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Centre for Atom Optics and Ultrafast Spectroscopy

Research Report 2004

CENTRE FOR
ATOM OPTICS
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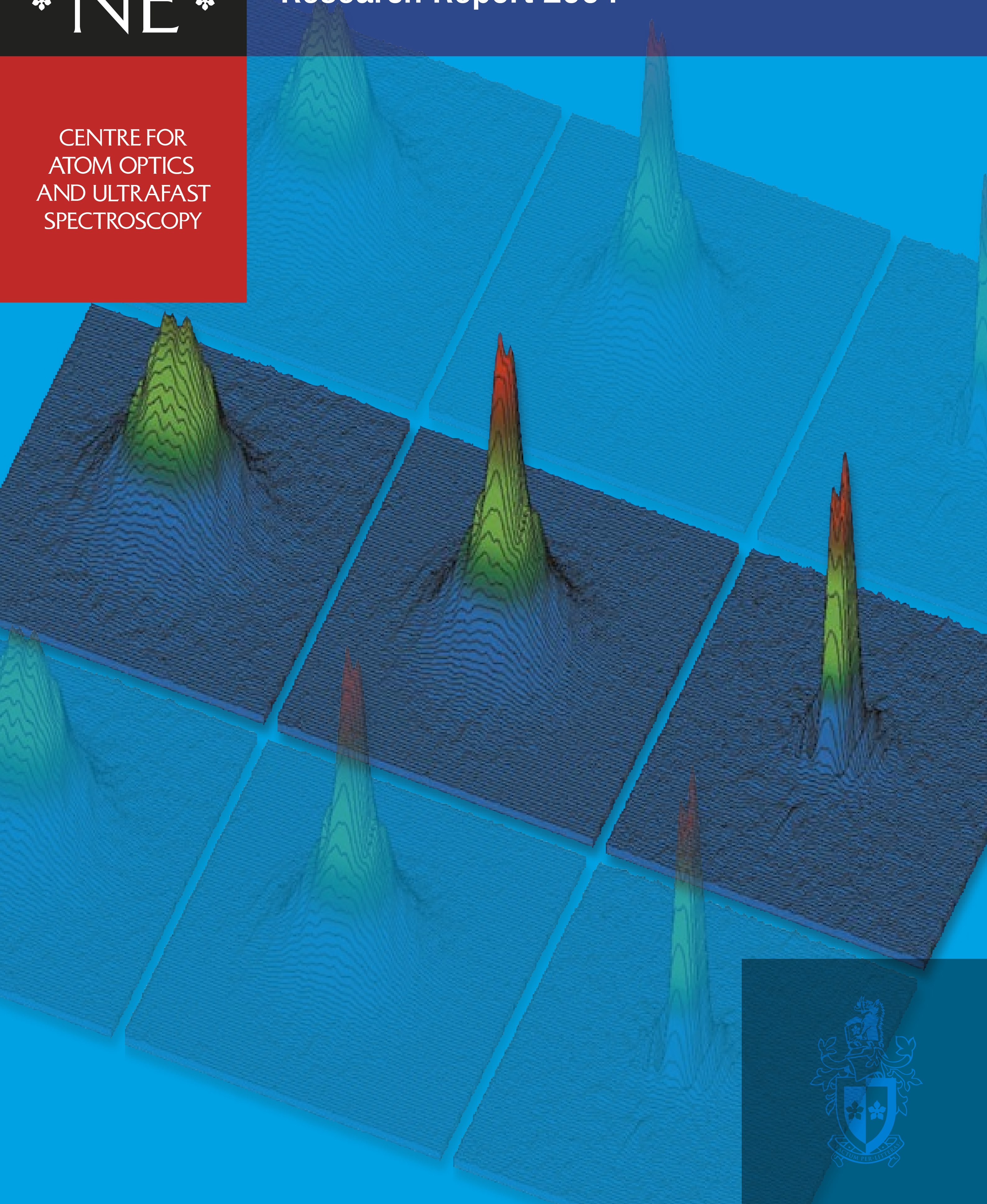
SPECTROSCOPY



CAOUS group, March 2005

Back: Bryan Dalton, Xiaoming Wen, Lap Van Dao, Heath Kitson, Saeed Ghanbari, Holger Wolff, Tim Mapperson, Veeravalli Gopisankararao, Jack Liang, Wayne Rowlands

Middle: Russell McLean, Alexander Akoulchine, Daniel White, David McDonald, Mark Kivinen, Jürgen Fuchs, Craig Lincoln, Martin Lowe, James Wang, Paul Stoddart, Shannon Whitlock

Front: Andrei Sidorov, Peter Hannaford, Grainne Duffy, Sharon Jesson, David Gough, Brenton Hall, My Thi Tra Do, Tien Kieu, Mandip Singh

Missing: Alex Mazzolini, David Booth, Peter Cadusch, Vladimir Dubaj, Falk Scharnberg

Front cover images:

Production of a Bose-Einstein condensate of rubidium atoms on an atom chip:

$T > T_{crit}$, $T \approx T_{crit}$, $T < T_{crit}$

(Details on pages 7, 8)

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FOREWORD

This is the second Research Report of the Centre for Atom Optics and Ultrafast Spectroscopy (CAOUS) and covers the period 2002-March 2005.

The Centre was opened in February 1999, by Nobel Laureate Professor Ahmed Zewail, as the Swinburne Centre for Ultrafast Laser Spectroscopy (SCULS). In February 2001 the Atom Optics Group at CSIRO in Clayton joined SCULS to form the Centre for Atom Optics and Ultrafast Spectroscopy. In January 2005 staff and students from the Swinburne Centre for Imaging and Applied Optics joined CAOUS to form an Applied Optics group. CAOUS currently has 17 research staff, 15 postgraduate students, an administration officer, and a mechanical workshop technician.

During the reporting period we welcomed a number of new staff members: Sharon Jesson from Edinburgh, Dr Bryan Dalton from the University of Queensland, Dr Barbara McKinnon from Monash University, Dr Alexander Akoulchine from the University of Melbourne, Dr James Wang from RMIT University, Dr David Lau from Sussex University, Dr Brenton Hall from Imperial College London, Dr Gráinne Duffy from the University of Otago NZ, as well as former staff of the Swinburne Centre for Imaging and Applied Optics: Drs Alex Mazzolini and Paul Stoddart and Professors Peter Cadusch and David Booth. We also welcomed a number of new postgraduate students: Shannon Whitlock, Xiaoming Wen, My Thi Tra Do, Saeed Ghanbari, David McDonald, Jürgen Fuchs, Holger Wolff, Mandip Singh, Veeravalli Gopisankararao, Vladimir Dubaj, Daniel White and Jack Liang.

The primary objective of CAOUS is to carry out fundamental and strategic research in the broad areas of Atom Optics, Ultrafast Spectroscopy, Quantum Information and Applied Optics. The Centre is currently structured around eight projects or groups, each with a Project Leader:

Integrated Atom Optics (Prof Andrei Sidorov)
Magnetic Mirror for Cold Atoms (Prof Russell McLean)
Magnetic Lattices (Prof Peter Hannaford)
Atomic Coherences (Dr Alexander Akulshin)
Ultracold Molecules (Dr Wayne Rowlands)
Ultrafast Spectroscopy (Prof Lap Van Dao)
Applied Optics (Dr Alex Mazzolini)
Theory Group (Prof Tien Kieu)

Reports on the activities of these projects are presented in subsequent sections. Recent research highlights include:

- Achievement in March 2005 of a Bose-Einstein condensate (BEC) on an ‘atom chip’, based on novel magnetic microstructures and current-carrying wires, for trapping, manipulating and transporting ultracold atoms and BECs on the surface of a substrate (Pages 6-8);
- Development of a new multidimensional femtosecond technique, based on spectrally resolved 2-colour 3-pulse photon echoes, for investigating ultrafast dynamical processes in complex systems, such as biomolecules, complex polymers, semiconductor materials and semiconductor quantum structures (Pages 12, 13);
- Development of a quantum algorithm based on quantum adiabatic computation that could extend the limit of classical computability and solve classically noncomputable problems such as the Turing halting problem in computer science (Page 15).

Research in CAOUS during the reporting period has led to 51 papers published in or submitted to peer-reviewed scientific journals, 26 papers in international conference proceedings, and 90 conference papers presented at 32 international and 7 national conferences and workshops. During this period CAOUS was successful in securing a number of competitive grants, including an ARC Centre of Excellence for Quantum-Atom Optics (ACQAO), together with the Australian National University and the University of Queensland; three ARC Discovery Grants; three ARC Infrastructure Grants; two Swinburne Research Development Grants; and a DEST Systemic Infrastructure Initiative Grant to establish a new Microfabrication Laboratory. In July 2003 CAOUS was honoured by co-hosting the prestigious Sixteenth International Conference on Laser Spectroscopy in Palm Cove, Queensland.

I would like to thank the staff and students of CAOUS for their contributions to the research described in this report, Swinburne University for substantial Strategic Initiative funding which allowed CAOUS to get up and running so quickly and the Australian Research Council for financial support. We also thank the present Vice-Chancellor Professor Ian Young, the former Vice-Chancellor Professor Iain Wallace, the Pro Vice-Chancellor (Research and Industry Liaison) Professor Kerry Pratt, the Pro Vice-Chancellor (Academic) Professor David Booth, the Deputy Vice-Chancellor Professor Dale Murphy, and the Dean of the Faculty of Engineering and Industrial Sciences Professor Tom Spurling for their continued support and encouragement.

Peter Hannaford, Director
March, 2005

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Prof Geoffrey Opat (Adjunct Professor, 2001-2002)
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How to find us
The Centre for Atom Optics and Ultrafast Spectroscopy is located in the Swinburne Optics and Laser Laboratories (SOLL), on the ground floor of the Applied Sciences building, at Swinburne University's Hawthorn Campus, 7 kms from the centre of Melbourne (Melways Directory, map 45, grid reference E-10). The entrance to CAOUS is in Serpells Lane, off Burwood Road, and next to Glenferrie Station, which is well served by trains on the Lilydale, Belgrave and Alamein lines. For parking we advise a nearby multi-storey car park in Wakefield Street, off Glenferrie Road.

Laser light may now be used to cool a cloud of atoms to within a few microkelvin of absolute zero. At such low temperatures the atoms behave as waves, and this has opened up a new branch of optics – 'Atom Optics' – in which beams of slowly moving atoms may be reflected, guided, diffracted and made to interfere in much the same way as beams of light. Interferometers based on beams of slowly moving ultracold atoms can be highly sensitive to quantities such as gravity fields, gravity gradients, accelerations and rotations. Further cooling of the atoms using evaporative cooling techniques, together with confinement of the atoms in a trap so that the atomic matter waves overlap, may allow all the atoms in the cloud to occupy the same macroscopic quantum state – a Bose-Einstein condensate. In this way the atoms may be cooled to within a few nanokelvin of absolute zero.

Magnetic Mirror for Cold Atoms

Holger Wolff, David Gough, James Wang, Andrei Sidorov, Peter Hannaford, Russell McLean

This project, which was initiated in collaboration with the late Geoffrey Opat, aims to develop high-quality atomic optical elements, including mirrors and beamsplitters, based on the interaction of the magnetic dipole moment of an atom with the exponentially decaying magnetic field above a periodic array of magnets of alternating polarity [1, 2]. The periodic magnetic structure may be turned into a diffraction grating (or a coherent beamsplitter), for example, by applying a small bias magnetic field normal to the structure surface to produce a spatial magnetic grating [1] or by applying an oscillating orthogonal magnetic field to create a temporal magnetic grating for cold atoms [3].

