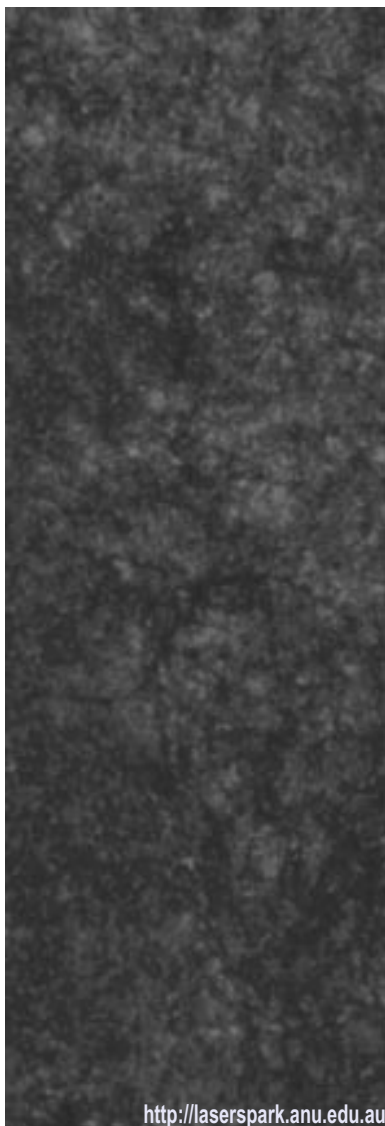


Laser Physics Centre



Professor Barry Luther-Davies
- Head of Laser Physics Centre



<http://laserspark.anu.edu.au>

The Laser Physics Centre is engaged in laser-based research on topics spanning both fundamental and applied physics and engineering.

Research Summary

Much of the research of the Centre involves some aspect of materials science, such as the development of linear and nonlinear materials for photonics, or laser-based methods for the production of new materials or unusual states of matter. Almost all of the projects undertaken in the Centre involve extensive collaboration with local and overseas groups. Within the School we have strong interactions with the Department of Electronic Materials Engineering; Applied Mathematics; the Optical Sciences Centre; the Atomic and Molecular Physics Laboratories, and the Plasma Research Laboratory. A collaboration involving Professor Luther-Davies and Dr Krolikowski, with members of the Optical Sciences Centre, resulted in a successful application to the University's Performance and Planning Fund (PPF) for work on Nonlinear Science and Solitons. Outside the School we have projects with the Departments of Chemistry and Physics and Theoretical Physics at the ANU; ADFA; James Cook University; University of Sydney; and overseas groups in USA, Germany, UK, Poland, France, Switzerland and Russia.

The Centre remains a significant contributor to the expanded Australian Photonics Cooperative Research Centre which was funded by the Government for a further seven year period early in the year. Professor Luther-Davies was reappointed as Research Director for the CRC and as one of the Directors of Australian Photonics Pty Ltd that is the Commercial and Management agent for the CRC. The CRC is expected to fund expansion of the Department's work on novel photonic materials and devices including an ongoing commercially sponsored project on fibre optic voltage sensors (FOVS).

Two new staff members joined the Centre during the year. In June Dr Max Lederer took up an ARC funded SPIRT Post Doctoral Fellowship, supported by Electro Optic Systems Pty Ltd, and Dr Robbie Charters took up a SPIRT funded PDF, with support from AOFR Pty Ltd. Therese Martin joined the FOVS project as a part-time research assistant, and Daniela Werner joined the Centre from the FH Aalen University of Applied Sciences, Germany, to undertake practical training also on the FOVS project. A cohort of PhD students, some with historical links to the Centre, completed their PhDs. They included Doug Body, Jason Christou, Hugo Giordano, Max Lederer, Wenqian Yu, Geoff Pryde, Bruce Stenlake and Weijian Lu. A further significant personal achievement was Anita Smith's selection to represent the ANU at the 8th International Women in Leadership Conference at Edith Cowan University in November.

