eliminate temperature and other environmental effects to meet the demands for state of the art Dense Wavelength Division Multiplexing (DWDM) telecommunication systems. This paper presents various processes and packaging techniques that have been developed for FBGs in order to meet these requirements.

Introduction

Demand for high bandwidth telecommunication systems has led to the development and deployment of high data rate DWDM optical fibre networks that span continents and oceans. These systems typically consist of many independently modulated optical channels, each at a different wavelength, that are multiplexed into a single optical fibre for long-haul transmission. In order to overcome various attenuation effects in the fibre, the optical signals are amplifed every 50-100 km using Erbium Doped Fibre Amplifiers (EDFAs). Finally, each wavelength channel is separated at the receiver where the data is demodulated. The technique of combining many optical channels onto a single optical fibre is known as Dense Wavelength Division Multiplexing (DWDM). Systems currently being manufactured typically have channel spacings of 50 GHz (approximately 0.4 nm) allowing for over eighty separate channels to be launched within the gain bandwidth of conventional EDFAs [1].

Optical fibre Bragg gratings (FBGs) have now been commercially available for approximately four years and have found applications in DWDM systems, principally as narrow-band filters to separate the densely spaced optical channels, and as broadband filters to equalise the gain profile of EDFAs. Another important area of application is dispersion compensation. In each application, tight specifications on the optical characteristics of the filter are required to be maintained over a large range of operating conditions and over long device lifetimes. Cost and reliability considerations have also demanded the development of passive packaging solutions to serve these operating requirements.

This paper will review some the packaging requirements for FBGs including:

- Environmental conditions for submarine (wet plant) and terrestrial (dry plant) applications
- Allowed spectral shifts for the lifetime of the device
- Reliability of devices
- Cost & Manufacturability
- Tunability

In order to meet the packaging requirements mentioned above for FBGs, various processes and technologies will be reviewed including:

- Optical fibre stripping techniques
- Passive temperature compensating packages
- Bonding materials.

Fibre Bragg Gratings

FBGs are manufactured by exposing the core of an optical fibre to interference fringes formed by a UV interferometer. The refractive index of the core increases slightly in regions of constructive interference, resulting in a periodic refractive index profile along a short length of the fibre – a Bragg grating. Light launched into the core of the optical fibre with a wavelength λ_B, satisfying the Bragg condition,

$$\lambda_B = 2n_{eff}d \qquad (1)$$

(where n_{eff} is the effective index of the fibre and d is the spatial period of the refractive index modulation) is strongly reflected whereas other wavelengths are transmitted.

Figure 1 illustrates the typical spectral features of an FBG used in the separation of 50GHz signals in a DWDM optical network. The length of the exposed region is approximately 10 mm in this case. FBGs have become the filter of choice for this application due to: flat rejection response; low cross-talk; and low insertion loss. One attraction of FBGs over other filter technologies is that FBGs are all-fibre devices. This greatly simplifies the package requirements in that no critical alignments of free-space optical elements or terminations are required. However, the effective index of the guided mode and hence, the centre wavelength of the grating, is both temperature and strain dependant and is governed by the following expression:

$$\partial n_{eff} = \frac{\partial n_{eff}}{\partial T}\Delta T + \frac{\partial n_{eff}}{\partial \sigma}\Delta\sigma \qquad (2).$$

where ΔT is the change in temperature, $\partial n_{eff} / \partial T$ is the temperature coefficient of the refractive index, $\Delta\sigma$

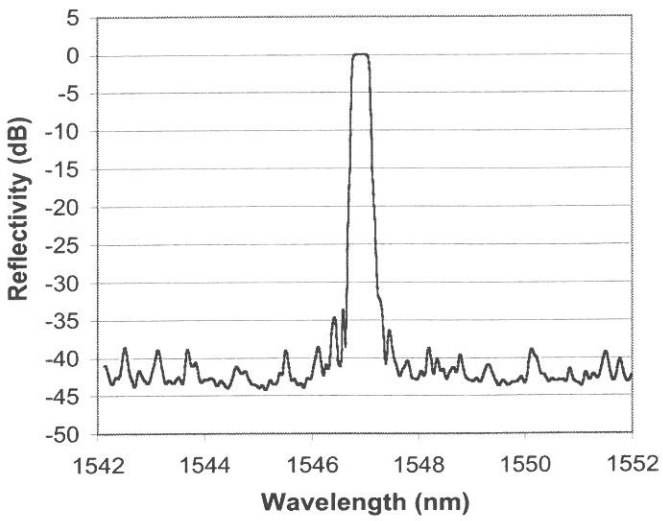

Fig. 1. Typical reflection spectrum for an FBG used in the separation of DWDM signals.

is the applied strain, and $\partial n_{eff} / \partial \sigma$ is the longitudinal stress-optic coefficient of the fibre[2]. As a consequence, a package that isolates the FGB from strain and compensates for temperature changes is required for most telecommunications applications.

The following sections discuss some of the methods and processes that have been developed in order to package and volume manufacture FBGs.

Wet Plant and Dry Plant Applications

FBG products have found applications in both submarine (wet plant) and terrestrial (dry plant) environments. These two environments are sufficiently diverse to warrant different processes and packages for essentially the same product function.