In order to produce a 'hard' magnetic mirror with short decay length or a magnetic diffraction grating for cold atoms, the periodicity of the magnetic structure needs to be very small, preferably of the order of a micron. Alternating magnetic arrays with such small periods are very difficult to fabricate, but recently we have developed a promising method for producing micron-period magnetic mirrors based on periodically *grooved* perpendicularly magnetized microstructures, above which the magnetic field also decays exponentially [4] (see Fig. 1).

The grooved magnetic microstructures were prepared [5] using the fabrication and sample characterization facilities in the newly established Swinburne Microfabrication Laboratory (page 11). An 0.5 μm thick TbGdFeCo magneto-optical film with large perpendicular magnetic anisotropy, consisting of alternating 150 nm layers of TbGdFeCo and nonmagnetic chromium, was deposited by magnetron sputtering onto a grooved silicon substrate with period 1.5 μm and groove depth 1 μm. Measurements using a SQUID magnetometer and a magnetic/atomic force microscope indicate that the magnetic films have magnetic and topological properties (remanent magnetisation 3.8 kG, coercivity 3 kOe, and excellent magnetic homogeneity), which are well suited for use in magnetic atom optics, while the grooved silicon substrate has excellent surface smoothness and flatness.

Magnetic force microscopy measurements indicate that the magnetic field above the periodic grooved surface decays exponentially at a rate consistent with the 1.5 μm period of the grooved structure. We are currently testing the specularity of the reflection of laser-cooled Rb atoms dropped towards the magnetic microstructure.

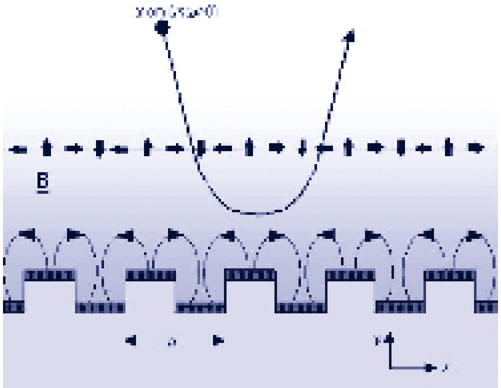

Figure 1. Magnetic field distribution above a periodic grooved microstructure coated with perpendicularly magnetized film.

1. G.I. Opat, S.J. Wark and A. Cimmino, *Appl. Phys.* **B 54**, 396 (1992).
2. A.I. Sidorov, R.J. McLean, G.I. Opat, W.J. Rowlands, D.C. Lau, J.E. Murphy, M. Walkiewicz and P. Hannaford, *Quantum Semisclass. Phys.* **8**, 713 (1996).
3. G.I. Opat *et al., J. Opt. B* **1**, 415 (1999).
4. A.I. Sidorov, R.J. McLean, F. Scharnberg, D.S. Gough, T.J. Davis, B.A. Sexton, G.I. Opat and P. Hannaford, *Acta Physica Polonica B* **33**, 2137 (2002).
5. J.Y. Wang, S. Whitlock, F. Scharnberg, D.S. Gough, A.I. Sidorov, R.J. McLean and P. Hannaford, *J. Phys. D* (submitted).

Bose-Einstein Condensation on an Atom Chip

ARC Centre of Excellence for Quantum-Atom Optics (ACQAO) Project

Brenton Hall, Shannon Whitlock, Falk Scharnberg, James Wang, Russell McLean, Peter Hannaford, Andrei Sidorov

Advances in atom optics and microfabrication techniques have recently led to the development of miniature surface-based current-carrying optical elements for manipulating ultracold atoms and Bose-Einstein condensates (BECs), allowing the construction of networks of microtraps, waveguides, beamsplitters and couplers on the surface of a substrate – an 'atom chip' [1]. Miniaturisation and scaling down the dimensions of the atom traps greatly simplifies the production of a BEC: it allows the use of moderate electric currents and provides large magnetic field gradients and curvatures and hence very tight confinement of the atomic matter waves, thereby increasing the elastic collision rate and allowing condensates to be produced in just a few seconds.

The aim of this project is to produce a BEC of ^{87}Rb atoms on a *permanent* magnetic film chip using technology developed in-house for the fabrication of perpendicularly magnetised grooved microstructures (page 6) [2]. Our studies include the construction of permanent magnetic waveguides that will allow the manipulation and transport of coherent matter waves across the surface of the chip. A long term aim is to construct an atom interferometer on a chip as a gravity sensor.

The Swinburne atom chip (Fig. 2) uses a unique two-layered structure consisting of a permanent perpendicularly magnetised magnetic film and current-carrying wires that allows one to combine the stability and reliability of permanent magnetic fields with the versatility of time-variable magnetic fields provided by the conductors. The bottom layer is made of 1 mm wide wires cut in a silver foil using a computer controlled milling machine. The milled pattern of the wires allows the creation of U-shaped (quadrupole), Z-shaped or H-shaped (Ioffe-Pritchard) magnetic microtraps. The top layer of the chip is formed by two glass slides coated with a gold film. One slide has a perpendicularly magnetised magnetic film (TbGdFeCo) with a thickness of 1 μm and is used for the construction of a tightly confining permanent magnetic trap and waveguide for ultracold atoms.

The atom chip is installed in an ultra-high vacuum chamber (Fig. 3) which operates at a background pressure of around 10^{-11} Torr. During the loading stage the rubidium atoms are trapped in a reflection magneto-optical trap (MOT) from a vapour provided by a rubidium dispenser. The cold rubidium cloud containing up to 5×10^8 atoms is positioned about 5 mm beneath the surface of the chip. During the next stage the atoms are transferred to a compressed MOT formed by a U-shaped current, the magnetic field gradient is increased to 60 G/cm, and the cold cloud is moved to within 2 mm of the surface. The trapping beams and the current through the wire are switched off and the atoms are optically pumped into the $F = 2$, $m_F = +2$ low magnetic field seeking state. A current of 22 A through a Z-shaped wire is switched on and about 5×10^7 atoms are magnetically trapped in a microtrap located about 1 mm beneath the surface. The current is ramped up to 28 A and the bias magnetic field increased to 55 G. The cold cloud is moved to within 450 μm of the surface and compressed in the trap with parameters $\nu_{radial} = 600$ Hz and $\nu_{axial} = 20$ Hz. The lifetime of the trapped atoms is about 25 s and is affected by proximity to the surface. The atoms are evaporatively cooled in 10 s using an oscillating magnetic field with a logarithmic sweep of RF frequency in the range 15 – 0.75 MHz. A bimodal distribution of atoms in a time-of-flight expansion corresponding to the onset of BEC is observed with a final RF frequency of 765 kHz (Fig. 4(b)). A pure condensate of around 150,000 atoms at a temperature of around 300 nK appears with a final RF frequency of 755 kHz (Fig. 4 (c)).

The next step is to transfer the condensate to the permanent magnetic trap formed by the edge of the TbGdFeCo magnetic film with current-carrying end wires and then to guide the condensate along the waveguide formed by the edge of the magnetic film without the end wires.

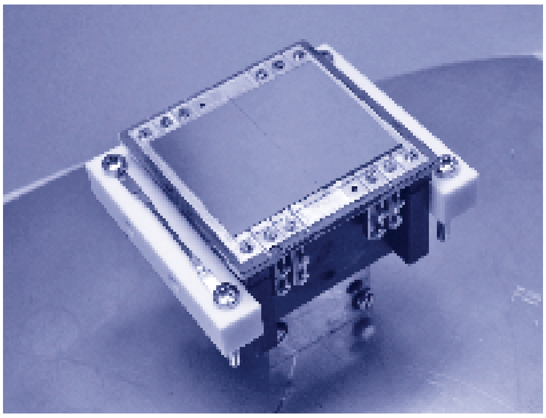

Figure 2. The Swinburne atom chip. The bottom layer is made of 1 mm wide wires milled in a silver foil, allowing the creation of U-, Z- or H-shaped magnetic microtraps. The top layer is formed by two glass slides coated with a gold film. One slide has a perpendicularly magnetised TbGdFeCo film which allows construction of a tightly confining permanent magnetic trap and waveguide for ultracold atoms

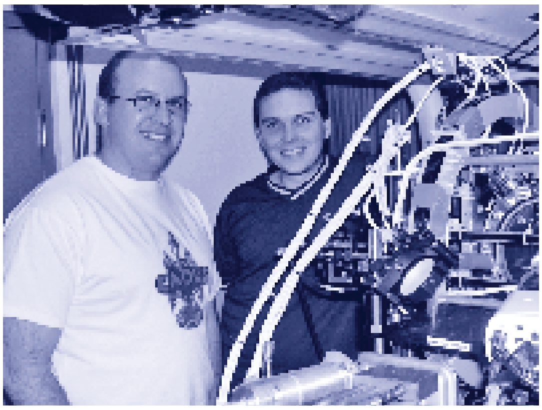

Figure 3. Brenton Hall and Shannon Whitlock with the BEC apparatus.

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2. J. Y. Wang, S. Whitlock, F. Scharnberg, D. S. Gough, A. I. Sidorov, R. J. McLean and P. Hannaford, *J. Phys. D* (submitted).

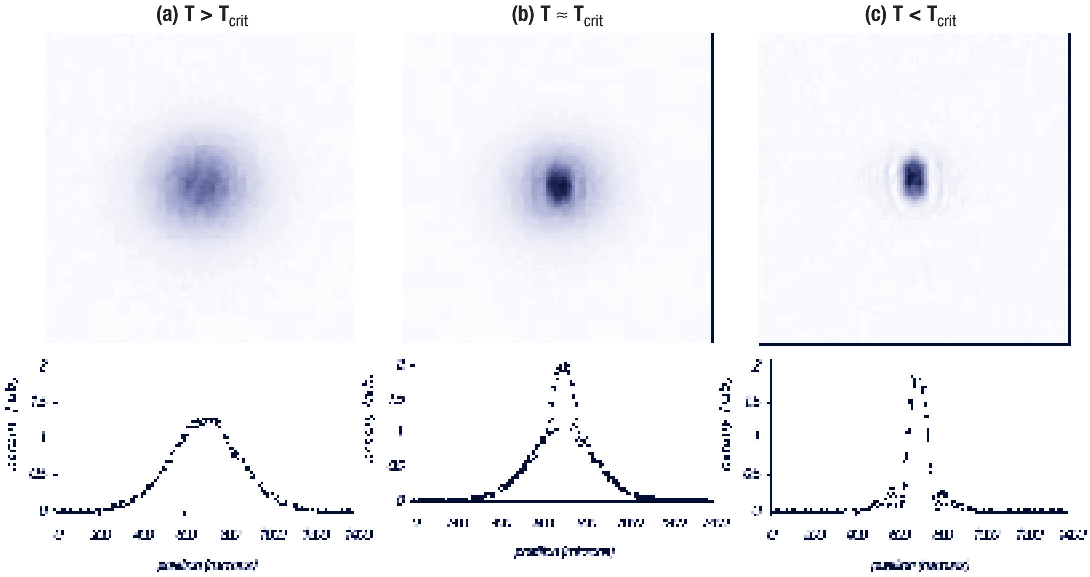

Figure 4. *Cloud of ultracold ^{87}Rb atoms observed in a time-of-flight expansion: (a) $T > T_{crit}$: purely thermal cloud, (b) $T \approx T_{crit}$: bimodal distribution of BEC plus thermal cloud, and (c) $T < T_{crit}$: pure condensate of around 150,000 atoms at about 300 nK.*

Double-Well Atom Interferometry

ARC Centre of Excellence for Quantum-Atom Optics (ACQAO) Project

Falk Scharnberg, Shannon Whitlock, Bryan Dalton, Tien Kieu, Andrei Sidorov

We consider a particular type of atom interferometer which involves the splitting of a single-well potential into two potential wells, phase evolution of the quantum states due to an applied spatially asymmetric potential, and finally recombination into the original potential well. The phase evolution stage leads to transitions between the nearly degenerate ground and first excited vibrational states of the confining potential, and the probability of finding the atom in the excited state provides a measure of the effect of the spatially asymmetric potential. Such an atom interferometer can be considered to be a Mach-Zehnder interferometer, where the quantum states localised in two separate potential wells represent different optical paths.