We were pleased to welcome a number of visitors during the year. Professor Byeong-Soo Bae from KAIST Korea is spending twelve months in the Centre supported by an IREX grant to work on silica-zirconia sol-gel glasses. Dr Abdolnassar Zakery from Shiraz University in Iran joined the Centre in October to work on pulsed laser deposition of chalcogenide glasses. Alex Boiko from Electro Optic Systems Pty Ltd continues to produce high quality optical coatings in support of the research as well as servicing the needs of the company. Dr Yanjie Wang and Dr Yue Gao, also from Electro Optic Systems remain as long term visitors. Short-term overseas visitors included Professor Eric Van Stryland from CREOL at the University of Central Florida, Dr Christian Bosshard from ETH Zurich, and Dr Nick Zheludev from the University of Southampton, UK. Dr Graham Atkins from the Optical Fibre Technology Centre at the University of Sydney is a regular visitor working on organically modified silicate (ORMOSIL) materials for photonics.

A summary of the various research activities in the Department follows:

Nonlinear Optical Materials and Structures

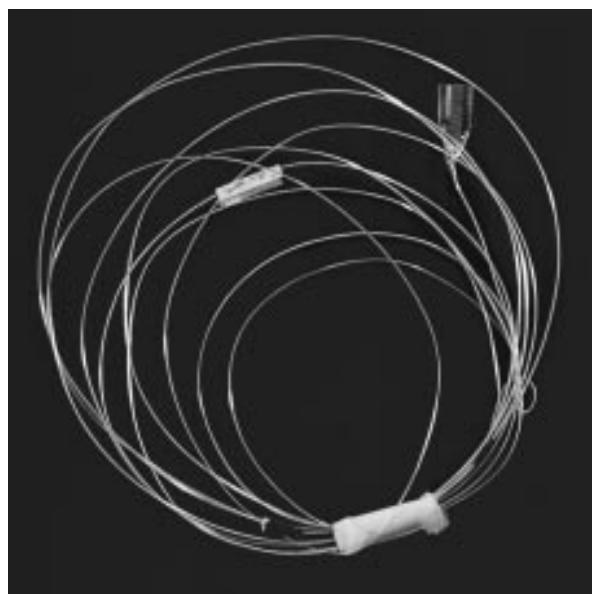
We continue to study the nonlinear optical properties of materials for applications in photonics as well as developing models of substances important for the understanding of the microscopic origin of nonlinear optical effects. In addition to the classes of materials studied previously, of particular interest this year has been the nonlinear properties of gallium-silica interfaces, and the behaviour of polyenes with different chain length.

Third-order NLO Properties of Conjugated Polymers and Model Molecules

We have established that some π -conjugated polymers have large but complex third-order nonlinear optical properties. Examples of such materials are poly(indenofluorene) which exhibits very strong absorption saturation for femtosecond laser pulses at 800 nm, and polymers of the poly(phenylenevinylene) family, which exhibit both very strong self-focussing and/or self-defocussing effects and nonlinear absorption. In collaboration with overseas groups we have investigated several polymers and π -conjugated molecules with the aim of finding materials with both the optimized nonlinear properties and good processability to be useable for low loss planar waveguide structures. While several polymers offer promise as good materials for nonlinear waveguides with low loss nonlinear merit factors, the real part of the electronic third-order susceptibilities are not among the highest measured at 800 nm. Finding a good compromise between factors such as the low optical loss and high nonlinearity at a useful operating wavelength, as well as good environmental stability, remains a challenge in this field. Both the fundamental and technological aspects of this research will be immensely enriched next year with the acquisition of a tunable source of high-power mid-IR femtosecond pulses with the aid of a RIEF grant. (A. Samoc, M. Samoc, B. Luther-Davies)

Nonlinear Properties of Organometallic Compounds

We have continued investigations of NLO properties of organometallic compounds in collaboration with the group of Dr M.G. Humphrey of the Chemistry Department in the Faculty of Science. A highlight of this year's research has been the



Doped optical fibre fluoresces under UV light

determination of nonlinear optical properties of a family of organometallic dendrimers: compounds with finely crafted spatial structures and with very strong nonlinear absorption properties. The effects of substitution and the resulting changes of the multipolar electronic structure on the nonlinear optical properties have been studied. (M. Samoc, B. Luther-Davies, M.G. Humphrey [Chemistry, The Faculties])

Development of Plastic Optical Fibres for Voltage Sensing Applications

We have been involved via the Australian Photonics CRC in a project sponsored by ABB and Transgrid to make plastic optical fibres as distributed voltage sensors for the power industry. The fibres rely on a novel mechanical alignment process acting on a specific structure of an electro-optic molecule in the fibre to create a sensitivity to voltage. The work this year was centred on obtaining single-mode optical fibres from a polymethacrylate material containing a specially designed electro-optically-active polymeric dopant in the fibre core. This research involved a diverse range of topics, from quantum mechanical calculations, through chemical synthesis in the two-stage preparation of fibre preforms, drawing of plastic fibres and to measurements of linear and nonlinear optical properties of the fabricated materials, and of optical fibres made from them. (B. Luther-Davies, A. Samoc, M. Samoc, R.M. Krolkowska, C. McLeod, T. Martin, J. Bottega, I. McRae)