In wet plant applications, the reliability of the device is paramount owing to the high costs incurred by a submarine cable owner for a recovery and repair operation if a device were to fail. Fibre strength must be ensured during the FBG manufacturing process in order to conform with typical FIT values of 0.5 (1 FIT = one failure in 10^9 device hours) for the device. Once deployed in a submarine repeater, however, the device spends its 25 year operating life under fairly benign conditions: temperatures rarely vary by more than a few degrees and the device resides in an inert atmosphere within the hermetically sealed repeater unit.

In contrast, dry plant applications require that the device operates over temperature ranges of –5°C to 70°C and relative humidities of 5% to 95%. This imposes stringent performance criteria on the temperature compensation technique and the fibre-to-package bonding material. However, the relative ease with which these devices can be replaced in the event of a failure, relaxes the reliability requirement to approximately 100 FIT.

Fibre Coating Removal

In order to expose the fibre to the UV radiation during the FBG inscription process, the acrylate coating protecting most optical fibres first needs to be removed. Typical window strip lengths are between 30 and 50 mm, although in some cases, up to 120 mm is required. Coating removal is also a requirement for most packaging geometries as fixing the fibre by its relatively soft jacket to a substrate would result in unacceptable drifts in centre wavelength.

Various techniques have been developed to remove the acrylate coating but each has its own advantages and disadvantages. Mechanical stripping is by far the simplest but this generally results in unacceptable damage to the fibre surface. Commercial stripping tools have been developed to remove the coating from the ends of optical fibres for operations such as fusion splicing, but no mechanical tool is currently available that can remove the coating from the centre of a length of optical fibre without causing significant damage to the glass, thus reducing the fibre strength.

A popular method for removing the acrylate coating is to use a solution of dichloromethane. This is available in both liquid and gel forms. In the liquid form, wicking of the solution along the length of the coating is a potential problem, making accurate strip lengths difficult. In both cases, some contact with the fibre is inevitable in order to remove the remains of the chemically treated coating, but fibre damage can be minimised if proper handling procedures are implemented. However, the process is slow (approximately 10-15 minutes per fibre for the gel) and difficult to automate for volume manufacture.

By far the quickest and most reliable method of coating removal is to dissolve it in a solution of hot sulphuric acid. This process typically takes less than a minute to remove the coating, leaving the fibre surface in a near pristine state. Consequently, the fibre surface is virtually free from flaws, making this process attractive for applications where high device reliability is required (see Figure 2).

Athermal Packages for FBGs

The operational temperature range of many terrestrial optical networks lies between –5°C and 70°C. If left unpackaged, the centre wavelength of an FBG drifts approximately 1 nm over this temperature range (see Figure 3). However, for most telecom system applications, wavelength stability of better than 50 pm is often required. Active techniques of wavelength control, such as the use of peltier heaters, are not usually possible due to cost, reliability and in the case of submerged systems, electrical power restrictions. Consequently, FBG manufacturers have relied on two basic passive temperature compensating schemes: (a) the combination of multiple materials of differing thermal expansion coefficients, and (b) bonding the

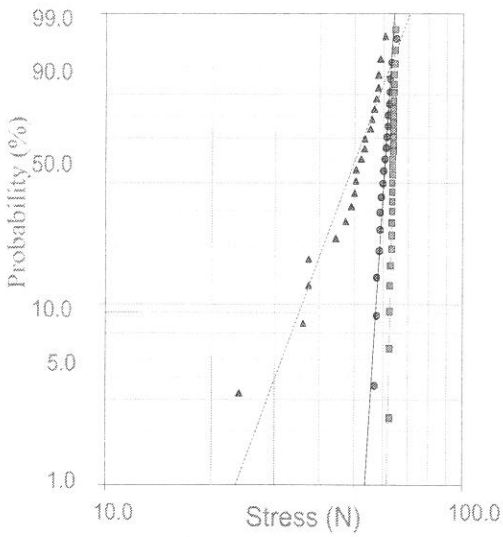

Fig. 2. Weibull plot showing failure probability as a function of applied stress for various stripping methods: Squares – pristine fibre; circles – acid strip; Triangles – dichloromethane solution.

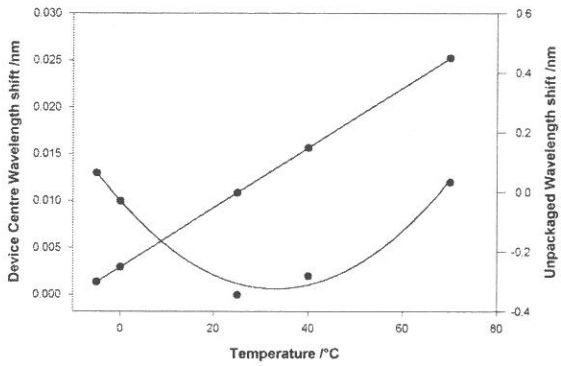

Fig. 3. Shift in centre wavelength with temperature for an unpackaged FBG (straight line, axis to the right) and a passively compensated FBG (curve, axis to the left). ♦Invar, • Kovar.

fibre directly to materials with a negative coefficient of thermal expansion (CTE).

