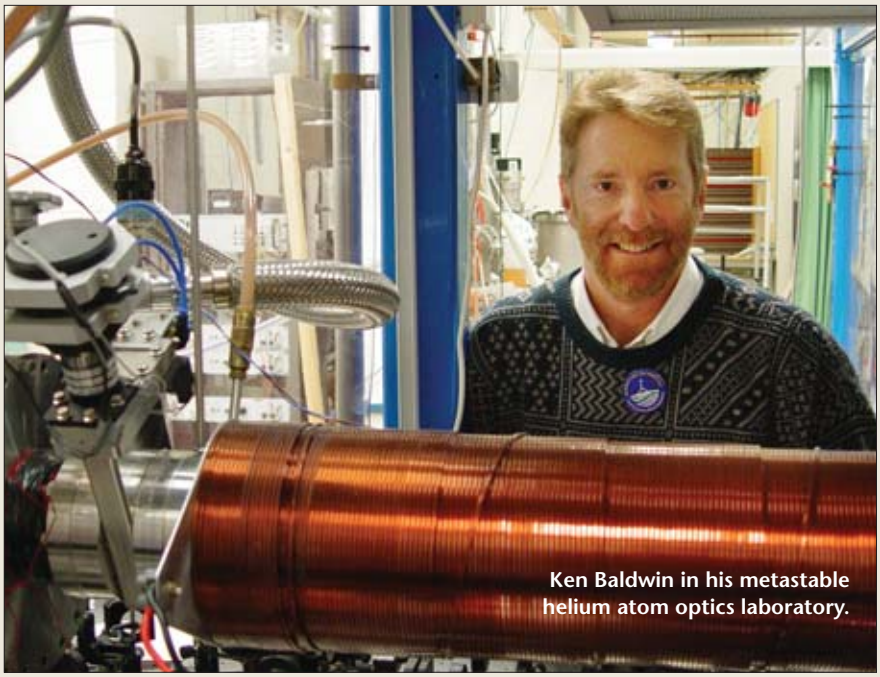
Optics in Australia

Ken Baldwin and Benjamin J. Eggleton



Ken Baldwin in his metastable helium atom optics laboratory.

Australia is renowned for its abundant sunlight, which enhances the vibrant colors of the continent—from its red deserts to the rainbow-colored fish of the Barrier Reef. In the scientific realm, Australia is also well known for its outstanding contributions to the study and application of light in science and engineering. This article presents a brief overview of Australian optics research and recent highlights.

Optical and quantum optical science are national research strengths in Australia, and the country has a substantial history of achievement in these fields. Optics was made a national research priority area between 1995 and 1997 through the Australian Research Council (ARC—the equivalent of the National Science Foundation in the United States). The field was also a cornerstone of the Photon Science and Technology priority area established by the Australian Government to guide research directions from 2001 to 2002.

One indicator of Australia's success is the number of major international optics conferences that were held there in recent years, including:

- The 14th International Conference on Vacuum Ultraviolet Radiation Physics, Cairns, 2004
- The 16th International Conference on Laser Spectroscopy, Cairns, 2003
- The 6th OptoElectronics and Communications Conference/ Integrated Optics and Optical Fibre Communication Conference, Sydney, 2001

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Photo by Tim Wetherell

Micrograph of the Sydney Opera House laser-fabricated in polymer at the CUDOS laboratory in SUT. [From M. Straub et al., Opt. Mater., **27**, 359-64, (2004).]

Ben Eggleton in the CUDOS laboratories investigating ultra-fast pulse propagation in photonic crystal fibers.

- The 3rd Asia-Pacific Conference on Communications, Sydney, 1997
- The International Quantum Electronics conference, Sydney, 1996.

Most recently, Australia has been selected to host the International Commission for Optics Congress in Sydney in 2008.