We have developed a novel theoretical treatment of a single-atom double-well interferometer that takes account of the presence of asymmetry during the splitting and recombination stages. An analytical model utilises a two-mode approximation and leads to a Bloch vector model. The formal similarity of the atom interferometer system to a driven two-level atom enables one to introduce atomic spin operators and to write the dynamical equations as Bloch equations. This approach allows the use of the Bloch sphere for a clear interpretation of the dynamical processes. In this approximation it is possible to obtain an analytical solution to the problem of the interferometric process under certain conditions. The outcomes of the Bloch vector model are compared with the results of numerical simulations of splitting and recombination carried out by solving the time-dependent Schrödinger equation using the XMDS (eXtensible Multi-Dimensional Simulations) software package developed by the ACQAO theory group at the University of Queensland. By studying time-dependent splitting processes we are able to optimise the sensitivity of the interferometer and its tolerance to external perturbations.

As an extension of the single-atom case to a multiple-particle Bose-Einstein condensate (BEC) situation, a theory of double-well interferometry using the two-mode approximation has been developed. This results in self-consistent equations coupling the two condensate wave functions and the amplitudes of Fock states describing possible fragmented condensates. In a Bloch sphere variant of the theory, the BEC behaves as a giant spin system.

Double-well atom interferometers for both the single-atom and the multiple-atom BEC cases are well suited to implementation on atom chips, where micron-scale dimensions of atom optical elements allow precise control over the splitting and recombining processes. An on-chip double-well atom interferometer can be integrated with a source of atoms in a ground state, e.g., a Bose-Einstein condensate, and used for sensitive measurements of gravitational fields. Double-well atom interferometers can also be used for studies of intrinsically quantum processes, such as tunnelling between potential wells or the adiabatic evolution of a quantum system.

Magnetic Lattices for Ultracold Atoms

Alexander Akulshin, Mandip Singh, Andrei Sidorov, Russell McLean, Saeed Ghanbari, Tien Kieu, Peter Hannaford

We are setting up an experiment to investigate the potential of 'magnetic lattices', comprising periodic arrays of permanent magnetic microtraps, for trapping and manipulating clouds of ultracold atoms and Bose-Einstein condensates (BECs). The magnetic lattices are fabricated using magnetic microstructure technology developed in-house for the grooved, perpendicularly magnetised TbGdFeCo magnetic mirror (page 6) [1].

Permanent magnetic lattices have a number of potential advantages over currently used 'optical lattices' generated by optical standing waves, including:

- They are permanent and constant from day to day, making them attractive for atom optics devices.
- They do not require a (high intensity) laser beam or laser beam alignment.
- They can be fabricated with large trap potentials (tight confinement) and precise spatial control.
- They are highly stable and have low technical noise.
- They can be fabricated with a wide range of periods down to about a micron.
- They can be fabricated with complex potentials, e.g., with varying distances between lattice sites within the same lattice.

A 1D magnetic lattice may be easily constructed, for example, by using a magnetic structure similar to the perpendicularly magnetized grooved microstructure shown in Fig. 1 together with an externally applied bias magnetic field. Model calculations [2] have shown that it is possible to construct a 2D magnetic lattice with Ioffe-Pritchard type microtraps (i.e., with non-zero magnetic minima to eliminate atom losses due to spin flips) using specific configurations with externally applied bias magnetic fields and to vary the lattice barrier height by varying the bias fields. An example of a permanent magnetic microstructure that produces such a magnetic lattice is shown in Fig. 5 [2]. By varying the barrier height between the magnetic microtraps and using a magnetic lattice with small period (~1 μm), it may be possible to perform quantum tunnelling experiments, including the BEC superfluid-Mott insulator quantum phase transition in a magnetic lattice, as has been performed using optical lattices [3]. Implementation of the BEC-Mott insulator phase transition would allow the preparation of a magnetic lattice with just one atom on each lattice site.

Magnetic lattices and the BEC-Mott insulator transition have important implications in quantum information processing.

1. J. Y. Wang, S. Whitlock, F. Scharnberg, D. S. Gough, A. I. Sidorov, R. J. McLean and P. Hannaford, *J. Phys. D* (submitted).
2. S. Ghanbari, CAOUS Internal Report (Jan 2005).
3. M. Greiner, O. Mandel, T. Esslinger, T. Hänsch and I. Bloch, *Nature* **415**, 39 (2002).

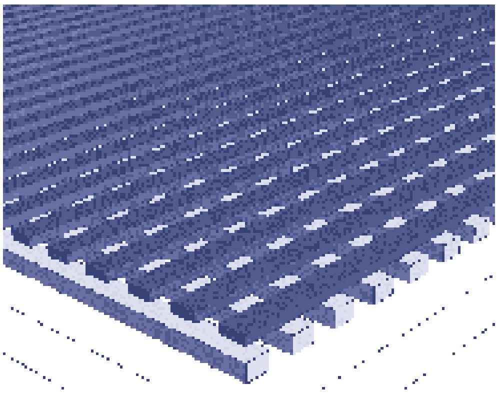

Figure 5. Two crossed periodic arrays of permanent magnets for producing a 2D magnetic lattice with Ioffe-Pritchard microtraps (with non-zero magnetic minima).

Towards a Molecular Bose-Einstein Condensate

ARC Centre of Excellence for Quantum-Atom Optics (ACQAO) Project

Jürgen Fuchs, Gráinne Duffy, David Lau, Heath Kitson, Veeravalli Gopisankararao, Bryan Dalton, Peter Hannaford, Wayne Rowlands

We are setting up an experiment to produce a Bose Einstein condensate of molecules (MBEC) via the association of ultracold atoms. Molecular BECs increase the complexity and richness of phenomena that can be investigated. In collaboration with the ACQAO theory group at the University of Queensland, we propose to use the MBEC to study the dissociation of the quantum degenerate molecules into correlated (entangled) atom pairs [1], and to investigate the coherent interaction between the MBEC and a quantum degenerate atomic gas and dynamical processes such as Bose enhanced molecule formation.

The systems initially chosen for study were molecular gases obtained from *bosonic* atoms (^{87}Rb, ^{133}Cs). However, investigations during the last year by several groups [2, 3, 4] have demonstrated that it is possible to produce a very stable MBEC obtained from *fermionic* ^{6}Li atoms, which exhibit lifetimes of some tens of seconds, compared with typically 100 μs in the case of quantum degenerate molecular gases obtained from bosonic ^{23}Na, ^{87}Rb or ^{133}Cs atoms. The huge enhancement of the lifetime for MBECs based on fermionic ^{6}Li atoms is largely a manifestation of Pauli blocking and represents a major breakthrough in the field of quantum degenerate molecular gases. In April 2004, a decision was made to switch from bosonic ^{133}Cs atoms to fermionic ^{6}Li atoms.

In our experimental scheme (Fig. 5) a σ^- Zeeman slower is used to produce a continuous high-flux beam of ^{6}Li atoms at speeds low enough to load a magneto-optical trap (MOT). The atoms are then transferred to a far-off-resonance optical dipole trap (FORT), which is used to trap and evaporate the atoms and molecules. The FORT is produced by beams from a 20 W single-frequency ELS Yb:YAG laser at 1030 nm. The scattering length of the atoms is controlled via Feshbach resonances in magnetic fields up to 1.5 kG. Evaporation in the optical dipole trap is performed at magnetic field strengths that enhance three-body recombination to form $^6Li_2$ dimers, similar to the scheme used in [2].

Theoretical research on processes for generating MBECs from atomic condensates is being carried out. One process of interest combines the Feshbach resonance with STIRAP (Stimulated Raman Adiabatic Passage) leading to a MBEC in the ground vibrational state, and hence closer to absolute zero in temperature. Ideally, such conversion processes are coherent, but various decoherent processes such as spontaneous emission need to be taken into account to be realistic.

In a related experiment we are setting up to produce ultracold (< 1 mK) Rb_2 molecules by the photoassociation ('light-assisted' collisions) of laser-cooled rubidium atoms using light from a titanium:saphire laser. The molecules are photoionised with a pulsed MOPO laser and detected by time-of-flight mass spectrometry and a channeltron. The photoassociated molecules are captured in a FORT trap, based on a tightly focussed infrared beam from a 20W Yb YAG laser.

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Figure 5. Jürgen Fuchs and Gráinne Duffy with the molecular BEC apparatus.

'Dark' and 'Bright' Atomic Coherent States

Alexander Akulshin, Andrei Sidorov, Russell McLean,
Peter Hannaford

Light-induced coherence between ground-state magnetic sublevels may cause extremely large enhancements of the dispersion and nonlinear susceptibility of alkali atomic vapours. Depending upon the parameters of the optical transition, the coherent superposition of sublevels may be either *'dark'*, producing electromagnetically induced transparency (EIT), or *'bright'*, producing electromagnetically induced absorption (EIA) [1]. An atomic gas prepared in a dark coherent state exhibits a very steep positive dispersion, allowing light propagation with ultra-slow *positive* group velocity. In a bright state the dispersion is also steep but *negative* [2], leading to the intriguing situation of a negative group velocity in which the peak of a light pulse actually leaves the atomic medium before the incoming peak enters the medium [3]. We have recently observed and measured the giant Kerr nonlinearity of the refractive index for atomic media prepared in a bright coherent state (Fig. 6) [4, 5]. We have also obtained efficient four-wave mixing at very low light intensity in atomic media in a bright coherent state (Fig. 7) [4].

We have found that atomic coherence can also be used for efficient frequency up-conversion of low intensity cw laser fields. Two infrared laser beams have been converted into well-collimated *blue* radiation in a resonant four-wave mixing process. Rubidium atoms with a cascade level configuration are excited by relatively weak laser fields tuned close to the single-photon resonances (Fig. 8). The four-wave mixing produces light at 420 nm.

We are currently extending these investigations on bright and dark coherent atomic states to samples of *ultracold* laser-cooled rubidium atoms in order to enhance the interaction times of the atoms and hence to increase the memory time of the atomic medium. The ability to slow and store light has potential applications in quantum information and quantum communication.

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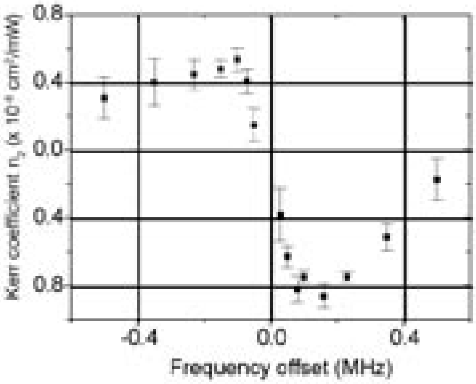

Figure 6. Nonlinear Kerr coefficient n_2 in caesium vapour enhanced by bright ground-state coherences.

