Chief Investigator: Judith Dawes

CI short biography

Judith Dawes is an Associate Professor in the Department of Physics and Astronomy at Macquarie University, working on photonic crystals, nanophotonic devices, nanoparticles and lasers. She teaches Physics and Photonics, and is a member of Macquarie's MQPhotonics Research Centre. During 2010 she was acting Director for the BSc (Photonics) degree program. She is the Physics and Astronomy Department Director for higher degree research students. During her career, she has supervised more than 30 successful PhD, Masters and Honours graduates and is currently co-supervisor for several research students. She was elected President of the Australian Optical Society in September 2010, is a member of OSA, SPIE and APS, and serves on the Editorial Board of the OSA members' magazine *Optics and Photonics News*. She has served on the technical program committee for CLEO (OSA) from 2009- 11. Judith Dawes received her BSc(Hons) and PhD from the University of Sydney and travelled on a 1-year Rotary International Fellowship to the University of Rochester. She pursued postdoctoral research at the University of Toronto, before joining Macquarie University in 1991.

Key areas of research contribution within the Centre

Judith's research program includes characterisation of light propagation and emission within opals (3D photonic crystals), linked to the 3D Bandgap Confinement flagship program. This includes the fabrication and characterisation of opals and inverse opals as well as waveguides within opals and inverse opals to create photonic devices, and metallised opals for nanoplasmonics. 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. Her group also aims to use waveguides incorporated within the photonic crystals to deliver pump light and extract the emitted light, with the goal of creating more efficient optical amplifiers for light propagating in photonic chips.

Researchers and students

Research students within Macquarie working on some aspect of 3D bandgap effects in photonic crystals are Faraz Inam (PhD), Carlo Bradac (PhD) and Markus Pasch, Michaela Micko, Matthias Brendle (exchange internship scholars from Ulm). Macquarie staff, Dr Peter Dekker, Assoc Prof Mike Steel, Assoc Prof Mick Withford, Dr Jim Rabeau, and Dr Torsten Gaebel also contributed to research on radiation dynamics in photonic crystals. We collaborate with Prof Martin Pemble's group at the Tyndall Institute in Ireland.

Research achievements during 2010

Our major research achievements of 2010 contribute to the flagship program on 3D bandgap confinement, where we aim to control the emission and propagation of light within 3D photonic crystals. We use self-assembly techniques to create opals (3D photonic crystals) from a mono-disperse suspension of polystyrene or silica microspheres. The chemical synthesis of the highly mono-disperse silica microspheres is carried out at Macquarie, using the Stober synthesis learned from our collaborators at the Tyndall Institute in Ireland. Inverse opals are synthesised by infiltrating silica sol-gel glass into the polystyrene opal and baking the structure at high temperature to remove the polystyrene. Tapered optical fibres (fabricated at University of Sydney by Dr Eric Magi) are coated by an opal to investigate the bandgap effect on propagating light. The taper is fixed to the opal substrate and then the opal is assembled around the taper.

We apply nano-diamonds to the opal surface to investigate the effect of the periodic environment on the emission properties of the nitrogen vacancy (N-V) colour centres in the nano-diamonds. The lifetime of the emitters decreases when the emitters are placed on the opal. The lifetime data were recorded only for single emitters that exhibited anti-bunching statistics where the second order correlation function $g^{(2)}$ was less than 0.5. This means that these colour centres are single electron optical emitters, and they can be classified as single photon sources.

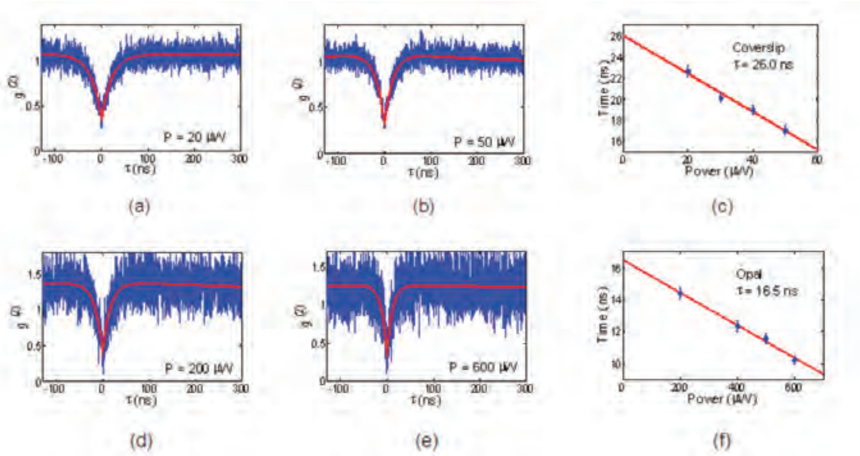

Fig 1: Averaged lifetime measurements for nano diamonds on flat coverslip and on opal showing typical second order correlation measurements.