The first approach involves a package design whereby a material of relatively high CTE (eg stainless steel or aluminium) is affixed to a slotted tube manufactured from a material with a lower CTE (eg. Invar or Kovar) as in Figure 4. The fibre (into which the grating has been previously exposed) is then bonded to the higher CTE material under a small strain (typically 100 g). By choosing the lengths of the high CTE material and the tube appropriately, the linear expansion of the tube with increasing temperature, coupled with the expansion of the high CTE material in the opposite direction causes the strain on the fibre to be reduced [3]. First-order changes in the effective index as a function of temperature, such as those described by Equation (2), can be adequately compensated. Wavelength shifts of less than 20 pm over a 80°C temperature range can easily be achieved using this technique as Figure 3 demonstrates.

The second approach involves the use of ceramic materials that have a negative CTE. The grating fibre is bonded directly to the ceramic substrate. If the temperature of the device increases, then the physical length of the ceramic package decreases. This decrease in length with temperature directly compensates for the thermal expansion of the silica fibre and the changes in effective index with temperature.

Careful control of the composition of the ceramic during its manufacture must be achieved in order to precicely match the fibre properties. Advantages of this packaging technique include: ease of design; simple manufacturing process; and a fibre bonded only under a minimum of tension (see next Section). One disadvantage of these materials is that if a different fibre type is used for the grating or if the properties of the fibre drift from batch to batch, then the composition of the ceramic must also be modified.

Fibre Bonding Techniques

A challenge encountered in the packaging of FBGs, different from most other fibre-optic component packaging, is that the fibre is held between its bonding points under strain. For most athermal package designs, the FBG is packaged with approximately 100 g of strain. As this load must be maintained over the 25 year lifetime of the device, fibre strength and drift in centre wavelength of the filter due to creep in the bonding material needs to be carefully considered [4].

To date, the bonding materials of choice are thermally cured epoxies. Care must be taken to ensure that the epoxy is sufficiently cured otherwise the bond will be too soft and the centre wavelength of the filter will tend to shift to shorter wavelengths as the tension across the grating decreases with life. These effects can generally be detected if a screen test such as temperature cycling is used as part of the manufacturing process.

One particular issue concerning the use of epoxies is their sensitivity to changes in relative humidity. Under high humidity, epoxies tend to swell, again relaxing the strain on the fibre causing the grating centre wavelength to shift to shorter wavelengths (see Figure 5). These shifts can be reduced by incorporating

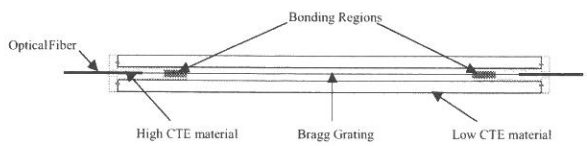

Fig. 4. Passive temperature compensating packaging consisting of materials with differing CTEs.

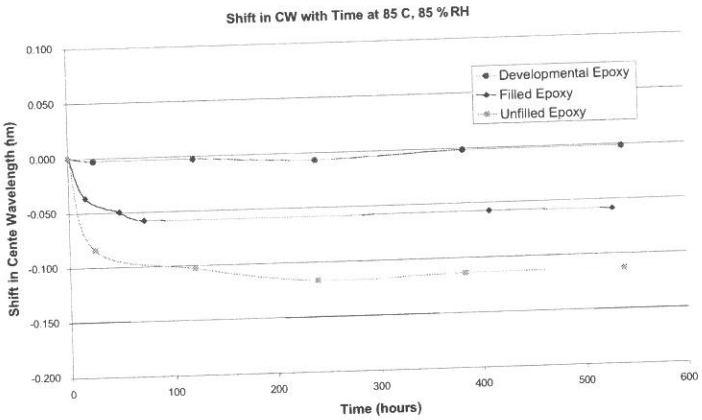

Fig. 5. Shift in centre wavelength of FBGs subjected to 85% RH and 85°C for three different epoxies.

the use of fillers in the epoxy.

The drift in the centre wavelength of an FBG, as a result of epoxy creep over life and changes in relative humidity, require FBG designers to include appropriate tolerances into the optical design of the FBG. This in turn, can compromise the yields of certain FBG designs if the amount of tolerance required is a significant proportion of the channel spacing requested by the customer.

As humidity effects tend to be the largest contributing factor to the allocation of these tolerances, solutions such as encasing the temperature compensating package in a hermetically sealed enclosure have been developed. Initial developments of this process involved the use of metal-coated fibre feed throughs. These are necessary in order to solder the package around the fibre and ensure a hermetic seal. The feed throughs are spliced to the grating fibre within the package. As a consequence, these packages tended to be bulky and difficult to produce. More recent versions have done away with the need for metal-coated fibres, but the packages are still difficult and costly to manufacture.

The problems associated with epoxy creep and humidity drifts in the package can be avoided by the use of glass solder to bond the fibre to the package. In this technique, a low melting point glass is applied to the regions that are to be bonded. A localised heat source such as a laser is then used to fuse the solder to the silica fibre and the package. Glass solder, being a harder bonding material, show no measurable wavelength shifts due to creep or changes in relative humidity. The humidity performance of FBGs fabricated using this technique is shown in Figure 6.