Nonlinear Optical Effects at Gallium/silica Interface

The reflectivity of a gallium-silica interface held close to, but below, the gallium melting point of 29.8°C can be changed significantly (> 40%) by light over a very broad spectral range 400–1600 nm. The effect has been attributed to a surface-assisted phase transition from the stable α -gallium phase to a phase of metallic nature. We have investigated the nonlinear switching phenomena occurring at the interface between a thin film of gallium and a silica substrate. In collaboration with Dr N. Zheludev of the University of Southampton we are studying these effects on samples obtained at the Laser Physics Centre using pulsed laser ablation. The preliminary results indicate that gallium mirrors can show relatively fast (2 picosecond risetime and nanosecond relaxation time) switching for short laser pulses. (B. Luther-Davies, A.V. Rode, M. Samoc, N. Zheludev [U. Southampton])

Semiconductor Nonlinear Optics and Applications

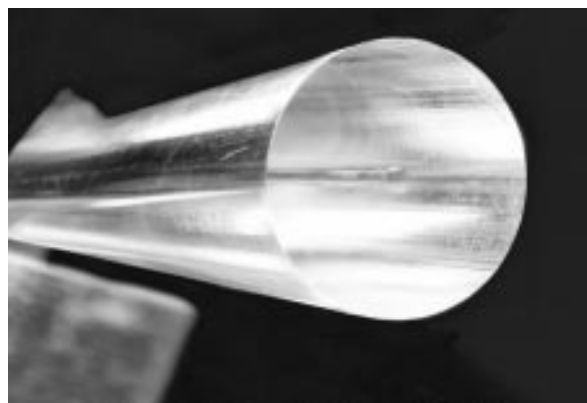
We have demonstrated for the first time that ion-implantation can be used to generate semiconductor optical materials with ultra-fast response (10^{-13} - 10^{-12} s) and well-preserved absorption modulation. The outcome of the study can serve as a guideline for ion-implantation in GaAs devices for applications such as ultra-fast all-optical switching and laser mode-locking using semiconductor saturable absorber mirrors (SESAMs). Work has begun to investigate beryllium or zinc doping of ion-implanted GaAs as a promising method to further increase the nonlinear modulation of implanted GaAs devices. We are also currently working on device design (SESAMs, all-optical switches and wavelength converters) incorporating quantum well structures of InGaAs/InP and other compounds suitable to extend passive modulator applications towards the communications wavelengths (i.e. 1.3 μm and 1.55 μm). The work involves collaboration

with both the Department of Electronic Materials Engineering and ETH Zurich. (M. Lederer, B. Luther-Davies; H. Tan, C. Jagadish [EME]; M. Haiml, U. Siegner, U. Keller [ETH Zurich])

A picosecond SESAM mode-locked Nd:YVO₄ laser has been developed which provides variable output pulse duration through a simple and user friendly "on-the-fly" adjustment. A very low repetition rate (7MHz), SESAM mode-locked high power diode pumped laser is currently under development for use in ultra-fast laser ablation experiments. We have also continued with the design of an oscillator-amplifier combination for the picosecond satellite laser ranging systems for Electro Optic Systems Pty Ltd. A novel and efficient thermal management scheme for diode side-pumped high power lasers and amplifiers has been developed. Incorporated in a laser amplifier the scheme was shown to result in superior thermal management especially for laser crystals with poor thermal conductivity and strong pump absorption such as Nd:YVO₄. (M. Lederer, V. Kolev, B. Luther-Davies)

Photonic Materials and Devices

We have continued to work on 2 × 2 thermo-optic space switches created by the laser writing of single mode channel waveguide devices in a photosensitized form of poly-methylmethacrylate (PMMA). In particular, we have concentrated on a new class of switching device, the mode evolution or digital directional coupler (DDC), in which adiabatic refractive index tapers are created along the guide length, by continuously varying the laser scanning speed in a smooth, precise manner. Since the writing system is under direct software control, a large range of taper functions is accessible, resulting in high-performance mode evolution couplers with crosstalk levels better than -30 dB. Working from this optimized passive device design, it has been demonstrated that complete switching can be achieved in digital directional couplers through the thermo-optic effect. Since the



Close-up of the end of a fibre blank prior to drawing, clearly showing the yellow doped core

device operating principle is based on the adiabatic evolution of a single local normal mode along the device length, DDCs display such desirable characteristics as wavelength independent and polarization insensitive operation. These features make them well suited to wavelength division multiplexed telecommunications systems.