The emission lifetime measurements are interesting for another reason. The variance in the lifetimes for a sample of N-V centres in nano-diamonds is relatively large compared with the variance for N-V centres in bulk diamond. (The average lifetime for nano-diamond emitters on a silica substrate is comparable with that for bulk diamond). We observe that the lifetime variance is significantly reduced for N-V centres in nano-diamonds scattered on top of an opal layer. This variance is not due to the size of the nano-diamond particles. This has been verified in a separate study by sampling the lifetimes of over 500 nano-diamond emitters on a planar silica substrate and comparing with *in situ* atomic force microscope measurements of the particle size. Our modelling of the emission lifetime as a function of dipole orientation with the substrate surface, shows that the lifetime also depends on local environment of the nano-diamond and on the local curvature of the substrate. A planar dielectric substrate such as a microscope slide leads to a wider range of emission lifetimes than the more corrugated profile of the opal surface for emitters that lie in the interstitial gaps of the opal. The emitters that lie on top of a sphere in the opal also produce a wider range of emission lifetimes, for specific dipole orientations. Measurements of the actual position of nano-diamonds on the surface of an opal (by scanning electron microscopy) show that 65% of the nanoparticles lie in the interstitial gaps compared with 10% lying on top of a sphere. By considering the statistical distribution of nano-diamonds on the opal surface, we find that our modelled lifetime average and variance is consistent within a constant factor with the observed lifetime variance for the different substrates. This work was recently submitted for publication. [1,2].

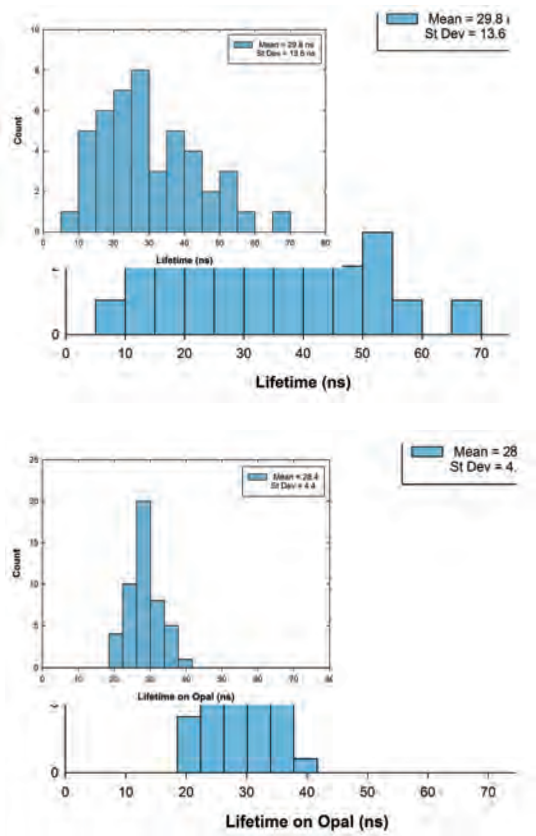

Fig 2: a) Lifetime for nanodiamonds on silica slide
b) Lifetime for nanodiamonds on opal surface

Using a number of novel approaches to opal self-assembly we are developing techniques for fabricating large area opals without cracks. The opal typically cracks as it dries during annealing, but a process of bicapillary growth using a capillary tube in a reservoir to control the opal assembly separately from the solvent evaporation has been successful. Opals with parallel cracks with separations of more than 200 μm have been obtained [3].

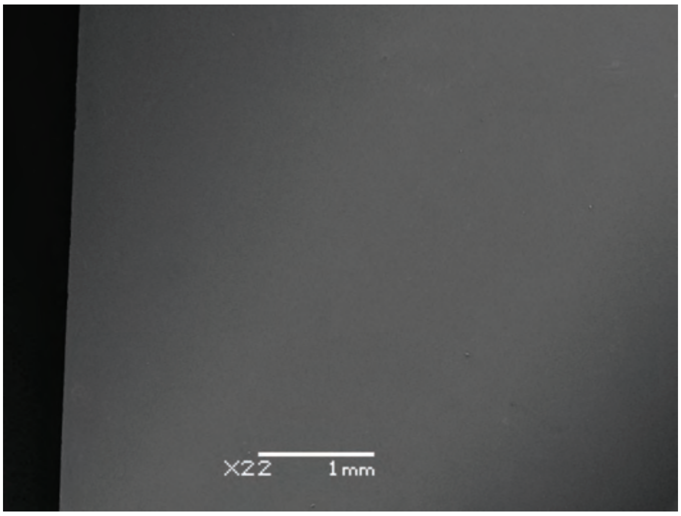

Fig 3: SEM micrograph of crack-free opal showing single domain opal.