Tunable Fibre Bragg Gratings

As the complexity of optical networks increases, there has been a steady demand for optical components whose properties can be tuned dynamically. Examples include reconfigurable add/drop multiplexors and tunable dispersion compensating gratings (DCG). Each of these applications presents different requirements for the tunable package.

In the case of the reconfigurable add/drop multiplexor, the challenge is to repeatably shift the grating center wavelength by one or more channel spacings thereby selecting a particular wavelength channel to be either dropped or added to the traffic. This is usually achieved by applying compression or strain to the grating. Preferably, the grating should latch at each of its states in order to minimise power consumption. Switching times between states tends to be in the microsecond to millisecond range. Furthermore, once in a latched state, passive temperature compensation is also usually required.

Tunable DCGs present a different challenge. In these gratings, the period, d in Equation (1) is a function of length along the grating. This linear chirp is either directly fabricated into the grating during the inscription process or can be induced by special design of the package. The device can act as a dispersion compensator to optical pulses incident on the grating, in that different wavelength components within a pulse reflect off different regions within the grating. Wavelength components that reflect off the back of the grating have a longer delay relative to wavelengths which are reflected from the front. In this way, pulses which have been stretched due to dispersion in the fibre can be recompressed by reflecting off the DCG [5]. In high data rate systems, the amount of dispersion in a system can be difficult to model during the design

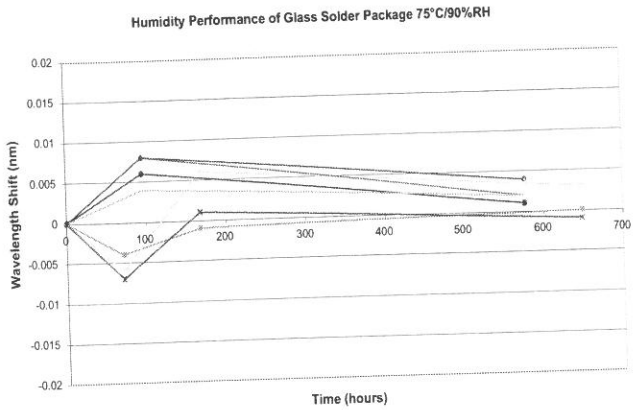

Fig. 6. Change in centre wavelength for FBGs packaged with glass solder. Compare with Fig. 5.

phase. Tunable DCGs can provide a fine level of control over the end-to-end dispersion of a system.

In order to provide a level of tunability either to a pre-chirped or unchirped DCG, a differential strain or temperature gradient must be established across the grating. An example of temperature tuning can be found in Ref. [6] whereby the grating is coated with a metal film, whose thickness varies along the length of the grating. Current flowing through the film heats the film at a rate dependent on the local resistance. Strain tuning has been achieved by fixing the grating to a tapered piezoelectric stack, for example [7]. Another technique describes the use of a series of independantly addressable piezo stacks to which the grating is bonded [8].

An alternative approach to differential tuning of the package is too fabricate a DCG with a nonlinear chirp. This simplifies the package considerably as only a direct change of strain or temperature is required to tune the dispersion of the device [9].

Reliability

The reliability of fibre bragg components must meet stringent demands when the use is in undersea systems. Fibre under strain has the problem of crack growth. The package design and tuning method must guarantee the lifetime of the component. This is achieved by limiting the strain on the fibre to less than 1/5 of the proof test level applied during the packaging process. Lifetime can be predicted from crack growth theory [10] or from field results. Data from field performance is shown below.

Product	DWDM and GFF Bragg Grating Filters Submarine Use.
Operating Period	June 1998 to November 2001 (3.4 years)
Cumulative device time	493,561,736 hours
Reliability Failures	0 (Zero)
Failure Rate	< 6.07 FIT
MTBF	164,755,080 hours

Conclusions and Future Challenges

The construction of packages to compensate for the temperature sensitivity of Fibre Bragg Gratings has been described. Components such as epoxy adhesives add sensitivity to environmental effects of humidity and also temperature. Although many of the techniques described above have pushed the performance of FBG packages to almost theoretical levels, many cost and manufacturing issues remain outstanding. Integrated, continuous manufacturing processes have yet to be developed with manufacturers relying on significant amounts of manual labour to meet their demand. Automation, at best, tends to lie within isolated islands of manufacturing equipment.

The requirement for low cost packages has emerged within the industry and most FBG applications are currently under cost pressures. As FBGs expand into the metropolitan access markets, costs will become a greater driving force. Packages will need to be designed for automatic assemby using low cost materials that still maintain the high performance and stability requirements outlined in previous sections. The reliability as demonstrated in present designs must be maintained.