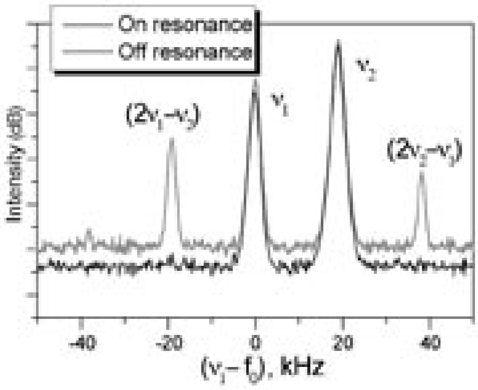

Figure 7. Spectrum of RF beat signal generated by four-wave mixing in rubidium vapour with a bright coherent state.

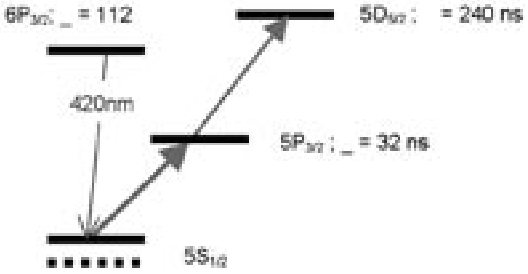

Figure 8. Cascade level scheme in atomic rubidium used for frequency up-conversion of low intensity infrared cw laser radiation into blue radiation.

The Swinburne Microfabrication Laboratory

James Wang, David Gough, Andrei Sidorov, Peter Hannaford

With funding from a DEST Systemic Infrastructure Initiative grant, we have established a new Microfabrication Laboratory with clean room facilities, to prepare and characterize thin films (Fig. 9). The facility includes:

- *A thin-film deposition system* (Kurt Lesker CMS-18 HV) with three sputtering heads and electron beam evaporation, and with cryopumping, giving a base pressure of about 10^{-8} Torr. The system is used for depositing thin films, including magnetic thin films, for the atom optics projects and for other groups within the Swinburne Optics and Laser Laboratories and from elsewhere.
- *An atomic force/magnetic force microscope* (NT-MDT P7LS). The AFM is used to observe surface morphology, analyse surface roughness, and measure the thickness of various thin-film samples. The MFM is used to analyse the domain structure of magnetic films and to characterise the magnetic properties of patterned magnetic films.
- *An optical microscope* (Olympus BX51) with Kerr/Faraday microscope accessory and CCD camera, for sample characterization, including analysis of the domain structures of magnetic films.
- *A double-sided mask aligner* (Suss Microtech. MA1006) with high-precision chuck for photolithography. This instrument is housed at MiniFAB within the Industrial Research Institute Swinburne (IRIS), where there are specialised photolithography facilities.
- *An optical confocal scanning microscope profilometer* (Olympus OLS1200) for characterising the surfaces of samples. This instrument is also housed at MiniFAB in IRIS.

The Microfabrication Laboratory is run, maintained and supervised by a Laboratory Manager, Dr James Wang.

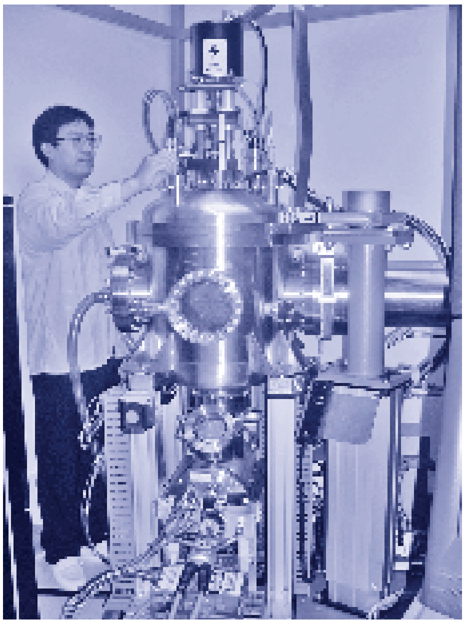

Figure 9. James Wang operating the thin-film deposition system.

ULTRAFAST SPECTROSCOPY

The Swinburne Femtosecond Laser Facility consists of a Spectra-Physics system with a Tsunami mode-locked titanium sapphire laser pumped by a 5 W Millennia Nd:YVO_4 laser; a Spitfire regenerative amplifier; and two independently tunable optical parametric amplifiers, with capabilities of second and fourth harmonic generation and sum frequency mixing of the signal and idler beams. The pump laser for the regenerative amplifier has recently been upgraded to a solid-state Evolution-30 system, which gives 25 mJ pulses at 1 kHz. The femtosecond laser system can produce pulses of duration down to about 50 fs, pulse energies up to about 2 mJ (allowing peak intensities up to about 10^{14} W cm^{-2}) at a repetition rate of 1 kHz, and wavelengths covering the range 250-2500 nm.

The Femtosecond Laser Facility is being used in a wide range of applications to investigate ultrafast phenomena in physics, chemistry, biology and microengineering.

Femtosecond Nonlinear Coherent Spectroscopy

Lap Van Dao, Craig Lincoln, Xiaoming Wen, My Thi Tra Do, David McDonald, Petrissa Eckle, Martin Lowe, Peter Hannaford

We have recently developed a multidimensional nonlinear coherent technique based on spectrally resolved 2-colour 3-pulse photon echoes in the visible to study vibrational and electronic dynamics in excited and ground states of molecules on a femtosecond time scale [1, 2]. The first two laser pulses have wave vectors k_1 and k_2 and the same wavelength λ_1, and the third pulse has wave vector k_3 and a wavelength λ_3 which may differ from that of the other two pulses. For two-colour experiments with $\omega_1 = \omega_2 \neq \omega_3$, conservation of momentum and energy leads to photon echo signals in the phase-matching directions $k_4 = -k_1 + k_2 + k_3$, $k_6 = -k_3 + k_1 + k_2$ with signal frequencies $\omega_4 = \omega_3 + \delta\omega_4$, $\omega_6 = -\omega_3 + 2\omega_1 + \delta\omega_6$, where the $\delta\omega$ represent frequency shifts associated with the transfer of optical coherence between levels. The spectra of the photon echo signals are recorded in a spectrometer equipped with multi-channel CCD detection as a function of the delay between the first two pulses t_{12} (the 'coherence time') for various values of t_{23}, λ_1 and λ_3, or as a function of the delay between the second and third pulses t_{23} (the 'population time') for various t_{12}, λ_1 and λ_3. The large number of available degrees of freedom allows one to separate and extract certain specific types of transient spectroscopic information. Spectral resolution of the photon echo signals provides detailed information about the temporal evolution of the amplitude of the nonlinear polarization $P^{(3)}(t, t_{12}, t_{23})$, and hence the nonlinear optical response function, induced in the sample by the three laser pulses. Suitable selection of the pulse wavelengths λ_1 and λ_3 allows different sets of energy levels in the vibrational manifolds to be interrogated and the vibrational dynamics in the excited and ground electronic states to be separated and investigated. The temporal evolution of the signal spectra in the k_4 and k_6 directions provides detailed information about the optical dephasing, the transfer of excited energy, and the splitting of the vibrational or electronic states. Spectrally resolved photon echoes also allows selection of quantum beats frequencies corresponding to specific coherently excited energy levels within the vibrational manifolds.

The technique is being used to study ultrafast processes such as vibrational relaxation and intermolecular charge and energy transfer in complex molecular systems, including the dye molecules Rhodamine 101, Rhodamine B, cresyl violet and DCM (Fig. 10) [1, 3]. The spectra in Fig. 11, recorded for Rhodamine 101, illustrate the richness of the spectra. [1, 2]. Figure 11 (a), which was taken for $\lambda_3 = 570$ nm, contains contributions from 'free induction decay' (no rephasing) at wavelengths near $\lambda_1 = 560$ nm, a long-lived 'population grating' component at wavelengths near $\lambda_3 = 570$ nm, and pure photon echo signals at wavelengths longer than 570 nm. Figure 11 (b), which was taken for $\lambda_3 = 580$ nm (where there is no spectral overlap with $\lambda_1 = 560$ nm), contains only the pure photon echo signals. These spectra illustrate how by suitable selection of the parameters in multidimensional space it is possible to select specific quantum pathways for the molecules.

A theoretical model based on the optical Bloch equations for a multi-level system is being developed to analyse the experimental results.

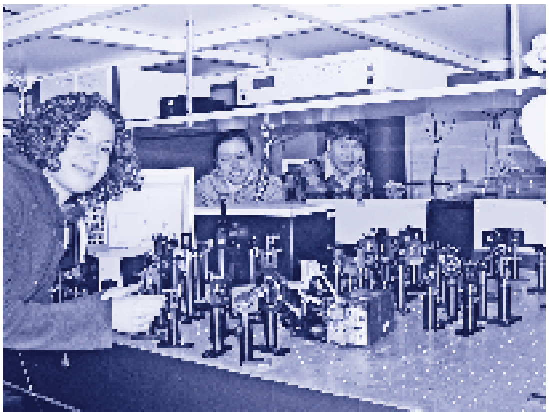

Figure 10. Petrissa Eckle, Tra My Do and Lap Van Dao working on the spectrally resolved two-colour photon echo experiment.

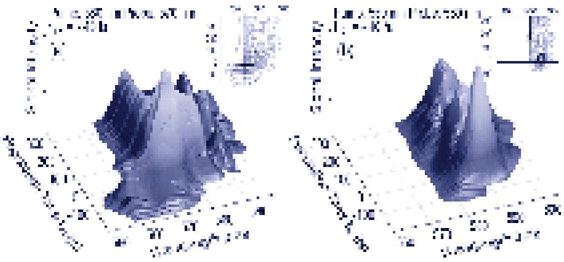

Figure 11. Two-colour three-pulse photon echo spectra for Rhodamine 101 detected in the phase-matching direction $k_4 = -k_1 + k_2 + k_3$ versus population time t_{23} for $t_{12} = -40$ fs, $\lambda_1 = 560$ nm, and (a) $\lambda_3 = 570$ nm, (b) $\lambda_3 = 580$ nm. The insets show contour plots of the spectra.

Biomolecules

Spectrally resolved 2-colour 3-pulse photon echoes and pump-probe spectroscopy using a white light femtosecond probe and spectrometer with CCD detector are being used to study ultrafast transient processes that occur during the photodissociation of carbonmonoxy myoglobin into myoglobin and carbon monoxide [3]; carbonmonoxy haemoglobin into haemoglobin and carbon monoxide; and intermolecular conversion and vibrational relaxation in light-harvesting carotenoid molecules such as lycopene.

Semiconductor Quantum Structures

Time-integrated and time-resolved photoluminescence, based on the *up-conversion* configuration with time resolution down to 100 fs, is being used to study the optical properties and carrier dynamics of low dimensional quantum structures such as silicon and InAs quantum dots and strained InGaAs intermixed quantum wells [4].

Efficient light emission from silicon nanostructures involving quantum confinement effects has led to current interest in silicon as a material for optoelectronic devices. Silicon is the most technologically important material of this century and the development of a light-emitting silicon device could result in a new generation of silicon technology from microelectronics to optoelectronics. We are investigating state-filling effects and carrier lifetimes, and the results confirm the parabolic confinement of silicon quantum dot structures. The photoluminescence intensities for different dot levels have decay times in the range 2 to 60 μs. The influence of the strain-induced potential energy on the carrier dynamics and carrier captures in InGaAs proton-implanted intermixed quantum wells is also being studied using time-resolved photoluminescence.

New Semiconductor Materials

The semiconductor GaN and its composite alloys with AIN or InN have great potential for fabricating high power, high temperature optoelectronic devices over an extremely broad wavelength range from the ultraviolet to the visible region. Two-colour three-pulse photon echoes and photoluminescence are being used to study the optical properties of GaN, including the dephasing times of the donor and the acceptor in the 'blue band' and the 'yellow band' and the origin of light emission in these bands [5].