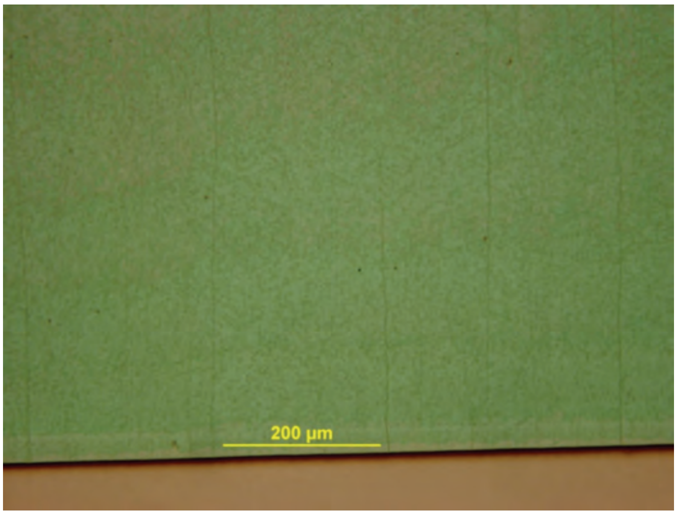

Fig 4: Optical micrograph of opal showing parallel cracks with wide spacing.

Tapered silica optical fibres are waveguides which allow the mode to sample the exterior environment of the guide. Using fibres tapered at the University of Sydney, we have produced opal-coated tapers, with a uniform bandgap (the opal growth direction appears to be radial from the axis of the fibre). The bandgap effect on the light propagating in the fibre is shown in fig. 6.

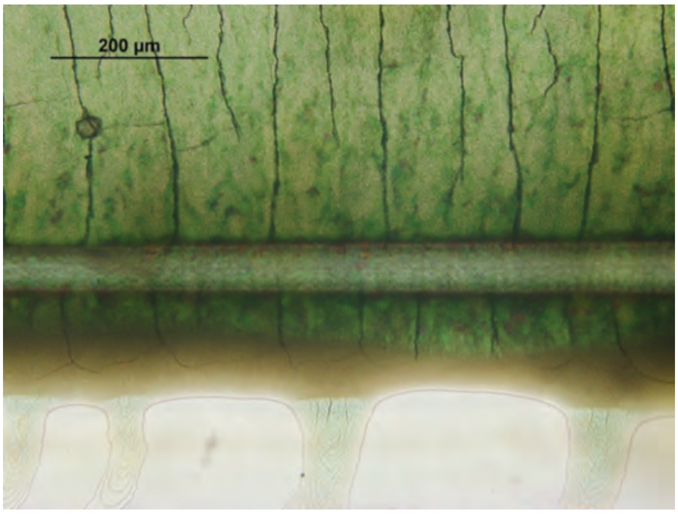

Fig. 5: Opal-covered tapered optical fibre. The bandgap direction is radial from the fibre axis.

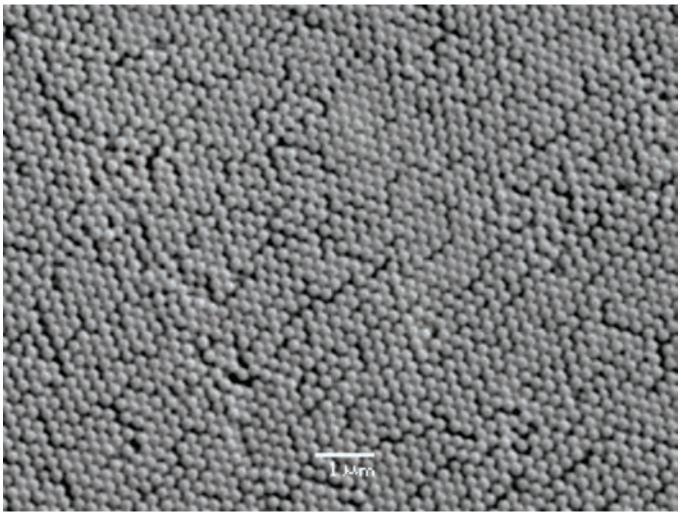

Fig. 7: Metallized silica spheres assembled to form an opal.