In collaboration with researchers from the Centre of Electronics and Microelectronics, University of Montpellier, an Organically Modified Silicate (ORMOSIL) exhibiting low loss at telecommunications wavelengths and a much-improved thermal stability compared to PMMA has been investigated. The laser writing process has been equally successful in this material system, resulting in the demonstration of many types of guided wave devices. In particular, multimode interference (MMI) splitter-based arrayed waveguide gratings with a wavelength selectivity of 2.0 nm have been routinely produced, and devices exhibiting 0.8 nm selectivity are under development.



Members of the photonic materials group

Work on new waveguide materials is proceeding through collaboration with Professor Byeong-Soo Bae from KAIST in Korea to develop photosensitive silica-zirconia ORMOSILs suitable for use with our laser direct write technology. In addition, collaboration with Dr Graham Atkins, University of Sydney, several new photosensitive sol-gel material systems have been developed. Preliminary investigations of laser written waveguides formed in these films have given excellent results. (R. Charters, A. Samoc, M. Samoc, B. Luther-Davies; G. Atkins [U. Sydney]; B. Bae, O. Park [KAIST, Korea])

Soliton Physics

Experiments on spatial solitons in photorefractive media are carried out within the Laser Physics Centre, whilst theoretical analyses of the observed phenomena involve close collaboration with members of the Optical Sciences Centre. This year the major interest has been in a new class of partially coherent spatial solitons that can have variable shape. These exist in media with Kerr-like response when a beam consisting of a superposition of mutually incoherent beams is present in the medium. These solitons undergo shape transformation during collisions. The phenomenon has been observed experimentally in photorefractive media that, although deviating from Kerr-like behaviour, can mimic the Kerr response at least for short propagation distances. (W. Krolikowski; N. Akmediev, A. Ankiewicz, A. Snyder [OSC])

Pulsed Laser Deposition of Novel Materials

We continue to develop our patented ultra-fast pulsed laser deposition (UFPLD) process for the creation of new materials including high quality thin films. We have upgraded our laser facilities to better approach the optimum for UFPLD. The upgraded laser generates trains of 25 – 35 laser pulses of 60 ps

pulse width, at repetition rates from 2 to 20 kHz. Up to 45 W average power was available after amplification providing up to 5×10^{11} W/cm² on the target surface. Conversion of the laser beam into second harmonic (532 nm) light has allowed us to use UFPLD with a variety of dielectric materials with high absorption at this laser frequency. (A.V. Rode, B. Luther-Davies)

Cluster-assembled Carbon Nanofoam

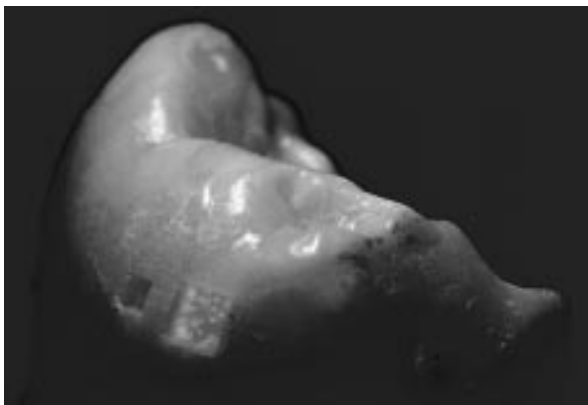
A new fractal amorphous carbon nanofoam with a large fraction of tetrahedrally-bonded atoms was produced by UFPLD. The efficient evaporation of carbon, which is beyond reach with other evaporation methods, resulted in a diffusion-limited aggregation of carbon atoms into clusters. The resistivity, measured in a collaboration with Dr R. Elliman EME, of $(1 - 3) \times 10^9$ Ohm-cm at room temperature and $(1 - 10) \times 10^{11}$ Ohm-cm at 80 K, is comparable with the RF-sputtered amorphous diamond-like carbon (DLC) film, while the density of the carbon foam is about 2 orders of magnitude lower than that of DLC. The current-voltage (I-V) characteristics of the foam at various temperatures from 85–130 K are nonlinear and demonstrate a voltage-dependent resistivity. The differential resistivity is approximately 10 times higher in the low-voltage region ($< \pm 30$ V) than in the high voltage region ($\sim \pm 100$ V).