Acknowledgments

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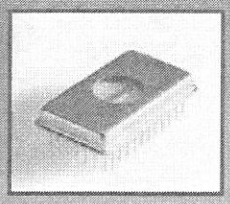
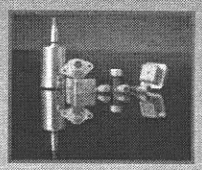
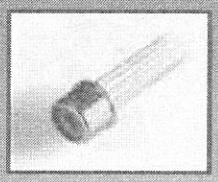
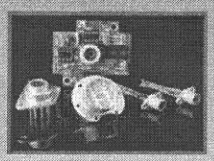
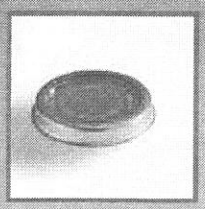
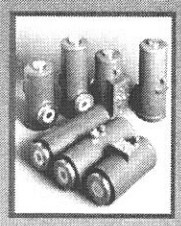

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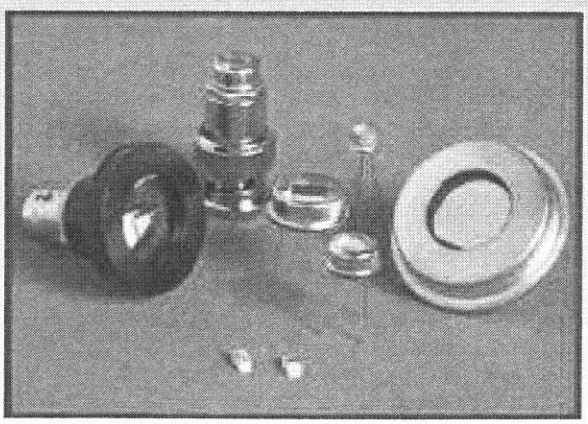

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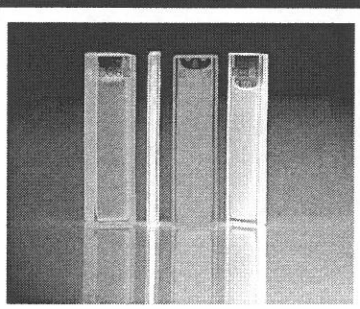

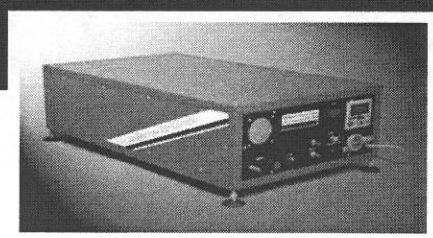

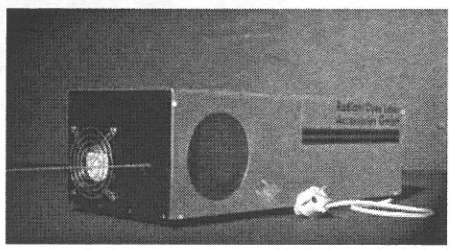

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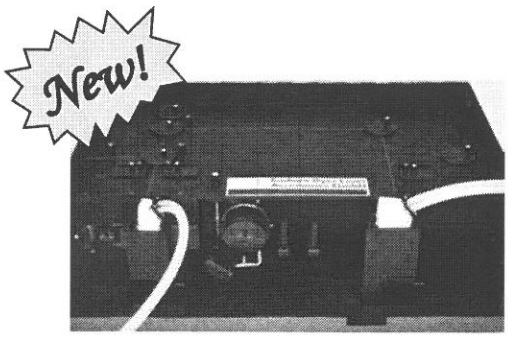

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1. PRESIDENT'S REPORT

On November 19, I formally took over as President of FASTS for the next two years. This follows an immensely successful two years in which the Presidency was shared by Sue Serjeantson and Peter Cullen.

Our first task is to establish an agenda with a new Government and a new Minister. Twelve months ago the tide was running our way. The Government was moving to respond to reports from the Chief Scientist and the Innovation Summit, and the Opposition was talking up its intention to re-energise science, research and higher education.

It seemed as though election 2001 was going to be a case of "Backing Australia's Ability" versus "Knowledge Nation", with the question of Australia's national investment in these areas the major topic of discussion.

We were to be disappointed. These issues were barely discussed in an election dominated by a series of international and domestic crises.

The present situation offers interesting challenges. The new Government's agenda does not appear to be crowded, and I believe they will be receptive to new ideas.

The Opposition has consciously tried to renew itself. The Leader, Deputy-Leader and half the members of the Opposition front bench are all new to their positions, and they will be looking closely at why "Knowledge Nation" failed to fire the Australian imagination.

The State Governments also offer interesting possibilities, with an increasing recognition of the capacity of science and research to generate new jobs and new industries at a regional level.

Australian scientists and technologists have two priceless contributions to make to politicians in Australia - ideas and solutions. Both these qualities are in short supply, and add to the importance of our regular contacts with Parliamentarians at national and regional level.

2. NEW MINISTERS AND SHADOW MINISTERS

Brendan Nelson and Peter McGauran are the Ministers with responsibility for Science in the new Government. Brendan Nelson is Minister for Education, Science and Training and is a member of Cabinet; and Peter McGauran is Minister for Science.

This is a strong team, with Brendan Nelson bringing a much-needed new perspective to Education and Higher Education. Peter McGauran was an energetic and accessible Minister for Science in the first Howard Government, and his return will be welcomed.

The Opposition is represented by Deputy Leader Jenny Macklin, who opted for Shadow Minister for Employment, Education, Training and Science over the shadow Treasury position. She will be supported by Senator Kim Carr, as Shadow Minister for Science and Research.

I have been in touch will all these people, and also Senator Natasha Stott-Despoja as leader of the Democrats and spokesperson for Science.

3. COUNCIL

Council this year was an opportunity to have a wide-ranging discussion on strategy and issues to take up at Parliamentary and bureaucratic levels. Our agenda and our approach has to be re-focussed in the light of the election, and the contributions from our Member Societies were particularly welcome.