Australia is particularly strong in the study of the behavior of atoms and photons at the quantum level, and the control of light for quantum computing and optical communications. In fact, in 2003 three ARC Centres of Excellence were established in these areas:

- The Centre for Quantum-Atom Optics[1]
- The Centre for Quantum Computing Technology[2]
- The Centre for Ultrahigh Bandwidth Devices and Optical Systems.[3]

Centres of Excellence play an important role in Australian scientific research. Only eight of them were established nationwide—a fact that demonstrates the pre-eminence of optics research in Australia. (Of the remainder, one was in the related field of solar photovoltaics). The Centres complement three existing research organizations that emphasize optics applications and commercialization–the Australian Photonics Cooperative Research Centre,[4] the Centre for Lasers and Applications[5] and the Australian Consortium for Interferometric Gravitational Astronomy.[6] There are also a large number of smaller optics research groups.[7–17]

Indeed, research in Australia now spans almost the entire field of optics. This will soon be enhanced by the opening of the Australian Synchrotron in 2007.[18] The Australian Optical Society (AOS) provides a network for these groups and centers, which come together at the various AOS-sponsored meetings. The AOS has reviewed and highlighted Australia's strength in optics in a 1994 report.[19]

Building on 20th Century foundations

Optics in Australia expanded rapidly during World War II, when a complete manufacturing industry was established to produce optical munitions. The skill base that was formed to meet the pressing national defense need led to the

formation of a number of optical manufacturing companies, and sparked the establishment of research groups in universities and government research labs.

Two key figures in Australian optics emerged during the immediate post-war period: W.H. ("Beattie") Steel and Sir Alan Walsh. Both worked for the government research laboratories of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Steel made major contributions to the theory of image formation and to interferometry, while Walsh developed the atomic absorption spectrometer—which created an industry whose market today exceeds $500 million per year.

Astronomy has been a key driver of innovation in Australian optics. The Anglo-Australian Observatory (Ben Gascoigne), the Intensity Interferometer (Hanbury Brown) and the CSIRO Solar Observatory (Ron Giovanelli) were unique instruments that helped put Australia at the international forefront of astronomy and drove a wealth of optical research programs.

This technology base placed CSIRO as a leading innovator in specialist optics manufacture,[8] including ion-assisted deposition techniques, teflon polishing for flat surfaces and phase shifting interferometry for precision measurement of optical surfaces (such as pioneered by Parameswaran Hariharan). The most recent contribution is the polishing of the test masses for the Laser Interferometer Gravitational-wave Observatory (LIGO) and precision optical components for the Jet Propulsion Laboratory.

Over time, Australian optics diversified, after having been founded on a strong classical optics base through contributors such as Hans Buchdahl. Neutron optics techniques were pioneered by Tony Klein and Geoff Opat starting in the 1970s and contributed to the development of atom optics in Australia. Strong connections with Dan Walls and Crispin Gardiner in New Zealand led to rapid growth in quantum optics on both sides of the Tasman sea. Other New Zealand contributors in optics and lasers, including Jack Dodd and Wes Sandle, also stimulated growth in Australian activity in lasers and other areas of optics.

Katja Lyytikainen operating the OFTC fiber draw tower in the APCRC.

Australia was an early player in the development of fiber optic communications—which was catalyzed by the work of Tony Karbowiak in the mid-1960s with support from the Australian telecommunications industry. This area mushroomed both academically and commercially following the widespread adoption of fibers in the Australian telephone network by the early 1980s.

Australian Photonics Cooperative Research Centre

Building on Australia's widespread expertise in optical fiber technology, the government established the Australian Photonics Cooperative Research Centre (CRC) in 1992 to synergize the activities of the many organizations involved in photonics. It is one of the largest of about 60 CRCs, which are part of a government initiative to build partnerships between the public and private sector, particularly to assist in building Australia's high technology industry.

The Australian Photonics CRC includes five universities: The Australian National University (ANU), the University of Sydney, the University of Melbourne, the University of New South Wales and the Royal Melbourne Institute of Technology University. Government labs and industry partners, ranging from small startups to transnational companies, are also part of the CRC. The Centre is in its 13th year and has about 300 participating staff and students.