Structural analysis of the foam performed using Transmission Electron Microscopy, X-ray scattering (in collaboration with Professor S. Hyde, AM) and electron energy-loss (in collaboration with Professor D. MacKenzie, University of Sydney) revealed that the foam has the following peculiar features that have not been observed before:

- The ablated carbon clusters which are ~6 nm in diameter, have a novel structure with well-defined structural units with a characteristic length of 5.6 ± 0.4 Å. The data indicate that the



Bronwen Taylor and Dr Andrei Rodé with the high power laser ablation equipment



The pulsed laser group continue to investigate a variety of new applications of femtosecond laser pulses, shown here: laser dentistry, note the accurately milled square in the human tooth and the purple plumes of plasma from the laser hits

structure is likely to be a graphite polymorph, generically called "schwarzites", which can be accomplished by warping of graphitic carbon sheets onto a random, isotropic hyperbolic sheet.

- In the larger micron-length scale the cluster-assembled carbon foam demonstrates a fractal ordering with the estimated fractal dimension of 2.4.
- The measured high sp^3 -fraction at the edges of the foam and at the edges of the clusters are a clear indication in favour of the proposal, based on high resistivity of the foam, that the sp^3 -bonding atoms are located mostly at the surface of the clusters, and that the connections between the clusters are due to sp^3 -bondings.

All these unusual features of this novel form of carbon, together with an extremely low density of 2–20 mg/cm³ and rather high surface area of 300–400 m²/g, are not only of particular academic interest, but also promise important applications, such as hydrogen supercapacitors. (A.V. Rode; E.G. Gamaly, S.T. Hyde [AM]; B. Luther-Davies; R.G. Elliman [EME]; A.S. Kheifets [AMPL]; D.R. MacKenzie and S. Balcock [U. Sydney])

Acceleration of Ions in the Skin-effect Laser-target Interaction Regime

Ionisation of the laser-ablated vapours with lasers producing ns and ps duration pulses at various wavelengths has been studied in order to understand the mechanisms of the vapour-plasma transition. It has been established that there are several regimes characterising the laser-target interaction that depend on laser intensity, wavelength, and pulse duration. The range of laser intensities for optimal laser evaporation is determined by the condition of transparent vapours. The intensity range is upper-limited by the opaque plasma formation due to vapour optical breakdown.

The results are illustrated on laser evaporation of graphite with Nd:YAG laser (1.064 μ m), KrF laser (248 nm) and ArF laser (193 nm). For the UV-laser wavelength the regime of skin-effect interaction was proposed as the mechanism of ion acceleration, and the range of validity of the skin-effect mode was established. For UV lasers the interaction has a bi-modal nature: the interaction may proceed initially in the skin-effect regime

resulting in a few high-energy ions, until the hydrodynamic expansion begins at the later stage. The skin-effect interaction at the initial stage of the UV laser pulse gives, to our knowledge, the first explanation for acceleration of ions up to ~ 100 eV at low laser intensities of 10^8 - 10^9 W/cm², and ns-range pulse duration. (E.G. Gamaly [AM]; A.V. Rode, B. Luther-Davies)

Formation of Single-wall Nanotubes by High-repetition-rate and Continuous-wave Laser Ablation

We performed a theoretical analysis of the continuous wave CO₂ laser and the high-repetition-rate Nd:YAG vaporization processes that leads to the formation of single-wall nanotubes (SWNTs). After a simulation of the experimental details we model the absorption mechanism, evaporation rate, collision rates, scanning rates, and then focus on the gas and heat diffusion processes. With these basic considerations we can qualitatively explain the experimental results under static and dynamic conditions, including the influence of the buffer gas, and the gas pressure on the formation of SWNTs. We also found that the heat transport, kinetic and diffusion processes explain seemingly different formation conditions in qualitative and semi-quantitative agreement with the experimental results. A self-consistent scenario for nanotube formation in the gas phase has been identified and suggests future experiments for checking the formation mechanism. (E.G. Gamaly [AM]; A.V. Rode)

