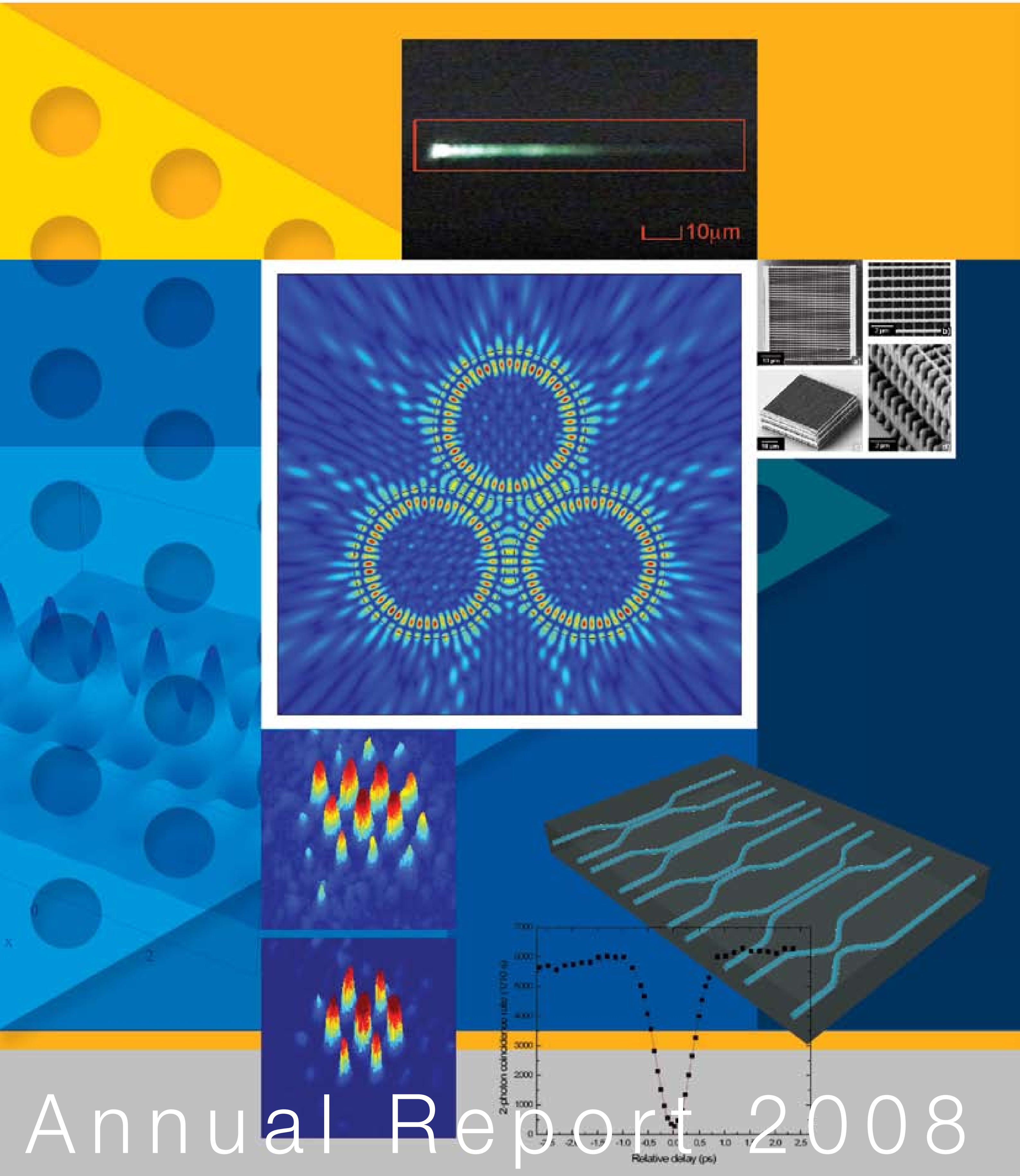
CUDOS

The Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS)



Annual Report 2008

Chief Investigator: Judith Dawes

CI short biography

Judith Dawes is Associate Professor in Physics at Macquarie University, working on photonic crystals and nanophotonic devices, and novel diode-pumped crystalline lasers and their applications in communications, medicine and dentistry. She teaches Physics and Optoelectronics, and is a member of Macquarie's MQPhotonics Research Centre. She is the Postgraduate Director for Physics, and the Director of the BTechnology (Optoelectronics) and B Optical Technology degrees. During her career, she has supervised 11 successful PhD graduates, 9 Masters graduates, and 10 Honours graduates and is currently co-supervising 3 PhD students and 2 Masters students. She is Vice President of the Australian Optical Society and is a member of OSA, SPIE and APS. She served on conference committees for the Microwave Photonics (IEEE) conference in October 2008 and CLEO (OSA) in June 2009. She received her BSc (Hons) and PhD from the University of Sydney, after a 1-year Rotary International Fellowship at the University of Rochester, and pursued postdoctoral research at the University of Toronto. She joined Macquarie University in 1991.