Members will be invited to support three major activities this year: a forum at the National Press Club in mid-year; "Science meets Parliament" Day at the end of the year; and to comment and contribute ideas to the new edition of the FASTS' policy document.

4. UNIVERSITIES - ONE GREAT UNRESOLVED ISSUE

The university sector remains one of the great unresolved issues in Australian public life. A decline which began 15 years ago is continuing. The pressure on academics to

perform more tasks is increasing, as their salary levels are steadily sliding down the ladder on international competitiveness. The quality of infrastructure declines as funding pressures increase. Neither major party seems willing to tackle the issue.

It is time for a national review of the university sector, with genuine discussion on what Australians want from their universities, and how much they are prepared to pay to achieve it.

5. CSIRO FIRST TEST FOR GOVERNMENT

CSIRO's triennium funding is due for renewal this year. Both the CEO and the CSIRO Staff Association have put the case for an additional $100 million per year. This will rebuild CSIRO's core capacities after a decade of Government thinly slicing away at its budget. It will also enable renewed efforts by CSIRO effort to commercialise its results.

6. NEW EXECUTIVE

The Board meeting on November 19 elected a new Executive. Successful candidates were:

President:	Prof Chris Fell
Vice-presidents:	Dr David Denham AM
	Prof Rob Norris
Secretary:	Dr Peter French
Treasurer:	Assoc. Prof John Rice
Chair, Policy Committee	Dr Ken Baldwin

The Executive has co-opted Jan Thomas to join the Executive for the next twelve months, in the role of past Vice-President. Peter Cullen is unavailable to serve as past-President.

7. NEW BOARD

Aquatic Sciences	Dr Alan Butler (CSIRO)
Biological Sciences	Assoc. Prof Melissa Little (UQ)
Chemistry	Prof Chris Easton (ANU)
Earth Sciences	Mr Mike Smith (Geo Instruments Pty Ltd, NSW)
Food & Ag. Sciences	Mr Ian Longson (Dept of Agriculture, WA)
Mathematical Sciences	Ms Judy Mousley (Deakin University)
Medical Sciences	Prof David Tracey (UNSW)
Physical Sciences	A/Prof John O'Connor (University ofNewcastle)
Plants & Eco. Sciences	Professor Snow Barlow (U. of Melbourne)
Technology Sciences	Mr Len Ferrari (Consultant, NSW)

Ian Longson has joined the Board as member representing the new Food and Agriculture sector.

8. "SCIENCE meets PARLIAMENT" DAY 2002

"Science meets Parliament" Day is a landmark event in Australian political circles.

Scientists are still the only group to organise a mass visit to Parliament, and a wonderful opportunity to put our case for increasing the national investment in science and research.

Over time this event will build up relationships and confidence between our sector and Parliamentarians. Increasingly MPs will see us as a group which has both ideas and solutions, two priceless asserts to them.

I will be seeking the advice of the new Science Minister about the best dates for SmP 2002. We expect to run the event October or November 2002.

This would be an excellent time to run your Society's Council meeting, and then go on to make a strong contribution from your discipline to Parliamentarians.

9. OCCASIONAL PAPERS

The Parasitology Society is about to launch an Occasional Paper "Parasitology in Australia: an Investment in Human and Animal Health".

The paper warns that Australia's capacity to respond to parasitic diseases affecting humans and animals is being eroded by lack of national investment. It points out the level of danger to Australia - 267 soldiers from the InterFET force in East Timor returned with malaria, even though they were issued with the standard anti-malarial drug doxycyclin.

Other Members Societies might consider a similar publication. Guidelines are available from our office, and FASTS offers considerable support with printing and publicity.

A copy of the paper will be sent to all Members upon publication, and it will be available electronically at the FASTS web site: www.fasts.org

10. FASTS IS GROWING

We now have 57 Member Societies.

The most recent are:

- Australian Institute of Agricultural Science and Technology
- Institute of Australian Geographers
- The Society for Reproductive Biology