Solid State Laser Spectroscopy

There are two major research efforts within the Solid State Laser Spectroscopy Group. One is directed towards optical processing and computing. This is an experimental project involving a novel laser facility developed by the Group, which comprises a special laser with very good frequency stability. New measurements achieved during the year include demonstration of time domain optical processing and the first demonstration of multi-pulse NMR techniques in the all-optical regime. The second research area involves studying nonlinear absorption of multiple electromagnetic fields by quantum systems. All measurements performed this year involved a particular colour centre in diamond that has proven to be a model system. The optical pumping cycle in the colour centre is not well understood, but significant progress in quantitative fitting of spectra has been made this year in phenomenological modelling of the optical spin polarization process. The most spectacular use of the diamond centre, however, continues to be the observation of many fundamental nonlinear quantum optics effects that have not previously been seen experimentally.

Optical Computing and Processing

Many optical transitions of rare earth ions in solids have long dephasing times of the order of milliseconds and may be of value for coherent optical processing. With this in mind, over a period of many years we have developed a special optical system, including a laser with a stability at least matching the transition line width, and optical phase sensitive detection. With these two attributes we now have capabilities beyond that of any other laboratory working in this area.

The rare earth materials used are known to have potential as optical storage media. Optical pulses occurring within the dephasing time coherently interfere, and as a consequence the pulse sequence is stored in the material via spectral holeburning

as a long-lived frequency grating. In other laboratories the information can only be stored once. However, because of the superior phase stability of our laser we can change or reverse the stored information. Phase sensitive detection also enables us to store the information in two orthogonal phases immediately doubling the storage capacity of the material. More importantly we have shown that the orthogonal phases can be used to avoid crosstalk between stored information, a problem that previously made the technique invalid when striving for better signal-to-noise ratio at higher light levels. We have, therefore, been able to show extra capabilities of time domain optical memories and demonstrated the coherent optical processing.

In a further demonstration of the capability of the laser system we have used it to burn a narrow spectral hole over a period of one second in a thin (5 mm) section of highly absorbing (80%) material. Subsequent measurement of the absorption and dispersion associated with this narrow transparency determines that the group velocity of light over the narrow bandwidth is 60 m/s, which is the second slowest on record. The slow group velocity implies a high nonlinearity, and it is this nonlinearity which is employed in the above time-domain optical processing where larger bandwidths are achieved by burning over a wider range of frequencies.

The experimental system has also attraction for more sophisticated spectroscopic investigations of the rare earth transitions themselves. For example, implementation of NMR-like pulse sequences for optical spectroscopy has been an important goal of many groups in Physics and Chemistry for several decades, and we have been able to demonstrate these for the first time. The essential component of the success of this work is the preparation of a narrow spectral feature. This is generated by the application of two overlapped pulses of opposite optical phase. The result is a sharp line of width 25 kHz in a wide spectral hole. Low optical absorption features within this prepared spectral feature are eliminated by the application of a train of π pulses. The consequence of this approach is to enable use of a gated low power frequency stabilized cw laser for successful multi-pulse measurement of the re-formed (image echo) pulse train to obtain dephasing times. The results allow investigation of ion-ion interactions and in the present case have highlighted the effects of the instantaneous spectral diffusion ion dynamics. More importantly the experiments demonstrate that sophisticated NMR-like pulse sequences for isolating specific interactions can be applied to the study of rare earth optical systems. (*N. Manson, M. Sellars, G. Pryde*)

Diamond Colour Centre Studies

Natural type 2b diamonds contain single substitutional nitrogen atoms. If such a diamond is subjected to radiation damage and then annealed, the carbon vacancies created by the radiation will be trapped by the nitrogen impurities to form a nitrogen-vacancy centre. This centre has been the subject of our studies. There is a ground state spin triplet, and an excited-state spin triplet which gives rise to absorption in the red. The unusual aspect of this centre is that when light is absorbed the ground state becomes spin polarized. This is now considered to arise through a spin selective cross over from the triplet system to a singlet and back to the triplet. The longest wavelength where spin polarization occurs is with excitation at the sharp zero-phonon line, 638 nm. Various holeburning and coherent (Raman heterodyne)

measurements can be made at this wavelength. These holeburning and coherent measurements have been observed to vary with magnetic field strength and alignment particularly about an avoided ground state level crossing. Quantitative phenomenological modelling of the spin polarization process this year has highlighted the characteristics and dominance of this mechanism in determining the holeburning and coherence signals. This has enabled us to obtain a better understanding of the centre properties, but the singlet electronic states involved in the spin crossover remains to be established.