Key areas of research contribution within the Centre

Judith's research program includes characterisation of the radiation dynamics of emitters within opals (3D photonic crystals), linked to the 3D Bandgap Confinement flagship program, the fabrication and characterisation of waveguides within opals and inverse opals to create photonics devices, and nanophotonics using metallic waveguides with active laser materials. The opals research program is focussed on understanding the behaviour of optical emitters such as rare earth ions and colour centres in nanodiamonds embedded within photonic crystals. We also aim to harness the emitted light in waveguide devices incorporated into the photonic crystals, with the goal of creating more efficient optical amplifiers and other optical devices for light propagating in photonic chips.

Researchers and students

Research students within Macquarie working on 3D bandgap effects in photonic crystals are Luke Stewart, Sara Ek, and on nanophotonics and plasmonics, Jacek Gosciniak. Darran Wu (University of Sydney PhD student) helped Sara with characterisation of light propagation in waveguides. Dr Peter Dekker, Dr Graham Marshall, Dr Jim Rabeau, Assoc Prof Mike Steel, Assoc Prof Michael Withford and Dr Yan-Hua Zhai (Macquarie staff) and Dr Adel Rahmani (UTS staff) also contribute to research on radiation dynamics in photonic crystals. Collaborating researchers are Dr Frank Dillon and Prof Martyn Pemble, Tyndall Institute in Ireland.

Research achievements during 2008

The major research achievements of 2008 contribute to our aim to control light propagating within 3D photonic crystals for micro-photonic devices. In particular, we are investigating the emission of light from nitrogen vacancy (N-V) centres in nanodiamonds, and rare earth dopant ions, both incorporated within opals, and we have shown spectral effects in light guided within waveguides embedded in opals. Since we are using low-refractive-index contrast photonic crystals, we observe stopgaps, or partial bandgaps, in the opals or inverse opals.

We have chosen to work with opals, self-assembled 3D photonic crystals, because they can provide large-area photonic devices and are relatively quick to fabricate. We are able to produce high-quality opals with tailored bandgaps, by selecting the initial microsphere size distribution. Inverse opals of good quality have been fabricated by infiltration of the initial opal structure. Silica microspheres are fabricated at Tyndall and at Macquarie using the Stöber reaction process. We have shown tunable and controlled adjustment of the opal stopgap using annealing of the photonic crystal. The accurate measurement of the peak stopgap wavelength enables us to estimate the refractive index or the microsphere diameter for our samples, and, using scanning electron microscope measurements, we note that the microspheres shrink slightly and increase their refractive index during annealing.

Waveguides are fabricated using UV contact lithography with SU-8, a photosensitive resin (photoresist). We have created high quality multimode waveguides, and measured their typical transmission/reflection spectra. We have successfully assembled opals around, below and above the waveguides using self-assembly, and, working with Darran Wu and Jeremy Bolger (University of Sydney) we have observed differences in the light propagation in the waveguides with and without the opal. Modelling to understand the light propagation (which is complicated by the presence of many modes and uncertainty in the opal orientation) is underway using the RSoft suite.

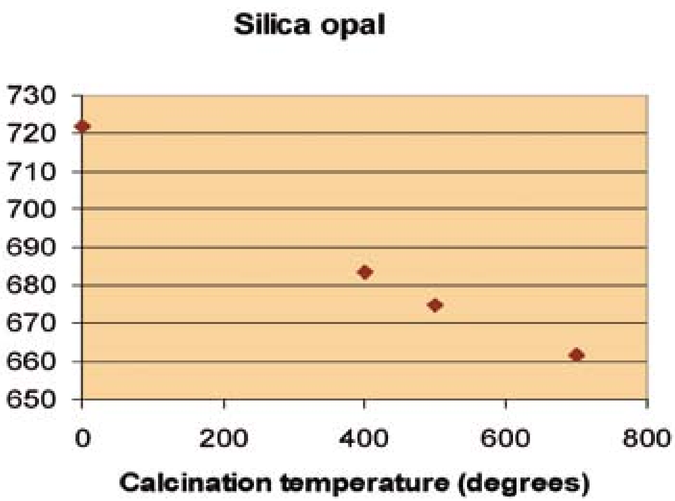


Fig 1. Stopgap peak wavelength as a function of annealing temperature for silica opal. The samples were heated for 3 hours.