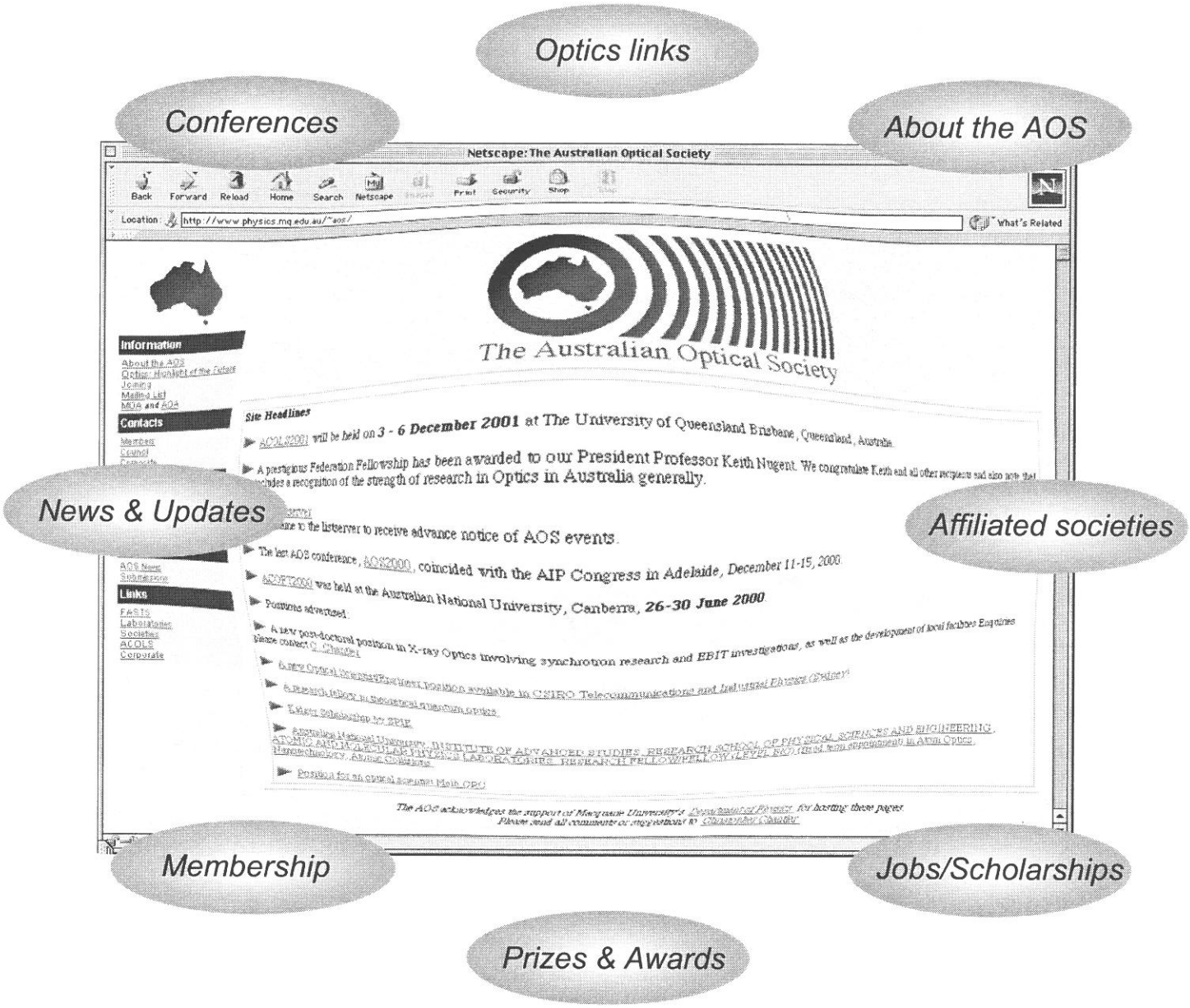
If you know of any non-Member Societies, please encourage them to join. Refer them to our office for information on the benefits and costs of membership.

A full list of Members is on our web site.

Chris Fells
President of FASTS

The Australian Optical Society Web Site

www.physics.mq.edu.au/~aos/



Keep up-to-date with what's happening in the AOS - add your name to the AOS listserver (see web page for details)

www.physics.mq.edu.au/~aos/

AOS MEDAL

AUSTRALIAN OPTICAL SOCIETY

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

Previous winners of the medal have been:

1995: Mr Bill James, James Optics, Melbourne
1996: Dr Parameswaran Hariharan, University of Sydney and CSIRO
1997: Professor Jim Piper, Macquarie University
1999: Professor Dan Walls, University of Auckland

This Medal is the most prestigious award of the Australian Optical Society. It would normally be presented only to a nominee at an advanced stage of his or her professional career and with a strong and sustained record of authority, enterprise and innovation in the field of optics in Australia.

Nominations for the 2002 AOS Medal Winner should include brief personal details and a curriculum vitae emphasising the main contributions made by the nominee to Australian optics. Two letters of recomm-endation should also be provided. Nominations may be made either by or on behalf of any eligible candidate. The selection panel reserves the option to seek additional information about candidates for the award. It is hoped that the person selected to receive the medal will be able to do so at the next AOS Conference.

The closing date for nominations is **15th February 2002**.

Nominations should be sent to the Acting Secretary:

Dr Duncan Butler
Ionising Radiation Standards
ARPANSA
Yallambie VIC 3085
Fax: (03) 9432 1835

EDITORIAL

By the time you receive this edition of the AOS News the ACOLS 2001 meeting in Brisbane will have come and gone. I am sure that all of the AOS members who attended will have had an enjoyable and scientifically stimulating time at the University of Queensland. The next edition will endeavour to give some reports from the conference, so if you feel that you have something to contribute, please contact me as soon as possible. Of particular interest are any photographs of the event.

As reported in the front of this edition, our AOS President was recently awarded a Federation Fellowship. This is an extremely promising sign for the optical sciences in Australia. Congratulations Keith!

I recently had a few interesting conversations with optical scientists who are not members of the AOS. Some of these expressed the view that the AOS was not a sustainable organisation, and that it potentially threatened the existence of other professional bodies (most notably the Australian Institute of Physics). Whilst I personally disagreed with most of the arguments presented, I thought that it was worth raising as an Editorial issue. It would be interesting for each member of the AOS to think hard about why the Society is important to them, and what changes could be made to improve it. Just a little something to ponder over the summer months, when a significant proportion of our membership put their noses to the ARC grindstone.