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Femtosecond Laser Ablation

Martin Lowe, James Wang, Lap Van Dao

In conventional laser ablation using, for example, nanosecond pulses from an excimer laser or Nd:YAG laser the ablation mechanism is predominantly thermally driven and involves heating, melting and vaporisation processes at the surface. In the case of ablation using femtosecond laser pulses, the pulse duration is shorter than the characteristic energy relaxation times (electron-ion energy exchange, electron heat conduction to lattice, hydrodynamic plasma expansion, etc) and very different ablation mechanisms occur. The very high peak power of femtosecond pulses (up to about 10^{14} W cm^{-2} from our femtosecond regenerative amplifier) leads to rapid ionisation at the surface and the production of free electrons during the laser pulse. Further laser energy is absorbed by the free electrons which can either escape the surface resulting in huge electrostatic fields which extract the parent ions from the surface or rapidly transfer energy to the lattice by electron cooling immediately after the pulse. The non-thermal nature of these processes results in minimal melting and more precise laser machining [1].

We are investigating femtosecond laser ablation as a means of machining permanent magnetic microstructures in magneto-optical films for use in integrated atom optics devices. TbGdFeCo films are prepared on glass substrates and machined by exposure to a focussed beam from our femtosecond regenerative amplifier. The laser beam (wavelength 800 nm) is frequency doubled in a BBO crystal to allow tighter focussing. Due to the thinness of the films (< 1 μm), the machining can be carried out using low beam energies from the laser, typically 30 – 50 nJ. Initial experiments have shown that the machining should be carried out in vacuum to avoid contamination of the structure by debris from the ablated material. Linear patterns with dimensions down to about 1 μm have been patterned into the magnetic films (see Fig. 12). Further work will be directed towards improving the edge quality of the ablated structures and investigating the potential for constructing complex shapes in magnetic films and other materials such as glass or silicon.

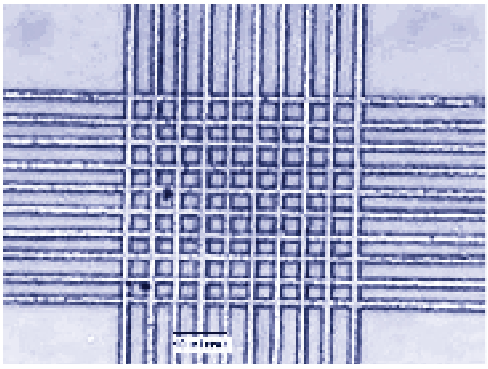

Figure 12. Grid structure machined in TbGdFeCo magneto-optical film by femtosecond laser ablation.

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In the standard quantum circuit model, the fundamental building block of the quantum computer is the quantum bit, or *qubit*, a generalisation of the binary bit of classical computing. A qubit can be in a quantum superposition of its two states, though upon measurement the superposition is destroyed, revealing one of the two classical values. The quantum computer involves a physical system of many qubits, whose quantum states define the quantum computer registers. Ideally, the quantum computer remains in a pure state involving *coherent superpositions* of these quantum states. Specific quantum computer processes (or algorithms) are defined by a sequence of gating processes, each made up of one or two qubit operations, and implemented by physical quantum control devices coupled to the quantum computer. The idealised behaviour of the standard quantum computer involves the features of parallelism (superposition), *entanglement* (qubit states are not independent of each other) and the *unitary evolution* of its (pure) quantum state. One of the key advantages that quantum computers are expected to have over classical computers is in the area of computational complexity. For certain algorithms, the number of computational steps required is expected to increase much more slowly with the input number than for classical computers; e.g., there is an exponential gain for the factorisation of integers (Shor's algorithm) and a square-root improvement for an unstructured search (Grover's algorithm).

Decoherence in Quantum Computation

Bryan Dalton

In practice, the physical system constituting the quantum computer and the quantum gating devices are never completely isolated from the environment, which acts as a heat bath or reservoir. The density operator describing the state of the quantum computer does not remain pure (non-unitary evolution), being changed by the system-environment interactions into a mixed state, with the coherences between the different evolved input states being partially or completely destroyed. This process of *decoherence* is the enemy of quantum computation, and ideally the decoherence time scale should be much longer than the gating time scales.

Quantum computers of practical importance would involve large numbers of qubits (about 10^5 qubits for searching or factoring algorithms), and we are investigating the limits decoherence places on quantum computation in large computers. Understanding how decoherence rates scale with qubit numbers may lead to quantum computer models less affected by decoherence.

Decoherence effects are conveniently described via the time dependence of the *fidelity*, which measures how closely the actual density operator of the quantum computer matches its idealised behaviour under purely unitary evolution. The intermediate time scale regime associated with exponential relaxation of the quantum computer state populations and coherences is the most important, and here Markovian master equations may be used. A general expression for the decoherence time scale in terms of Markovian relaxation elements and expectation values of products of system fluctuation operators has been obtained, which could also be applied to decoherence studies in other macroscopic quantum systems such as Bose-Einstein condensates. The computer system models chosen for study are those more likely to be implemented experimentally. Currently these involve N two-level or N three-level lambda systems trapped in periodic lattices, with environments involving both external systems (e.g., EM field modes) and other internal degrees of freedom (e.g., vibrational modes associated with trapped qubits' centre of mass motion). Coherent gating processes involve classical external laser fields. The two-qubit gating process may be facilitated by the presence of an auxiliary system consisting of a high-Q cavity mode. Both the internal states of the qubits and their centre of mass position/momentum states are being treated. Decoherence affects some states more than others; so important quantum computer states such as: (a) the Hadamard state; (b) generalised GHZ (Greenberger-Horn-Zeilinger) states are treated.

In the short time regime where the fidelity loss has a quadratic time dependence, results have been obtained for both two-level [1] and three-level ionic qubit systems with no gating effects present. Further results have been obtained for three-level lambda ionic qubit systems in the Markovian medium time regime at finite temperature with no gating processes, and at very low temperatures with one and two qubit gating processes present [2]. In the Markovian regime, decoherence times scale inversely with the number of qubits for the no gating case, but are very long. For both one and two qubit gating, the decoherence rate contains terms only involving the gated qubit(s) and terms involving the non-gated qubits. The latter scale linearly with the number of qubits. For one qubit gating, the non-gated terms are negligible, and the decoherence time is suitably long and essentially independent of qubit numbers. For two qubit gating processes in which the resonant gating fields are coupled to different transitions in the control and target qubits (as in the work of Tregenna et al. [3]), the non-gated terms are zero and scaling effects are absent. However, for other parameter choices, the non-gated qubit terms are no longer negligible, and could become comparable to the gated qubit terms for moderate qubit numbers ($N \sim 10^3$). The effect is due to Lamb-Dicke coupling of the qubits with the cavity mode and the vibrational modes. This might limit the size of quantum computers based on ionic qubits, though a quantum computer with $N \sim 10^3$ would still be much faster than a classical computer for many-body theory calculations.

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Quantum Adiabatic Computation

Tien Kieu

We study Quantum Adiabatic Computation (QAC) as an alternative model to and more powerful approach than the standard model of quantum computation based on qubits and quantum gates. QAC leads to new algorithms which not only improve upon the computational complexity of classical algorithms but also extend the notion of computability, as we have found with a quantum algorithm for Hilbert's tenth problem.

In 1900, David Hilbert gave a list of the most important mathematical problems of the time. The tenth problem on that list is the only so-called decision problem. It took more than 70 years for mathematicians to finally show that this problem cannot be solved in recursive Mathematics. The proof involved showing the connection of Hilbert's tenth problem to the Turing halting problem in Computer Science, which limits what Turing machines can and cannot do. What cannot be done is to have a single universal Turing machine to decide whether any other given Turing machine started with a specified input will eventually halt or not. The negative results of Hilbert's tenth and the Turing halting problems establish the limit of formal procedures in Mathematics and Computer Science.

We are employing [1] the theory of quantum physics to solve these problems and at the same time to remove the current limits on what can be decided in Mathematics and on what can be computed by present day computers. We have been exploring Quantum Adiabatic Computation [2] and have proposed a quantum algorithm that could extend the limit of classical computability. We start the computation by preparing the system in a readily obtainable ground state of some Hamiltonian. We then deform this Hamiltonian adiabatically in time into the Hamiltonian whose ground state is the desired one. Measurements then take place to identify this final ground state, from which the solution to our otherwise noncomputable problem can be deduced. Preliminary numerical simulations of the quantum adiabatic algorithm on some simple Diophantine equations have been shown to be very promising [3]. Already these numerical simulations have been verified and extended by another research group at Universidad EAFIT, Columbia. We have also investigated the related issues of computability and hypercomputability in the more general mathematical framework [4, 5].

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Quantum Phase Transition of Superfluid to Mott Insulator

Saeed Ghanbai, Tien Kieu

A Quantum Phase Transition (QPT) is different from the usual Thermal Phase Transition (TPT) in that it is driven purely by quantum fluctuations and not by the thermal fluctuations associated with thermal phase transitions. While the thermal fluctuations of a TPT have their origin in the competition between the minimization of energy and the maximization of entropy at a given temperature, the quantum fluctuations associated with a QPT stem from the competition between terms of conjugate properties and different symmetries in the quantum Hamiltonian that is responsible for the dynamics under consideration. Consequently, a QPT can in principle take place at any, and even at zero, temperature. One particular QPT of interest, which has recently been realised elsewhere in optical lattices, is the transition from superfluid to Mott insulator states [1]. The state of the neutral atoms making up a trapped Bose-Einstein condensate (in the superfluid state) is switched, when the lattice height is slowly raised within the BEC, from delocalisation throughout the condensate to localisation within each of the many individual potential wells forming the lattice. A remarkable property of the newly formed Mott-insulator is that the number of atoms so confined in each well of the lattice can be fixed with appropriate experimental parameters – provided the lattice height is raised sufficiently slowly, such that the adiabaticity condition is satisfied.

We point out that such a superfluid to Mott-insulator quantum phase transition can be identified as a physical realisation of an instance of a quantum adiabatic algorithm for Hilbert's tenth problem, briefly described in the above section on Quantum Adiabatic Computation, for the class of simple linear Diophantine equations. This connection originates from the fact that the quantum phase transition is itself a quantum adiabatic process, which is also the process employed in the algorithm. Thus, on the one hand, the identification is a demonstration of a partial implementation of the algorithm; on the other hand, understanding and results obtained from our study of the algorithm could be employed in the investigation of quantum phase transitions.

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Quantum Heat Engines, Maxwell's Daemon and the Second Law

Tien Kieu

We introduce and study a class of quantum heat engines of two-level systems, the simplest of quantum mechanical systems, which respectively undergo quantum adiabatic processes and energy exchanges with heat baths at different stages of a cycle (Fig. 13). Bose-Einstein condensates or other coherent quantum systems of meso/macroscopic size would be ideally suitable candidates for such heat engines.

By providing an interpretation of heat transferred and work performed at the quantum level, we are then able to clarify some important aspects of the second law of thermodynamics through the operation of those engines. In particular, we find that it is not sufficient to have the heat source hotter than the sink, as usually but erroneously expected, but there must be a minimum temperature difference between the hotter source and the cooler sink before any work can be extracted through the engines. The size of this minimum temperature difference is dictated by the size of the energy gaps of the quantum engines involved. Our quantum heat engines also offer a practical way, as an alternative to Szilard's engine, to physically realise Maxwell's daemon – a way in which they explicitly clarify and confirm the role of quantum measurement and information erasure in compensation for any apparent violation of the second law.