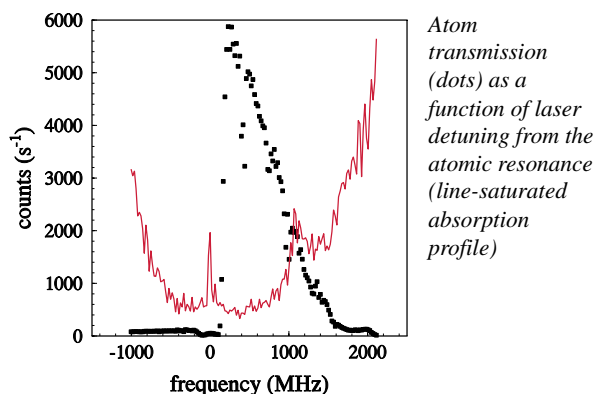
The Raman heterodyne magnetic resonance signals associated with the nitrogen-vacancy centre is also used in an entirely different study. The signals are used to study the effects of a strong near-resonance electromagnetic field on an absorbing transition where we capitalize on the exceptional sensitivity of our detection technique. Normally a strong driving field will saturate the system, and measurements of absorption are then too weak to detect. However, in this case we are easily able to detect optical signals in the presence of strong radiofrequency driving fields and we have used this capability for various situations. This year our work centred around experiments where there was more than one saturating field. We concluded a study where there were two driving fields, and also showed that it was possible to get informative data using up to four driving fields. The experiments are in excellent agreement with calculations.

The most recent study involving the same colour centre in diamond illustrated the phenomenon of electromagnetic induced transparency. Here application of an electromagnetic field resonant with one transition can change the absorption of another transition. It is a topic of considerable current interest as it can enable lasing action to be achieved without inversion. Our interest is in the fundamentals of the phenomenon, and our system provides one of the clearest examples of this effect. We have been able to show further that the transparency feature can be split by applying a coherent perturbing field. Electromagnetic induced transparency normally only involves three energy levels and two fields. The transparency can then be split by applying a field at the third transition of such a three level system or by applying a field resonant with a transition between one of these levels and a third level. These effects are shown to have parallels with the Mollow effect and the Autler-Townes effect for driven systems probed by more conventional weak fields. We have experimental data of each of these cases that compare well with calculations of a model system. The calculations can also be extended beyond the range of parameters that can be accessed experimentally. (*N. Manson, J. Martin, C. Wei, E. Wilson*)

Spectroscopy

A wide range of other specialised optical spectroscopic techniques are employed to study materials. These include laser selective excitation and emission and we have recently completed a study of a potential microlaser material Er doped KLiF₅. This work was conducted in conjunction with Professor B. Henderson, Cambridge University, UK and Professor A. Silversmith, Hamilton College, NY, USA.

Together with Dr E. Krausz and Ms R. Purchase (both of the Research School of Chemistry) we have studied electric field and magnetic field effects of zinc phthalocyanine. The particular measurements done in our laboratories were high-resolution



spectral hole burning which complemented lower resolution holeburning and conventional spectroscopy investigations made in RSC. The studies established that there was a significant dipole induced in the plane of the molecule that was contrary to previous understanding that the only dipole was in the plane.

A holeburning study of rare earth triple chain soaps has also been concluded during the year. The rare earth ion acts as a probe of its local environment and in this study highlighted the glassy structures created by different methods of cooling the soaps. This work was in conjunction with Mr R. Corkery (AM) who obtained his doctorate during 1998.

Another holeburning study has been with Dr H. Reisen (Australian Defence Force Academy) and Dr V. Bursian (Ioffe Institute, St Petersburg). Together we have been investigating the holeburning process in cobalt doped strontium oxide. The dopant in this material substitutes for a host crystal ion but is displaced from the substitutional position. The orientation can be changed by optical excitation and it is considered that this reorientation may provide the basis for a memory device.

We have also been involved with electron spin resonance studies of Si nanocrystals in amorphous silica with Dr S. Choi (Kyung Hee U., South Korea) and Dr R. Elliman (EME). (*J. Martin, N. Manson, A. Smith, M. Sellars*)

Atom Manipulation

This year the bright metastable helium beam line has been used to extend experiments on atomic wave guiding, as well as being used to load experiments using the magneto-optic trap (see AMPL report). The beam line delivers over 10^{10} atoms/second in the helium 2^3S_1 excited state in an area of several square millimetres and with velocities of about a hundred metres/second in the longitudinal direction, and a few metres per second in the transverse direction.