Happy Christmas and Peaceful Photons to all.

Wayne Rowlands

Meetings Calendar

The following list of optics-related conferences is compiled from several sources and should be used as a guide only.

Date	Meeting 2002	Contact	Location
Jan 14-16	OPTRO 2002: International Symposium on Optronics and Defence	EOS	Paris, France
Jan 19-25	Photonics West	SPIE	San Jose, USA
Feb 3-6	ASSL - Advanced Solid-State Lasers	OSA	Quebec City, Canada
Feb 5-7	Workshop on Integrated Modeling of Telescopes	SPIE	Lund, Sweden
Feb 7-10	Laser Applications to Chemical and Environmental Analysis	OSA	Boulder, USA
Feb 23-28	Medical Imaging	SPIE	San Diego, USA
Mar 17-22	Optical Fiber Communication Conference	OSA	Anaheim, USA
Mar 19-21	12th International Workshop on Lidar Multiple Scattering Experiments	SPIE	Germany
Mar 24-27	Organic Optoelectronics: Technology and Devices	EOS	Engelberg, Switzerland
Apr 21-26	High Power Laser Ablation	SPIE	New Mexico, USA
Apr 23-25	Photomask Japan	SPIE	Yokahama, Japan
May 12-17	02UP - 13th International Meeting on Ultrafast Phenomena	OSA	Vancouver, Canada
May 19-24	CLEO - Conference on Lasers and Electro-Optics	OSA	Long Beach, USA
May 19-24	QELS - Quantum Electronics and Laser Science Conference	OSA	Long Beach, USA
May 26-29	Photonics Prague 2002 - 4th International Conference on Photonics, Devices and Systems	EOS	Prague, Czech Republic
May 28-31	46th International Symposium on Electron, Ion, and Photon Beams and Nanofabrication	OSA	Anaheim, USA
Jun 2-6	Photonics North (ICAPT '02)	SPIE	Quebec City, Canada
Jun 11-12	International Symposium on Photonics in Measurement	EOS	Aachen, Germany
Jun 22-28	IQEC 2002 - International Quantum Electronics Conference	OSA/SPIE	Moscow, Russia
Jul 7-11	International Symposium on Optical Science and Technology	SPIE	Seatlle, USA
Jul 8-12	Optoelectronics and Communications Conference	SPIE	Yokohama, Japan
Jul 14-17	Optical Amplifiers and Their Applications	OSA	Vancouver, Canada
Jul 17-19	International Conference on Smart Materials, Structures and Systems	SPIE	Bangalore, India
Aug 11-15	Seventh International Conference on Near-field Optics and Related Techniques	OSA	Rochester, USA
Aug 16-18	2nd International Conference on Imaging and Graphics	SPIE	Hefei, China
Aug 25-30	19th Congress of the International Commission for Optics	EOS	Florence, Italy
Sep 1-6	ICEM-15 - 15th International Congress on Microscopy	EOS	Durban, South Africa
Sep 2-4	Nonlinear Guided Waves and Their Applications	OSA	Stresa, Italy
Sep 2-5	OWLS-VII: 7th Conference of the International Society of Optics Within Life Sciences	EOS	Luzern, Switzerland
Sep 22-25	ISOS 2002 - 6th International Symposium on Optical Storage	SPIE	Wuhan, China
Sep 29-Oct 3	Laser Science XVIII	OSA	Orlando, USA
Sep 29-Oct 3	25th International Congress on High Speed Photography and Photonics	SPIE	Beaune, France
Oct 14-18	Photonics Asia	SPIE	Shanghai, China
Oct 30-Nov 1	International Symposium on Biomedical Optics and Photomedicine	SPIE	Tokyo, Japan

Further information on the above conferences can be obtained from:

OSA
(The Optical Society of America)
2010 Massachusetts Avenue, N.W.
Washington, D.C. 20036-1023
USA

Tel: +1 202.223.8130
Fax: +1 202.223.1096
email: custserv@osa.org
www.osa.org

SPIE
(The International Society for Optical Eng.)
PO Box 10
Bellingham WA 98227-0010
USA

Tel: +1 360 676 3290
Fax: +1 360 647 1445
email: spie@spie.org
www.spie.org

EOS
(The European Optical Society)
Hollerithallee 8
30419 Hannover
Germany

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email: no@lzh.de
www.europeanopticalsociety.org

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info@xrt.com.au
http://www.xrt.com.au

AOS NEWS
Submission Guidelines

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

What can you submit?

* ***Scientific Article***
A scientific paper in any area of optics.
* ***Review Article***
Simply give a run down of the work conducted at your laboratory, or some aspect of this work. Authors of scientific or review articles will receive proofs by fax.
* ***Conference Report***
If you have been to conference recently, writing a short report would be greatly appreciated.
* ***News Item***
Any newsworthy stories in optics from Australia or abroad.
* ***Book Review***
If you have read an interesting (and relatively new) book in some field of optics please consider a review for the *AOS News*.
* ***Cartoon or drawing***
If you have some artistic bent why not consider submitting a cartoon!

How can you submit?

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

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

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AUSTRALIAN OPTICAL SOCIETY

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