We are also able to modify the quantum heat engines above with the inclusion of single-mode cavities in order to, while respecting the second law on the average, extract more work from the heat baths than that which is otherwise possible in thermal equilibria. Some of the results above can also be generalised to quantum heat engines of an infinite number of energy levels such as those of the 1-D simple harmonic oscillators and 1-D infinite square wells.

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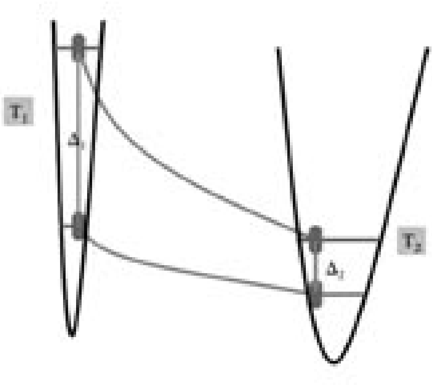

Figure 13. A two-level system with an energy gap of Δ_1 is removed from thermal equilibrium with a heat bath of temperature T_1 to perform work in an adiabatic process, until the energy gap is reduced to Δ_2. It is then put into contact with another heat bath of temperature T_2 before being adiabatically compressed to the original gap Δ_1, completing a cycle of the heat engine. Work can only be derived from this quantum heat engine if $T_1 > (\Delta_1/\Delta_2) T_2$, which is to be contrasted to the naïve expectation of $T_1 > T_2$ of the classical second law of thermodynamics. In other words, no work can be derived even if $T_2 < T_1 < (\Delta_1/\Delta_2)T_2$, which would have been allowed under the classical second law.

Fibre Optic Chemical Sensing

Daniel White, Paul Stoddart, Alex Mazzolini

Chemical sensing is a comparatively neglected area of optical fibre sensing as glass is, in general, relatively insensitive to chemical changes in its environment. However, a number of traditional spectroscopic techniques have started to benefit from integration with fibre optic sampling and interfacing systems. In this context, surface-enhanced Raman scattering (SERS) has generated substantial interest, due to its sensitivity and generally well-resolved spectra that provide a unique fingerprint for every Raman-active substance or compound. SERS is attributed to electromagnetic and chemical interactions between a surface with nanoscale metal structures and the target molecule absorbed onto or in close proximity to the surface.

We have developed a technique for building nanoscale metal structures onto the tips of optical fibres. This approach is relatively cheap and lends itself to both high sample-to-sample repeatability and the potential for commercial manufacturing. An example of the sensor surface is shown in Fig. 14. Our tests have confirmed that these structures can generate enhancements that are comparable to those observed for traditional planar substrates.

Current research is directed towards assessing the reproducibility of results obtained from high-quality, commercially fabricated SERS fibres. Success in this task will open up a range of potential applications, including measurement of glucose at physiological concentrations [1]. The availability of miniaturised optical fibre SERS sensors has been identified as one of the barriers to developing a continuous, minimally invasive glucose monitor for improved control of insulin levels in diabetics.

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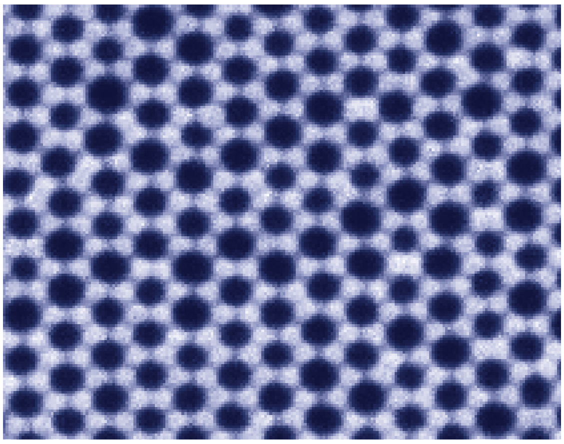

Figure 14. Scanning electron microscope image of etched optical fibre tip.

Fibre Bragg Grating Sensors

Jack Liang, Paul Stoddart, Alex Mazzolini

Fibre Bragg gratings (FBGs) allow many of the basic optical processes, such as reflection, diffraction and filtering, to be carried out within the optical fibre itself, rather than with bulk optics. This has enabled the rapid development of optical fibre telecommunication systems by reducing losses, improving stability and increasing portability. An FBG consists of a periodic modulation of the refractive index in the fibre core, which serves to reflect a phase-matched wavelength back along the fibre. Variations in the strain, temperature or pressure applied to a fibre grating result in a shift in the Bragg wavelength. This property of FBGs makes them attractive for use in optical fibre sensors.

In collaboration with the Defence Science and Technology Organization and Monash University, the Applied Optics Group operates an FBG fabrication facility at Swinburne, based on a standard phase mask exposure technique. Gratings fabricated in this facility have opened up a number of new application areas in optical fibre sensing. Our current focus is on continuous respiration monitoring, which is an important requirement in many areas of science and medicine. Respiration monitors are used in intensive care units and for sleep, sport and olfactory studies.

A differential pressure sensor is currently used to monitor respiration for olfactory research in Swinburne's Sensory Neuroscience Laboratory. The pressure sensor is sensitive to any small movements of the mask and its associated fittings add to the weight of the apparatus. We have demonstrated that a simple, light-weight FBG sensor is sensitive to the small temperature change between inhaled and exhaled breath. The sensor is presently being packaged in a prototype system for further testing with human subjects (Fig. 15).

Figure 15. Respiration monitoring with a breathing mask.

RESEARCH PUBLICATIONS

2004 – 2005

Books and Book Chapters

1. **L.V. Dao, C.N. Lincoln, R.M. Lowe and P. Hannaford**
   Spectrally resolved two-colour femtosecond photon echoes.
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3. **P. Hannaford, A.I. Sidorov, H-A. Bachor and K.G. Baldwin**
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   Laser Physics **15**, No. 9 (in press, 2005).

5. **L.V. Dao, X. Wen, M.T.T. Do, P. Hannaford, E-Ch. Cho, Y.H. Cho and Y. Huang**
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25. **A.M. Akulshin, A.I. Sidorov, R.J. McLean and P. Hannaford**
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CONFERENCE PRESENTATIONS

2004 – 2005

French-Australian-German Workshop on Quantum Engineering with Photons, Atoms and Molecules,
Les Houches, France, 14-17 February 2005

1. F. Scharnberg, S.M. Whitlock, B.J. Dalton, P. Hannaford and A.I. Sidorov
   The time-dependent asymmetric double well: dynamics of single trapped particles.
2. B.R. Hall, S. Whitlock, F. Scharnberg, J.Y. Wang, R.J. McLean, P. Hannaford and A.I. Sidorov
   Towards Bose Einstein condensation with a permanent magnetic film atom chip.
3. C.H. Wolff, D.S. Gough, J.Y. Wang, S. Whitlock, A.I. Sidorov, P. Hannaford and R.J. McLean
   Manipulation of cold atoms by grooved magneto-optical mictrostructures.
4. J. Fuchs, G. Duffy, B. Dalton, P. Hannaford and W. Rowlands
   Molecular BEC via the association of ultra-cold fermionic atoms.
5. J. Nes, A.L. Gehrmann, T. Müther, F. Scharnberg, W. Ertmer and G. Birkl
   Evaporative cooling in an optical dipole trap.

11th Young Atom Opticians Conference,
Hannover, Germany, 8-12 February 2005

1. F. Scharnberg, S.M. Whitlock, B.J. Dalton, P. Hannaford and A.I. Sidorov
   The time-dependent asymmetric double well: dynamics of single trapped particles.
2. B.R. Hall, S. Whitlock, F. Scharnberg, J.Y. Wang, R.J. McLean, P. Hannaford and A.I. Sidorov
   Towards Bose Einstein condensation with a permanent magnetic film atom chip.
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   Manipulation of cold atoms by grooved magneto-optical microstructures.
4. J. Nes, A.L. Gehrmann, T. Müther, F. Scharnberg, W. Ertmer and G. Birkl
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16th National Congress of the Australian Institute of Physics, Canberra, Australia, 31 January – 4 February 2005

1. B.R. Hall, S. Whitlock, F. Scharnberg, J.Y. Wang, R.J. McLean, P. Hannaford and A.I. Sidorov
   Bose Einstein condensation with a permanent magnetic film atom chip.
2. C.H. Wolff, D.S. Gough, J.Y. Wang, S. Whitlock, A.I. Sidorov, P. Hannaford and R.J. McLean
   Magneto-optical film-based grooved microstructures for manipulating cold atoms
3. T. Kieu
   The superfluidity-Mott insulator quantum phase transition as an instance of a quantum adiabatic algorithm for Hilbert's tenth problem.
4. G.J. Duffy, J. Fuchs, B.J. Dalton, P. Hannaford and W.J. Rowlands
   Molecular BEC via the association of ultracold fermionic atoms.
5. A.M. Akulshin, A.I. Sidorov, R.J. McLean and P. Hannaford
   'Fast light' atomic media with giant Kerr nonlinearity.
6. S.M. Whitlock, F. Scharnberg, B.J. Dalton, T. Kieu, B.R. Hall, R.J. McLean, P. Hannaford and A.I. Sidorov
   Atom interferometry with an asymmetric double-well potential.
7. P.R. Stoddart, P.J. Cadusch, J.B. Pearce, B. Smith and D.J. Booth
   Fibre optic distributed temperature sensor (DTS) with integrated background correction function.

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1. L.V. Dao, M.T.T. Do, P. Eckle, P. Hannaford, P. Reece, M. Aizengendler and A. Stanco
   Femtosecond multidimentional spectroscopy to study carrier dynamics of photonic materials.
2. L.V. Dao, M.T.T. Do, P. Eckle and P. Hannaford
   Femtosecond nonlinear coherence spectroscopy of the blue band of GaN.
3. L.V. Dao, X. Wen, M.T.T. Do, P. Hannaford, E.-Ch. Cho, Y.H. Cho, Y. Huang and M.A. Green
   Time resolved and time integrated photoluminescence for study of optical properties of silicon quantum dots.
4. P. Gareso, H.H. Tan, W. Leung, C. Jagadish and L.V. Dao
   Proton irradiation induced intermixing in $In_xGa_{1-x}As/InP$ quantum well.

Workshop on Quantum and Atom Optics, Kioloa, NSW, 5-7 December 2004

1. T.D. Kieu
   Mott insulator-BEC transition and a quantum adiabatic algorithm for Hilbert's tenth problem.
2. T.D. Kieu
   A class of quantum heat engines.
3. B.J. Dalton
   Two-mode theory of BEC interferometry.
4. G. Duffy, J. Fuchs, B.J. Dalton, P. Hannaford and W.J. Rowlands
   Molecular BEC via the association of ultracold fermionic atoms.
5. C.H. Wolff, D.S. Gough, J.Y. Wang, S.M. Whitlock, A.I. Sidorov, P. Hannaford and R.J. McLean
   Magneto-optical film-based grooved microstructures for manipulating cold atoms.
6. A.M. Akulshin, A.I. Sidorov. R.J. McLean and P. Hannaford
   Pulses of 'fast light', signal velocity and few-photon nonlinear optics.
7. S. Whitlock, F. Scharnberg, B. Hall, J. Wang, R. McLean, P. Hannaford and A. Sidorov
   Atom chip with a permanent magnetic film.

VIII International Conference on Optics within Life Sciences – OWLS8 2004, Melbourne, Australia, 28 November – 1 December 2004

1. L.V. Dao, M.T.T. Do, P. Eckle, P. Hannaford, J. Akahane and Y. Koyama
   Spectrally resolved femtosecond nonlinear spectroscopy for study of carotenoid light harvesting.
2. L.V. Dao, P. Eckle, M.T.T. Do and P. Hannaford
   Femtosecond multidimensional nonlinear spectroscopy: a new spectroscopic tool for studying charge transfer and molecular folding.