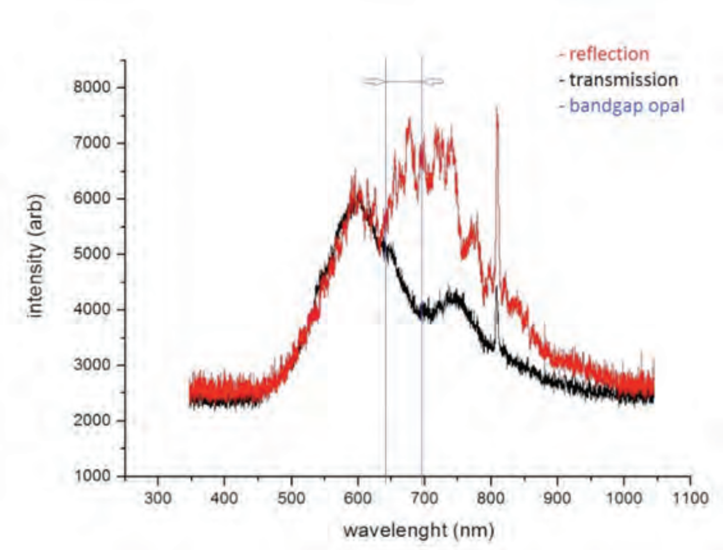

Fig. 6: Transmission and reflection spectra for light propagating along the opal-coated tapered fibre. The corresponding bandgap of the opal (measured perpendicular to the opal surface) is shown in grey. The spikes in the spectra due to the white light source at 808 nm are attributed to the pump laser.

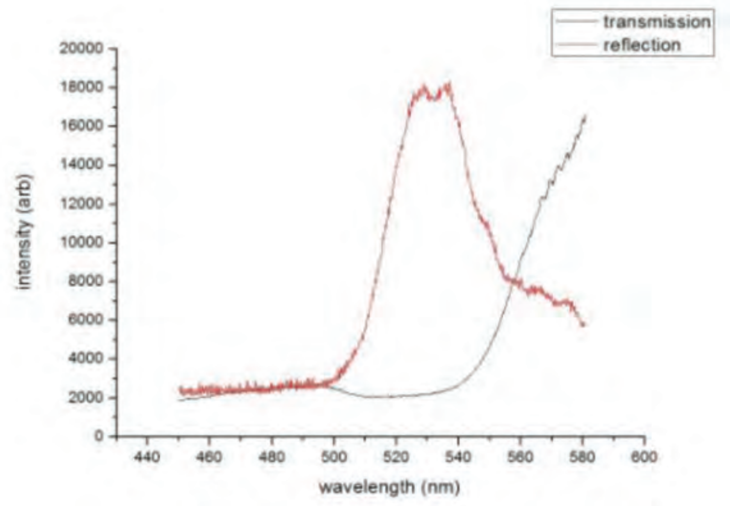

Fig. 8: Transmission and reflection spectra of metallized opal. Bandgap occurs at 530 nm, which is red shifted by the presence of silver coating on silica spheres.

The key feature of a 3D photonic crystal is the potential for it to exhibit a complete bandgap for light. This is difficult to realise with normal opals due to the low refractive index contrast typical of a polystyrene or silica opal. However, the addition of a high refractive index material such as a thin layer of silver allows the possibility of a complete bandgap with simple fabrication techniques. We have created silver coated silica microspheres and then allowed these to self-assemble to form an opal. We have also investigated electro deposition of silver to an opal as an alternative fabrication technique. The optical properties of the silver-coated opals are consistent with expectations, although there is significant loss for light propagating in the material.

Our work in photonics outreach has continued in 2010, with the Photonics Simulator in demand as a hands-on activity for secondary school students. Together with the OSA Student Chapter at Macquarie who operated laser maze and laser graffiti outreach activities, we have worked with over 500 students from over a dozen schools, engaging the students to learn more about photonics and optics.

1. "Enhanced spontaneous emission from nanodiamond colour centres on opal photonic crystal" F Inam, T Gaebel, C Bradac, L Stewart, M Withford, J Dawes, M Steel, J Rabeau, http://arxiv.org/abs/1102.0051
2. "Spontaneous Emission from Nanodiamond NV Color Centers on Structured Surfaces" M Steel, F Inam, T Gaebel, C Bradac, L Stewart, M Withford, J Dawes, J Rabeau, accepted, CLEO 2011.
3. "Fabrication of large single domain photonic crystals" M Pasch and J Dawes, AIP Congress 2010.