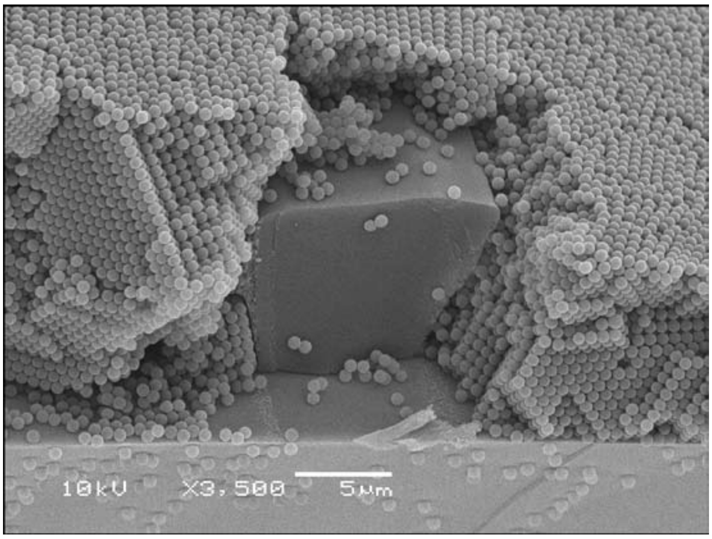


Fig 2. Scanning electron micrograph of Su-8 waveguide on silicon substrate, with silica opal on the sides and top, showing good regularity of the photonic crystal structure.

We have investigated europium ions doped into opals, but we have not been able to observe an effect of the photonic crystal stopgap on the emission, as the Eu ions were doped within the silica microspheres of the opal. In comparison, we have doped nanodiamonds in the interstices of the opal lattice. The typically broadband emission from N-V centres in nanodiamonds has been manipulated by incorporating the N-V centres into polystyrene opals with appropriate stopgaps. Fluorescence lifetime measurements of the emission of N-V centres in free space, and in opals of varying stopgap bands, also show differences that are consistent with stopgap effects in the photonic crystal lattice. N-V centres in diamonds are of interest in quantum optics and quantum information research, as these emitters do not bleach (fade or reduce in intensity) or blink (exhibit downtime) and N-V centres in nanodiamond are promising as single photon sources. Measurement of the photon coincidence from this emitter demonstrates its effectiveness as a single photon source.

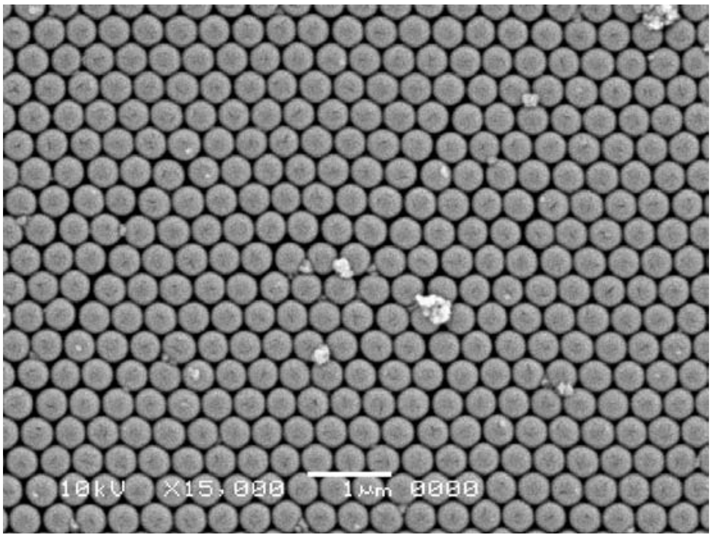


Fig 3. Scanning electron micrograph of nanodiamond particles on the surface of a polystyrene opal.

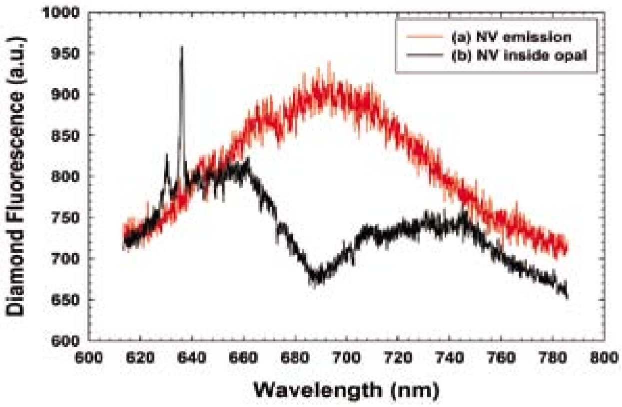


Fig 4. Emission spectra for N-V centres in nanodiamonds on a silica substrate (red) and embedded in opal with a partial bandgap at 690 nm (black).