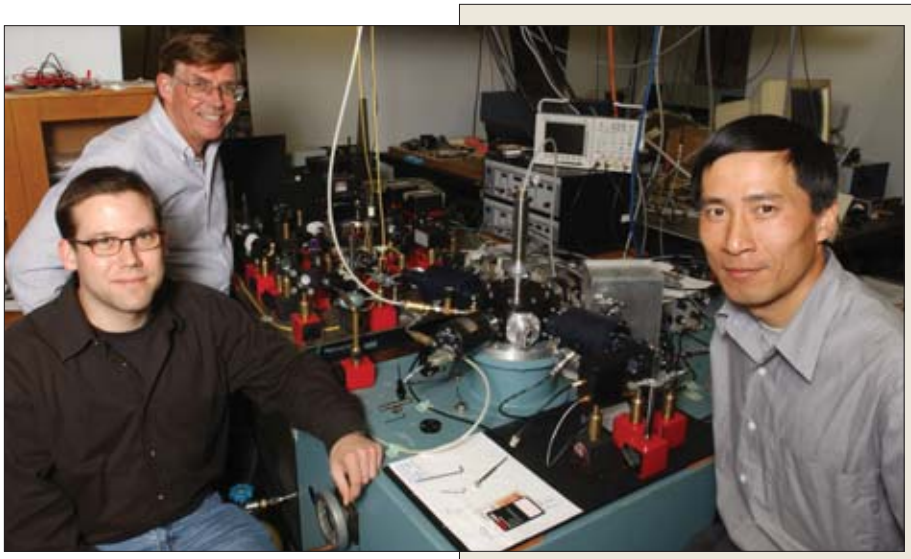
The CRC has major research capabilities in specialty fiber, fiber devices, telecommunications technologies and sensor systems. The CRC has focused these capabilities into four major "Challenge Projects": fiber to the premises, long haul systems impairment mitigation, transponders for coarse wavelength division multiplexing (CWDM) and defense and distributed sensing systems.

The CRC program places a strong emphasis on commercialization and is widely regarded as successful in this respect; it has spun-off about 15 photonics companies, including some that have progressed to become global market leaders. These companies span the technology of photonics from fiber to advanced CWDM equipment for metropolitan area networks, and are based in Australia, The United States, China and Germany.

Centre for Lasers and Applications

Established in 1988 as an ARC special research center, the Centre for Lasers and Applications (CLA) is located at Macquarie University in Sydney. Its emphasis on laser applications is based on the fundamentals of optics, electronics, physics, chemistry and biology. The CLA's longstanding research on high-power metal-vapor lasers has been extended to solid-state lasers (e.g., those based on novel crystals), optical fiber lasers and nonlinear-optical wavelength conversion (e.g., Raman lasers and narrowband tunable optical parametric oscillators).

The Centre's advanced laser-micromachining services have produced precision orifices for Olympic torches, laser-scribed coding of machine parts



(*Left to right*) Florian Englich, Brian Orr (CLA Director) and Yabai He with a continuous-wave cavity ringdown spectrometer for multiwavelength molecular sensing.

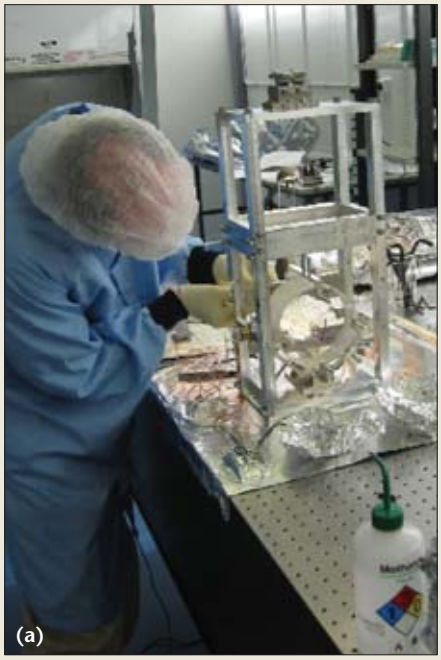
and new photonic crystal devices (among the CLA's CUDOS-related activities).

Other CLA success stories include the "Magic Wand'—a compact, solid-state Raman laser system that delivers coherent yellow light for ophthalmology, dermatology and treatment of blood vessels. In other medical applications, the CLA has developed laser-cured protein solder for microsurgical repair, short-pulse laser treatment of teeth and breath-test diagnostics by rapidly swept cavity ringdown spectroscopy.