3. C. Lincoln, L.V. Dao, M. Lowe and P. Hannaford
   Spectrally resolved three-pulse photon echo spectroscopy of the photo-dissociation of carbonmonoxy myoglobin.

Annual Conference of Australia Engineering and Physical Sciences in Medicine, Geelong, Australia, 14-18 November 2004

L.V. Dao, C. Lincoln, M.T.T. Do, P. Eckle, M. Lowe and P. Hannaford
Spectrally resolved femtosecond 2-colour 3-pulse photon echoes: a new spectroscopic tool to study molecular dynamics.

Fourth International Symposium on Modern Problems in Laser Physics, Novosibirsk, Russia, 22-27 August 2005

1. L.V. Dao, C.N. Lincoln, R.M. Lowe and P. Hannaford
   Spectrally resolved femtosecond 2-colour 3-pulse photon echoes (Invited Talk).
2. A.M. Akulshin, A.I. Sidorov, R.J. McLean and P. Hannaford
   Pulses of 'fast light' and the signal velocity.

19th International Conference on Atomic Physics, Rio de Janeiro, Brazil, 25-30 July, 2004

1. B. Hall, S. Whitlock, F. Scharnberg, J. Wang, B. Dalton, R. McLean, T. Kieu, P. Hannaford and A. Sidorov
   A permanent magnetic film atom chip for BEC and interferometry.
2. L.V. Dao, M.T.T. Do, P. Eckle, C. Lincoln, R.M. Lowe and P. Hannaford
   Spectrally resolved femtosecond photon echoes for studies of vibrational and electronic dynamics.

7th International Conference on Quantum Communication, Measurement and Computing, Glasgow, UK, 25-29 July 2004.

B J Dalton
Decoherence rates in large scale quantum computers.

1st Pacific International Conference on Applications of Lasers and Optics, Melbourne, Australia, 19-21 April 2004

J.Y. Wang, S. Whitlock, R.M. Lowe, L.V. Dao, D.S. Gough, A.I. Sidorov and P. Hannaford
Femtosecond pulsed laser ablation of magneto-optical thin films for applications in atom optics.

International Conference on the Foundations of Quantum Information, Camerino, Italy, 16-19 April 2004

T.D. Kieu
An anatomy of a quantum adiabatic algorithm that transcends Turing computability.

International Workshop on Photonics and Applications (IWPA-2004), Hanoi, Vietnam, 5-8 April 2004

L.V. Dao and P. Hannaford.
Multidimensional spectroscopy for studying energy structures and carrier dynamics of photonic crystal based porous silicon (Invited Talk).

Quantum Limited Atom Optics Workshop, Hannover, Germany, 8-12 March 2004

1. S. Whitlock, F. Scharnberg, B. Hall, J. Wang, R. McLean, P. Hannaford and A. Sidorov
   Atom chip with a permanent magnetic film.
2. F. Scharnberg, S. Whitlock, P. Hannaford and A. Sidorov
   The asymmetric single-atom beamsplitter.

2003

Workshop on BEC and Quantum Information, Caloundra, Queensland, 16-20 February 2003

1. A.I. Sidorov, F. Scharnberg, A. Leigh, D.S. Gough, R.J. McLean and P. Hannaford
   Magnetic microstructures in integrated atom optics.
2. B.J. Dalton
   Scaling of decoherence rates in quantum computers.
3. T.D. Kieu
   Numerical simulations of quantum adiabatic processes for Hilbert's tenth problem.
4. W.J. Rowlands
   Towards a molecular BEC.

SPIE's AeroSense International Conference, Orlando, Florida, USA, 21-22 April 2003

T.D. Kieu
Numerical simulations of a quantum algorithm for Hilbert's tenth problem.

Eleventh International Conference on Time Resolved Vibrational Spectroscopy, Castiglione della Pescaia, Italy, 24-29 May 2003

L.V. Dao, C. Lincoln, R.M. Lowe and P. Hannaford
Spectrally resolved 2-colour 3-pulse femtosecond photon echoes: direct study of vibrational dynamics in molecules.

Ultrafast Optics IV, Vienna, Austria, 29 June – 3 July 2003

L.V. Dao, C. Lincoln, M. Lowe and P. Hannaford
Spectrally resolved femtosecond two-colour three-pulse photon echoes for studying the dynamics of ground and excited states of molecules.

Femtochemistry VI, Paris, France, 6-10 July 2003

L.V. Dao, C. Lincoln, M. Lowe and P. Hannaford
Spectrally resolved femtosecond two-colour three-pulse photon echoes for study of molecular dynamics: influence of pulse wavelengths and pulse sequence.

16th International Conference on Laser Spectroscopy, Palm Cove, Australia, 13-18 July 2003

1. B.J. Dalton
   Decoherence rates in large scale quantum computers.
2. A.M. Akulshin, A. Cimmino, A.I. Sidorov, R. McLean and P. Hannaford
   Fast and slow light pulses in a nonlinear atomic medium.
3. L.V. Dao, C. Lincoln, M. Lowe and P. Hannaford
   Spectrally resolved femtosecond 2-colour 3 pulse photon echoes for studies of molecular dynamics.
4. A.I. Sidorov, S. Whitlock, R.J. McLean and P. Hannaford
   Towards BEC with permanent magnetic microstructures.
5. M. Volk, T. Müther, F. Scharnberg, A. Lengwenus, R. Dumke, W. Ertmer and G. Birkl
   Atom optics and quantum information processing with atoms in optical microstructures.
6. T.D. Kieu
   Quantum physics and classical computability.

CONFERENCE PRESENTATIONS

Fourth International Conference on Discrete Mathematics and Theoretical Computer Science, Dijon, France, 7-12 July 2003

T. Ord and T.D. Kieu
Representations of Ω in number theory: finitude versus parity.

Spring 2003 Western Section Meeting of the American Mathematical Society, San Francisco, 3-4 May 2003

T.D. Kieu
Quantum mechanical principles and computation (Invited Talk).

2nd Quantum Challenges Conference, Warsaw, Poland, 4-7 September 2003

B.J. Dalton
Decoherence rates in large scale quantum computers: Markoff theory.

1st National Meeting on Quantum, Atomic, Molecular and Plasma Physics, Milton Keynes, UK, 7-11 September 2003

B.J. Dalton
Decoherence rates in large scale quantum computers: Markoff theory.

14th European Research Conference on Quantum Optics, Granada, Spain, 27 September – 2 October, 2003

1. B.J. Dalton and B.M. Garraway
   Non-Markovian decay of a cascade atom in a photonic band gap reservoir.
2. A.I. Sidorov, S. Whitlock, R.J. McLean and P. Hannaford
   Towards BEC with permanent magnetic microstructures.

6th Australasian Conference on Optics, Lasers and Spectroscopy, Melbourne, 1-4 December 2003

1. L.V. Dao, C. Lincoln, M.T.T. Do, X. Wen, M. Lowe and P. Hannaford
   Multi-channel detection of spectrally resolved 2-colour 3-pulse femtosecond photon echoes.
2. L.V. Dao, X. Wen, P. Hannaford, T.B. Sim and S. Yuan
   Laser surface treatment of improving the optical properties of InGaN/GaN quantum wells.
3. T.D. Kieu
   Quantum heat engines, the second law and BECs.
4. S. Whitlock, B.J. Dalton, F. Scharnberg, T.D. Kieu, P. Hannaford and A.I. Sidorov
   Splitting and recombining matter waves in surface-based microtraps.
5. B.A. McKinnon
   A semi-classical model of spectrally resolved femtosecond four-wave mixing.
6. B.J. Dalton
   Markovian decoherence rates in large scale quantum computers.
7. H. Kitson and W.J. Rowlands
   Photoassociation spectroscopy of ultracold rubidium atoms.
8. D.S. Gough, J.Y. Wang, R.J. McLean, A.I. Sidorov and P. Hannaford
   Magnetic microstructures for manipulating slowly moving atoms.
9. A.M. Akulshin, A.I. Sidorov, R.J. McLean and P. Hannaford
   Giant Kerr nonlinearity due to ground-state Zeeman coherence.
10. A.M. Akulshin
    Mode-hop free diode laser with all-optical frequency stabilization.

■ 2002

2002 Conference on Optoelectronic and Microelectronic Materials and Devices, Sydney, Australia, 11-13 December 2002

1. L.V. Dao, H. Makino, T. Takai, R.M. Lowe, P. Hannaford and T. Yao
   The optical properties of very thin-layer CdTe/ZnSe.
2. L.V. Dao, R.M. Lowe and P. Hannaford
   Femtosecond three-pulse photon echo and transient grating studies of the yellow band of GaN.
3. C. Carmody, H.H. Tan, C. Jagadish, J. Zhou, L.V. Dao and M. Gal
   Structural, electrical and optical properties of MeV ion implanted InP.

13th Norddeutscher Lasertag, Hannover, Germany, December 3002

R. Dumke, T. Müther, M. Volk, F. Scharnberg, W. Ertmer and G. Birkl
Atom optics with microfabricated optical elements.

Lasers and Applications Workshop, Dunedin, New Zealand, 20 November 2002

P. Hannaford
Atom optics and ultrafast spectroscopy at Swinburne, University (Invited Talk).

7th International Workshop on Atom Optics and Interferometry, Lunteren, The Netherlands, 28 September – 2 October 2002

R. Dumke, T. Müther, M. Volk, F. Scharnberg, W. Ertmer and G. Birkl
Atom optics with microfabricated optical elements.

18th International Conference on Atomic Physics, Boston, USA, 4-9 August 2002

A.I. Sidorov, R.J. McLean, F. Scharnberg, D.S. Gough, T.J. Davis, B.A. Sexton, G.I. Opat and P. Hannaford
Magnetic microstructures for atom optics.

13th European Research Conference on Quantum Optics, San Feliu de Guixois, Spain, 21-26 September 2002

B.J. Dalton and B.M. Garraway
Non-Markovian decay of a three-level cascade atom.

6th International Conference on Quantum Communication Measurement and Computing, Boston, USA, 22-26 July 2002

B.J. Dalton
Decoherence and scaling in quantum computers.

International Conference on Quantum Information, Oviedo, Spain, 13-18 July 2002

1. B.J. Dalton
   Decoherence and scaling in quantum computers.
2. T.D. Kieu
   Classical versus quantum computability.

15th National Congress of the Australian Institute of Physics (AIP), Sydney, Australia, 8-11 July 2002

1. R.J. McLean, A.I. Sidorov, D.S. Gough, F. Scharnberg, B.A. Sexton, T.J. Davis, A.M. Akulshin, G.I. Opat and P. Hannaford
   Reflection of laser-cooled atoms from high quality, micron-scale, grooved magnetic mirrors.
2. F. Scharnberg, A.I. Sidorov, D.S. Gough, R.J. McLean, T.J. Davis, G.I. Opat and P. Hannaford
   Application of permanent magnetic microstructures in integrated atom optics.
3. P. Hannaford
   Geoff Opat's impact on atom optics 1983-2002 (Invited Talk).

Biannual meeting of the International Quantum Structures Association (IQSA), Vienna, Austria, 1-7 July 2002

T.D. Kieu
Quantum principles and mathematical computability.

International Quantum Electronics Conference, Moscow, Russia, 22-27 June 2002

A.I. Sidorov, F. Scharnberg, D.S. Gough, R.J. McLean, P. Hannaford, T.J. Davis and G.I. Opat
Application of permanent magnetic microstructures in atom optics.