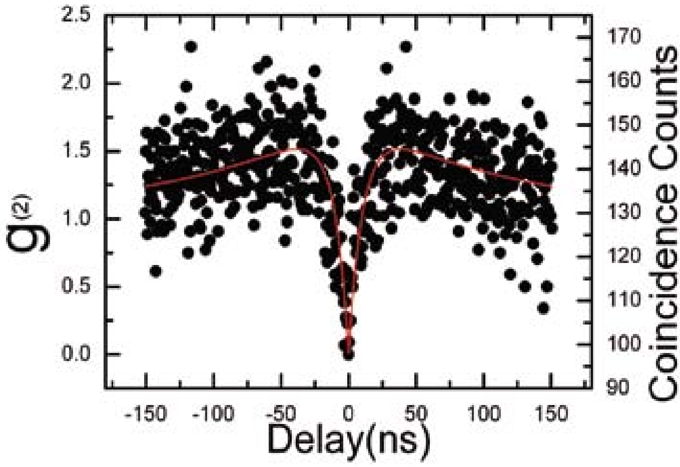


Fig 5. Photon coincidence measurement and normalised second order correlation function of a single N-V centre in nanodiamond in polystyrene opal. The measurements indicate that the emitter is a single photon source.

Using a commercial ND-MDT scanning head, we have constructed a scanning near field optical microscope for use in nanophotonics and plasmonics studies. This microscope offers us the ability to measure with high spatial accuracy and resolution topographical information and to compare this with optical emission from optical waveguides in dielectrics such as glass or crystals. We obtain detailed information on the mechanism of fs laser writing of waveguides, for example as a function of writing beam polarization.

We also used the scanning near field optical microscope to characterise plasmon losses propagating in metallic “nano-wires” with excellent agreement between modelling and experiments. The 50 nm thick gold waveguides were fabricated by ion-assisted deposition, and then fs laser ablation was used to define each micron-wide waveguide. The surface plasmons were excited using a low power laser beam, and their propagation/attenuation along the waveguides were monitored directly using the scanning near field optical microscope to detect scattered light.

Finally, as an outreach activity, we have developed a Photonics simulator to give secondary school students a sense of how photonic networks for communications are constructed, and how messages are coded in binary form. This simulator is available for free web download, currently accessed through the Macquarie CUDOS node: www.ics.mq.edu.au/cudos/education/Simulator.html

Results of trials of an early version of this simulator with school students were discussed at the Uniserve Science conference in October. We obtained funding from SPIE Education and Outreach Fund to support the improvements in graphical interface and new game developments. We have also presented the game to school science teachers, and students attending the Siemens Science Experience recently had their own “hands-on” experience.

Conference papers submitted within CUDOS

A. Strickland, R. Williams, N. Jovanovic, B Johnston, J.M. Dawes “Build your own virtual photonics communication system: a photonics simulator for high school students”, Uniserve Science Symposium Proceedings, Visualisation and concept development, p109-114, Sydney, Oct 2008.

D.M. Haynes, M.J. Withford, J.M. Dawes, R. Haynes, J. BlandHawthorn, “Focal ratio degradation: a new perspective” SPIE Proceedings 7018, Astronomical Instrumentation Marseille, France, June 2008.

L. A. Stewart, Y.H. Zhai. J.R. Rabeau, J.M. Dawes, M.J. Withford, “Controlling emission in diamond doped opals” ICO 21 Sydney 2008 Congress, July 2008.

J. Gosciniak, R Williams, M.J. Steel, G.D. Marshall, J.M. Dawes, “Propagation of surface plasmons on gold metal stripes” ICO 21 Sydney 2008 Congress, July 2008.

S. Ek, L. Stewart, J.M. Dawes, M.J. Withford, “Artificial opals for photonic crystal devices” ICO 21 Sydney 2008 Congress, July 2008. *Sara won the SPIE student prize for this talk.*

D. J. Little, P. Dekker, G.D. Marshall, J.M. Dawes, M.J. Withford, “Spatial correlation of the topographical and mode features of fs laser written waveguides using NSOM” ICO 21 Sydney 2008 Congress, July 2008.

Y.H. Zhai, L. Stewart, M.J. Withford, J.M. Dawes, J.R. Rabeau, “Diamond based single colour centres in an opal photonic crystal” 4th Asia Pacific Conference in Quantum Information Science, July 2008.

M. Ams, D. Little, R.J. Williams, G.D. Marshall, P. Dekker, J.A. Piper, J.M. Dawes, M.J Steel, M.J.Withford, “Overview of laser microfabrication techniques for photonic devices” OECC/ACOFT, *invited talk*, Sydney, July 2008.

J. Rabeau, Y.H. Zhai, L.Stewart, M.J. Steel, J.M. Dawes, M.J. Withford, “Nanodiamond single colour centres in an opal photonic crystal” *invited talk*, XII International Conference on Quantum Optics and Quantum Information, September, 2008, Vilnius, Lithuania.