Innovative flow cytometry techniques developed at the CLA use high-repetition-rate pulsed lasers or lamps to identify and enumerate pathogenic microorganisms. CLA research also includes fluorescence-based microscopy.

Australian Consortium for Interferometric Gravitational Astronomy

The Australian Consortium for Interferometric Gravitational Astronomy (ACIGA) has a research and development program aimed at improving the performance of laser interferometer gravitational wave detectors to reach the limits set by mechanics, quantum mechanics, lasers and optics. The Consortium is applying this knowledge to develop methods to improve the performance of current detectors to the level where gravitational wave events should be regularly recorded. It is establishing the capability to build the southern hemisphere component of the worldwide observational network—which will be internationally funded—once the angular resolution of the existing network becomes a major limiting factor.



(a) Installation of suspended test masses at (b) the Gingin test facility.

The consortium comprises the following institutions:

- The ANU, where researchers are working on advanced interferometer configurations and control systems, quantum optics and data analysis;
- The University of Western Australia, which houses efforts to study suspensions and isolation systems, develop sapphire test mass development and conduct source modeling;
- The University of Adelaide, which specializes in injection locking, high power laser development and wave front distortions; and
- Monash University, where investigators are making gravitational wave form calculations.

The CSIRO Space Optics Group is an affiliate member. The ACIGA universities operate a facility at Gingin in Western Australia (see photos at left). This facility can house a suspended interferometer that is 80 meters in length. Initial research is focused on diagnosing the operation of a high power optical system (on the order of 1 MW circulating power).

ACIGA actively collaborates with groups conducting international projects, including the U.S. LIGO Project, the French Italian VIRGO project, the British German GEO Project and TAMA in Japan.

Centre for Quantum Computing Technology

A multi-university collaboration, the Centre for Quantum Computing Technology (CQCT) undertakes research on the fundamental physics and technology involved in building, at the atomic level, a solid-state quantum computer in silicon. There are two optics programs in the Centre, both at the University of Queensland (UQ).

The aim of the linear optics program is to construct the basic building blocks for an optical quantum processor

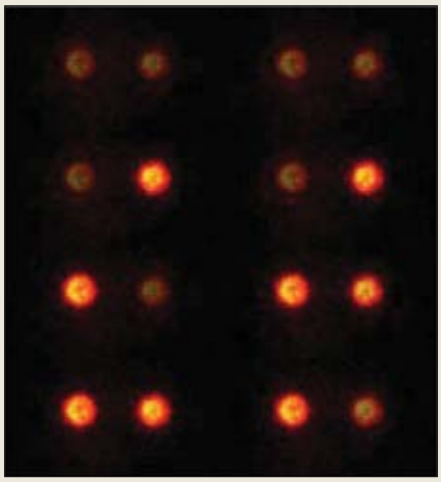
focusing on the two-qubit controlled-not (CNOT) gate and to develop the foundation for a scalable architecture. The strategy involves both experimental and theoretical research into how to: 1) develop measurement techniques for characterizing the relevant quantum states and processes; 2) improve photon sources and optical circuitry performance; 3) create and apply measures of gate performance; and 4) realize simple quantum circuits.

Through the quantum dot program, investigators aim to develop a hybrid electro-optical quantum gate technology whereby the nonlinear interaction required for quantum gate operation is provided by a strong cavity quantum electrodynamical interaction between a single photon and a quantum dot. The use of nanocrystal quantum dots and fused silica microcavities allows for potentially scalable technology, as well as a possible "bridging" technology between optical and electronic quantum circuits.

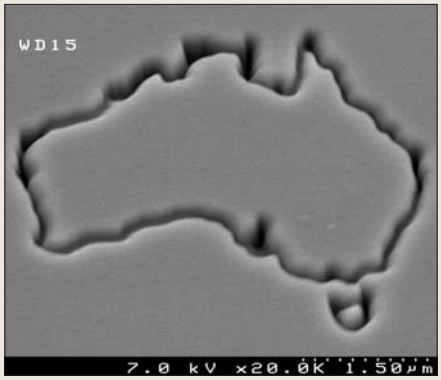
The Centre for Ultrahigh Bandwidth Devices and Optical Systems