International Conference on Photons, Atoms and All That, Krakow, Poland, 31 May – 1 June 2002

A.I. Sidorov, R.J. McLean, F. Scharnberg, D.S. Gough, T.J. Davis, B.A. Sexton, G.I. Opat and P. Hannaford
Permanent-magnet microstructures for atom optics (Invited Talk).

XIII International Conference on Ultrafast Phenomena, Vancouver, Canada, 12-17 May 2002

L.V. Dao, C. Lincoln, M. Lowe and P. Hannaford
Direct measurement of vibrational relaxation and dephasing of molecules by spectrally resolved two-colour three-pulse photon echoes.

23rd International Conference on Microelectronics, NIS, Yugoslavia, 12-15 May 2002

M. Buda, P.N.K. Deenapanray, L. Fu, H.H. Tan, P. Reece, L.V. Dao, M. Gal and C. Jagadish
Quantum well intermixing for optoelectronic device integration.

SEMINARS AND COLLOQUIA

2002 – 2005

1. **T.D. Kieu, Faculty of ICT Seminar,**
   Swinburne University of Technology, 25 February 2005
   Computing the noncomputable.
2. **P.R. Stoddart, University of Witwatersrand,**
   Johannesburg, South Africa, 13 January 2005
   Novel substrates for surface-enhanced Raman scattering.
3. **P.R. Stoddart, National Metrology Laboratory, CSIR,**
   Pretoria, South Africa, 14 January 2005
   Research in optical fibre sensors.
4. **P. Hannaford, Yunnan University,**
   Kunming, China, 15 November, 2004
   Atom optics in Melbourne.
5. **P. Hannaford, Australian Academy of Science**
   Lloyd Rees Lecture, CSIRO, 22 September 2004
   The golden jubilee of atomic absorption – approaching absolute zero.
6. **B.R. Hall, National Science Week,**
   Swinburne University of Technology, 19 August 2004
   My life as a young scientist in Australia.
7. **B.J. Dalton, University of Strathclyde, UK,**
   11 August 2004
   Two-mode theory of BEC interferometry.
8. **A. Sidorov, ACQAO Meeting, Coolum, Queensland,**
   8 June 2004
   Coherence of BEC on a chip.
9. **W. Rowlands, ACQAO Meeting, Coolum, Queensland,**
   8 June 2004
   The molecular BEC project.
10. **G. Duffy, SOLL Seminar,**
    Swinburne University of Technology, 30 April 2004
    The quantum kicked rotor using a Bose-Einstein condensate.
11. **T.D. Kieu, University of Calgary,**
    Alberta, Canada, 30 April 2004
    An anatomy of a quantum adiabatic algorithm that transcends Turing computability.
12. **T.D. Kieu, Los Alamos National Laboratory,**
    New Mexico, USA, 22 April 2004
    An anatomy of a quantum adiabatic algorithm that transcends Turing computability.
13. **T.D. Kieu, Bell Labs, Lucent Technologies,**
    New Jersey, USA, 21 April 2004
    An anatomy of a quantum adiabatic algorithm that transcends Turing computability.
14. **A.I. Sidorov, University of Innsbruck, Austria,**
    15 October 2003
    Slow and fast light down under.
15. **A.I. Sidorov, University of Innsbruck, Austria,**
    14 October 2003
    Magnetic atom mirrors.
16. **T.D. Kieu, SOLL Seminar,**
    Swinburne University of Technology, 19 September 2003
    Quantum heat engines and the second law of thermodynamics.
17. **T.D. Kieu, Colloquium, School of Physics,**
    The University of Melbourne, 10 September 2003
    Quantum heat engines and the second law.
18. **A. Akulshin, Physical Lebedev Institute,**
    Moscow, Russia, 25 July 2003
    Light propagation in highly nonlinear dispersive atomic media.
19. **P. Hannaford, University of Vienna, Austria,**
    23 May 2003
    Ultrafast laser spectroscopy in Melbourne.
20. **P. Hannaford, University of Florence, Italy,**
    15 April 2003
    Atom optics and ultrafast spectroscopy in Melbourne.
21. **S. Whitlock, Tübingen University, Germany,**
    6 March 2003
    Permanent magnetic mictrostructures for atom chips.
22. **P. Hannaford, Hanoi University of Education,**
    Hanoi, Vietnam, 6 January 2003
    Recent developments in atom optics and ultrafast spectroscopy at Swinburne University.
23. **P. Hannaford, Ho Chi Minh City National University,**
    Vietnam, 20 December 2002
    Recent developments in atom optics and ultrafast spectroscopy at Swinburne University.
24. **T.D. Kieu, RMIT University,**
    1 December 2002
    Computing the non computible.
25. **P. Hannaford, University of Otago, Dunedin,**
    New Zealand, 20 November 2002
    Atom optics and ultrafast spectroscopy at Swinburne University.
26. **F. Scharnberg, University of Hannover, Germany,**
    20 November 2002
    Integrated atom optics and more at CAOUS at Swinburne.
27. **F. Scharnberg, University of Hannover, Germany,**
    October 2002
    Computing the noncomputable.
28. **P. Hannaford, LaTrobe University, Melbourne,**
    22 August 2002
    Probing ultrafast chemical, biological and physical processes in real time.
29. **T.D. Kieu, University of Innsbruck, Austria,**
    2 July 2002
    Computing the non computable.
30. **B.J. Dalton, Swinburne University of Technology,**
    19 April 2002
    The photon model in quantum optics.

Visiting Positions

Andrei Sidorov, Guest Professor, University of Innsbruck, October 2003.

Peter Hannaford, Visiting Scientist, European Laboratory for Nonlinear Spectroscopy (LENS), Florence, Italy, March-April 2003.

Bryan Dalton, Engineering and Physical Sciences Council (UK) Visiting Research Fellow, University of Sussex, UK, August – September 2002.

Bryan Dalton, Visiting Scientist, University of Strathclyde, Glasgow, UK, September 2002.

Tien Kieu, Visiting Scholar, Institute for Advanced Study, Princeton, USA, June 2002.

Tien Kieu, Visiting Scientist, University of Innsbruck, Austria, June 2002.

Peter Hannaford, Visiting Scientist, European Laboratory for Nonlinear Spectroscopy (LENS), Florence, Italy, June 2002.

Tien Kieu, Australian Academy of Science Exchange Fellow, Center for Theoretical Physics, MIT, USA, May 2002.

Collaborations

2002 – 2005

International

University of Auckland, NZ
Prof Cris Calude

Bell Labs, Lucent Technologies, USA
Dr Steven van Enk

University of Calgary, Canada
Prof Barry Sanders

Universidad EAFIT, Columbia
Prof Andres Sicard

Harvard University, Cambridge, Massachusetts, USA
Dr Alexander Zibrov

IBM, USA
Dr Gregory Chaitin

University of Oxford, UK, Department of Philosophy
Mr Toby Ord

University of Sussex, UK, School of Chemistry, Physics and Environmental Science
Dr Barry Garraway

University of Strathclyde, Glasgow, UK, Department of Physics and Applied Physics
Prof S. Barnett, Dr J. Jeffers

Kwansei Gukuin University, Uegahara, Nishinomiya, Japan,
Prof Yasushi Koyama

University of Hannover, Germany
ACQAO Partner Investigators: Dr Gerhard Birkl, Prof Wolfgang Ertmer

Novosibirsk State University, Russia
Dr. V. Yudin, Dr. A. Tachenachev

Montevideo University, Uruguay
Prof Arturo Lezama

Caltech, Pasadena, USA
Dr Andrew Rawlinson

Tohoku University, Sendai, Japan, Institute for Materials Research
Dr. Hisao Makino, Prof Takafumi Yao

European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, Italy
Prof Massimo Inguscio, Dr Giovanni Modugno

Nanyang Technological University, Singapore
Professor Shu Yuan

Sumitomo Heavy Industries, Japan
Dr Yanping Zhang

The Femtosecond Technology Research Association, Tsukuba, Japan
Dr Akira Endo

University of Reims, France
Dr Safa Bouazza

Tulane University, New Orleans, USA
Dr Mike Wilson

National

The University of Melbourne, School of Physics
Dr Cameron Wellard

CSIRO Manufacturing and Infrastructure Technology, Clayton
Dr Tim Davis, Prof Alan Head

The University of Queensland, Brisbane, Physics Department
ACQAO node: Prof Peter Drummond, Drs Karen Kheruntsyan, Matthew Davis, Joel Corney and Margaret Reid

The Australian National University, Physics Department and RSPS&E
ACQAO Node: Prof Hans Bachor, Prof Yuri Kivshar, Drs Ken Baldwin, John Close, Elena Ostrovskaya, Andrew Truscott, Craig Savage, Joe Hope, Ping Koy Lam

The Australian National University, Research School of Physical Sciences and Engineering
Dr Andrei Rode, Dr Eugene Gamaly, Professor Barry Luther-Davies, Professor Chennupati Jagadish

The University of Melbourne, School of Chemistry
Dr Trevor Smith

The University of Melbourne, Department of Philosophy
Mr Toby Ord

The University of New South Wales, School of Physics
Professor Mike Gal

The University of Western Australia, Physics Department
Dr Andre Luiten, Dr John McFerran

RMIT University, Melbourne
Dr Arnam Mitchell

Lastek Laboratories Pty, Ltd, Adelaide
Alex Stanco, Mark Aizengendler

COMPETITIVE GRANTS

2004 – 2005

1. **ARC Linkage Infrastructure**
   T.A. Smith, K.G. Ghiggino, S.H. Kable, P. Hannaford and L.V. Dao
   Ultrafast laser facility for chemical, biological and physical investigations of advanced materials.

2. **Swinburne University Strategic Initiative**
   P. Hannaford and L.V. Dao
   Femtosecond laser ablation for fabricating high quality microstructures.

3. **ARC Discovery**
   P. Hannaford, T. Smith and L.V. Dao
   New multidimensional femtosecond spectroscopic techniques for complex molecular systems.

4. **ARC Linkage Infrastructure**
   K. Pratt, P. Hannaford, D. Nicolau, M. Gu, K. Doyle, M. Brandt, R. Crawford, F. Malherbe, M. Straub, Y. Durandet and D. Trimm
   Multi-function high resolution analytical scanning electron microscope facility.

5. **The National Natural Science Foundation of China (NSFC) for International Academic Exchange**
   X.M. Wen and X.Y. Pu

6. **Swinburne Research Development**
   A. Sidorov, A. Akulshin and R.J. McLean
   Laser control of optical properties of a coherent atomic medium.

2003

7. **Swinburne Research Development**
   L.V. Dao and P. Hannaford
   New coherent nonlinear femtosecond spectroscopic techniques.

8. **ARC Centre of Excellence**
   A. Sidorov, P. Hannaford, R. McLean, W. Rowlands, B. Dalton, T. Kieu, in collaboration with the Australian National University and the University of Queensland.
   ARC Centre of Excellence for Quantum Atom Optics.

2002

9. **ARC Discovery**
   A. Sidorov, P. Hannaford, R. McLean, G. Opat and T. Davis
   Integrated atom optics: guiding matter waves with magnetic microstructures.

10. **DEST Systemic Infrastructure Initiative**
    P. Hannaford, A Mazzolini, E. Harvey, M. Gu and M. Austin
    Integrated microfabrication facility.

11. **Swinburne Research Development**
    T. D. Kieu
    Quantum computation.

12. **ARC Linkage Infrastructure**
    A. Luiten, D. Sampson, P. Hannaford and D. Kane
    A transportable optical frequency counter, synthesizer and super-continuum generator.

13. **ARC Discovery**
    W. Rowlands
    Generation and application of ultracold molecules.

Further information

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SP0339-07-0405