Following the first demonstration of atomic wave guiding for metastable helium atoms in our experiments last year, we have extended these studies to include a range of different hollow fibre geometries and conditions. Using commercially available fused silica capillaries with both round and square cross-section holes ranging from 50 to 10 microns across (see figure 1), we have succeeded in transmitting up to 10,000 atoms/second through the capillaries by using laser light focused into the glass. The evanescent light field thus created on the inside of the fibre wall repels the atoms via the dipole force when the laser frequency is detuned above the atomic resonance frequency (see figure). Without the light field present, the transmitted flux is

reduced to around 100 atoms/second when the fibre is perfectly aligned with the atomic beam, and to zero when the capillary is slightly curved.

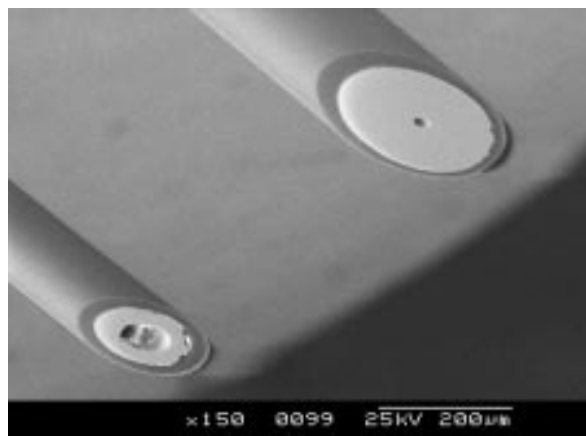
However, it was difficult to improve the transmission efficiency in the presence of laser light above a few percent. This is probably a result of multimode propagation of the laser through the uniform glass capillary, which results in interference on the inside walls of the fibre that allows atoms to strike the wall in the darker regions. To avoid this problem, a single mode fibre was developed that has a stepped refractive index profile around the hole. This fibre was manufactured using special techniques developed by the Optical Fibre Technology Centre in Sydney, part of the Photonics CRC. It is anticipated that the more uniform light field created in this unique hollow fibre will enable much more efficient transmission of the atoms for future experiments in atomic waveguiding. (*M. Colla, R. Dall, L. Robinson, J. Swansson, K.G.H. Baldwin; M.D. Hoogerland, S.J. Buckman [AMPL]*)

UV Laser Spectroscopy

Experiments continued this year on high resolution VUV cross-section measurements of the oxygen Schumann-Runge system near the dissociation limit near 175 nm. These experiments employ four wave difference frequency mixing of high power dye laser radiation in a nonlinear medium (xenon), which we have demonstrated in an international comparison of spectroscopic techniques to yield the most accurate available high resolution cross section measurements for these systems. Currently our best laser resolution is 0.06 cm^{-1} in the VUV, which is limited primarily by the bandwidth of the dye lasers employed.

A significant improvement in resolution can be achieved by moving to cw injection-seeded pulsed laser systems, which can yield Fourier transform limited laser bandwidths. Such a system employing a seeded dye laser amplifier system was employed in the collaboration between this laboratory and the US National Institute for Standards and Technology which measured the helium 1S-2S two-photon (at 120 nm) transition for the first time. However, even these experiments are limited by chirp induced in the dye pumping process.

We have embarked on a collaborative project with Professor Brian Orr at Macquarie University to develop an injection seeded solid state laser system that may yield improved bandwidth laser radiation for such high resolution spectroscopy studies. This



Electron micrograph of glass capillaries with 40 and 10 micron hole diameters

system uses a cw diode laser to injection-seed an Optical Parametric Oscillator (OPO) followed by an optical parametric amplifier (OPA) which uses periodically poled lithium niobate pumped by the second harmonic of a Nd:YAG laser. Following a successful RIEF proposal with Macquarie University for 1999, we have recently acquired the pump laser for this project and

are commencing development of the OPO/OPA system. Establishment of this new high-resolution source should significantly enhance the spectroscopic capabilities of this laboratory. (*K. Waring, K.G.H. Baldwin; B.R. Lewis, S.T. Gibson [AMPL]*)

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