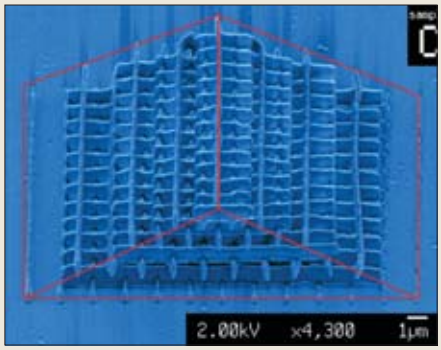
The mission of the Centre for Ultrahigh Bandwidth Devices and Optical Systems (CUDOS) is to demonstrate all-optical processing applications and devices that will enable next-generation optical communication systems by drawing on research into non-linear optical materials, photonic crystals, micro-structured optical fibres and micro-photonics. Headquartered at the University of Sydney, CUDOS includes research groups at the ANU, Macquarie University, Swinburne University of Technology (SUT) and the University of Technology Sydney.

Research at CUDOS focuses on two major areas: micro-photonics and non-linear photonics. Investigators hope to achieve ultrahigh-speed all-optical signal processing on a single photonic chip by using knowledge in these two areas to develop micron-scale photonic components incorporating nonlinear photonics processes. Light is coupled to the chip from sophisticated optical fibers, including microstructured fibers. The Centre is initially focused on creating the building blocks for this photonic chip.



CQCT linear optics CNOT gate truth table. Left column pairs are ideal input qubits (dim = 0, bright = 1) used to generate control and target qubits in the experiment (right column pairs).





(*Top*) Micron scale map of Australia viewed at 45 degrees, fabricated at the ANU CUDOS node with a focused ion beam on an ultrafast pulsed-laser deposited chalcogenide glass film. (*Bottom*) Prism woodpile device, laser-fabricated in polymer by the SUT CUDOS group.

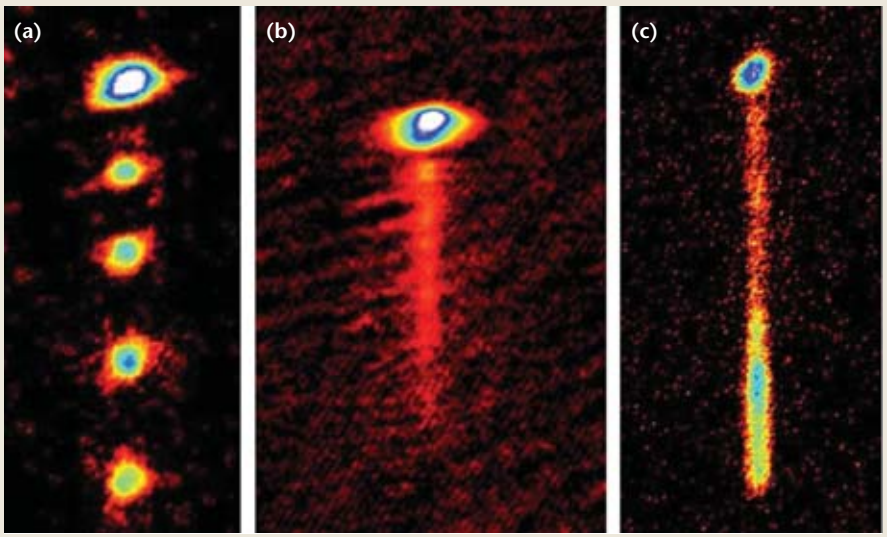
Central to this vision are photonic bandgap materials because of their potential for miniaturization and their highly nonlinear optical response function. A large part of the CUDOS program is therefore devoted to studies of their fundamental properties, ways to fabricate them and applications of these materials to new optical technologies. Centre researchers are studying one, two and three dimensional photonic bandgap structures in a range of different materials and have a strong interest in the nonlinear optical properties of these materials.

The Centre for Quantum-Atom Optics

The fields of quantum optics and atom optics are brought together at the Centre for Quantum-Atom Optics (ACQAO), where scientists aim to understand and exploit the quantum nature of multiple-particle states—whether they be atoms, photons or both. Building on Australia's strong history of research in quantum optics, ACQAO's goal is to study fundamental quantum effects, such as optical entanglement for future applications in secure communications and data storage.

Atom optics, which aims to control atomic de Broglie waves in an analogous manner to light optics, has developed rapidly in the past 15 years, and Australian researchers have played a prominent role. ACQAO aims to apply quantum optics concepts to atom optics in order to study the fundamental properties of Bose-Einstein condensates (BECs), with potential applications such as gravity gradiometry based on the quantum control of coherent matter waves.

ACQAO is headquartered at the ANU in Canberra, and has major partners at UQ and SUT. The Centre houses the world's only quantum laser pointer as well as Australia's only atom laser experiment located at ANU, the latter based on a rubidium BEC. (There is another rubidium BEC outside the Centre in the UQ Physics Department.) Three more BEC experiments are under development in the Centre, one at ANU (in metastable helium), and two at SUT (rubidium



The atom laser output beam from the ACQAO rubidium BEC: (a) in pulsed mode, (b) in overlapping pulsed mode, and (c) in continuous mode.

Quantum laser pointer laboratory with ACQAO director Hans Bachor and European Partner Investigator Claude Fabre.

on a chip using permanent magnetic microstructures, and a lithium-6 molecular BEC). The experimental activities are integrated with a strong theory core, with the eventual aim of spawning the first-generation quantum technologies.

The Australian Optical Society

The Australian optics community is represented by the AOS[19] and has approximately 300 members across the country. The AOS links its membership through its annual conference and provides connections internationally to optics organizations overseas.

The Society has joint membership agreements with both the OSA and SPIE. To reinforce these linkages, the AOS hosts their respective presidents-elect at the AOS annual conference. Currently there are 137 Australian members of the OSA—roughly 1 percent of total OSA membership—and 61 members of SPIE. AOS members serve on the editorial boards of several OSA journals and many OSA-sponsored conferences.

Australian optics researchers are also key contributors to the growing proportion of authors outside America publishing in OSA journals: Two percent of OSA journal submissions are from Australia, with over two-thirds of all articles coming from outside the United States. And given the rapid growth of Australian research in optics in just over half a century, there is reason to believe that more is yet to come.

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OSA Member

To learn more about Ben Eggleton, visit www.physics.usyd.edu.au/cudos/people/eggleton.htm.

References

1. The Centre for Quantum-Atom Optics, www.acqao.org.
2. The Centre for Quantum Computing Technology, www.qcaustralia.org.
3. The Centre for Ultrahigh Bandwidth Devices and Optical Systems, www.cudos.org.au.
4. Australian Photonics Cooperative Research Centre, www.photonics.com.au.
5. Centre for Lasers and Applications, www.ics.mq.edu.au/cla/.
6. Australian Consortium for Interferometric Gravitational Wave Astronomy (ACIGA), www.anu.edu.au/physics/ACIGA/.
7. Australian National University, Research School of Physical Sciences and Engineering and Physics Department, www.rsphysse.anu.edu.au and www.anu.edu.au/physics.
8. CSIRO Industrial Physics, www.tip.csiro.au.
9. Griffith University Centre for Quantum Dynamics, www.gu.edu.au/centre/quantumdynamics/.
10. National Measurement Institute, Time and Frequency Standards Laboratory, www.measurement.gov.au.
11. Swinburne University of Technology, Optronics and Laser Laboratories, www.swin.edu.au/bioscieleceng/.
12. University of Adelaide Optics Group, www.physics.adelaide.edu.au/optics/.
13. University of Melbourne Optics Group, http://optics.ph.unimelb.edu.au/.
14. University of Queensland School of Physical Sciences, www.uq.edu.au/departments/unit.html?unit=116.
15. University of Sydney Physics Department and Optical Fibre Technology Centre, www.oftc.usyd.edu.au/ and www.physics.usyd.edu.au/.
16. University of Western Australia Frequency Standards and Metrology Group, www.fsm.pd.uwa.edu.au.
17. Victoria University Optical Technology Research Laboratory, www.staff.vu.edu.au/OTRL.
18. Australian Synchrotron, www.synchrotron.vic.gov.au.
19. K.G.H. Baldwin et al. "Optics: Highlight of the Future": AOS report on the status of Australian optics (1994), http://aos.physics.mq.edu.au/.