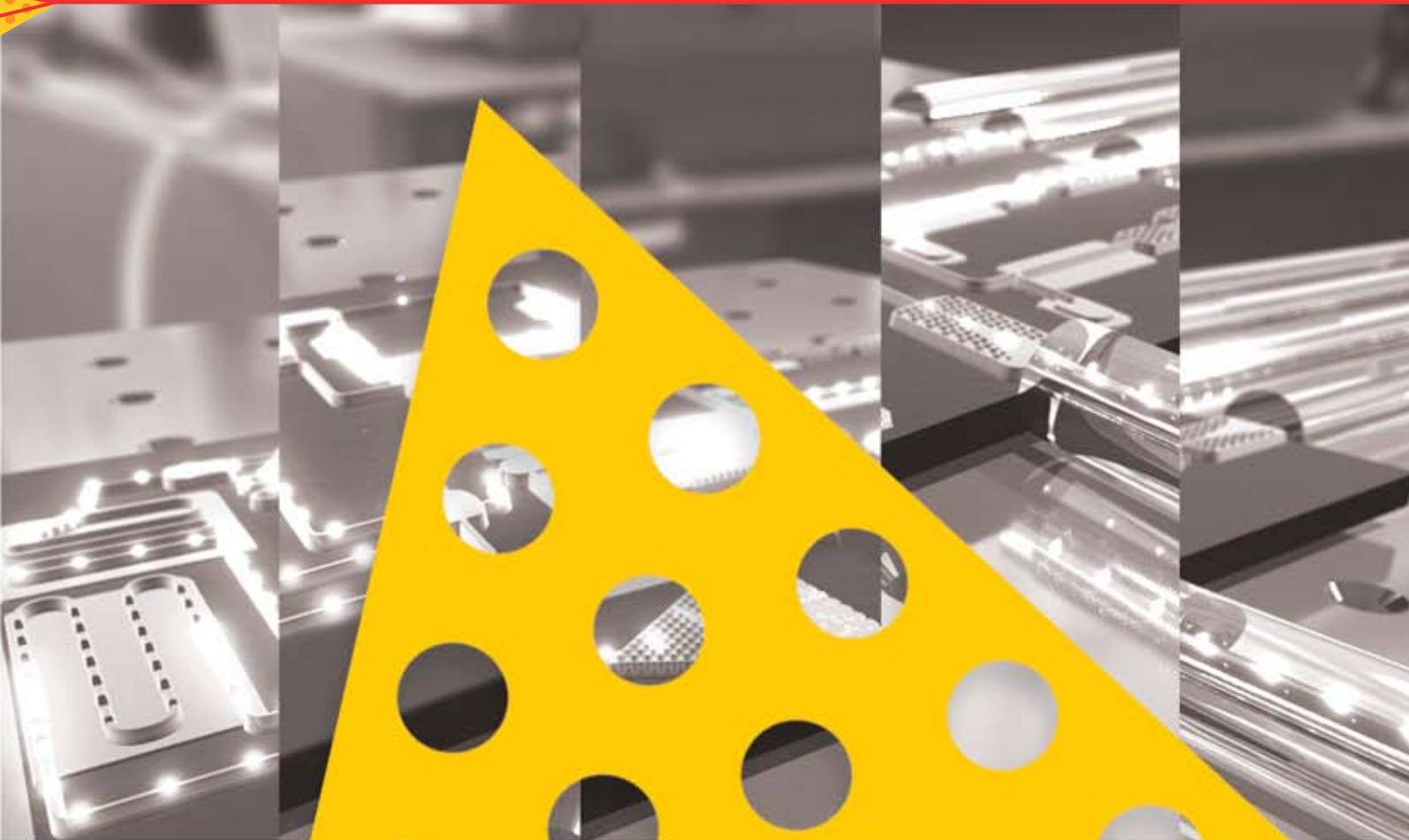




CUDOS

The Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS)
An Australian Research Council Centre of Excellence



Annual Report 2007



Min Gu, a University Distinguished Professor in optoelectronics, is a Node Director of the CUDOS and the Director of the Centre of Micro-Photonics at Swinburne University of Technology. His research interests span nanophotonics and biophotonics with internationally renowned expertise in nanophotonics, biophotonics and three-dimensional optical imaging theory. Prof. Gu is a Fellow of both the Australian Academy of Technological Sciences and Engineering and the Australian Academy of Science. He is also a Fellow of the Australian Institute of Physics, the Optical Society of America and the International Society for Optical Engineering. He is a topical editor of *Applied Optics: Optical Technology and Biomedical Optics* of the Optical Society of America, a topical editor of *Optics and Photonics Letters* (Singapore). He has been appointed as a member of the Fellows and Honorary Members Committee of the Optical Society of America. During 2007, Prof. Gu was a Bureau member and the Vice-President of the International Commission for Optics, the Vice President of the International Society of Optics with Life Sciences, member of the Council of the Australian Optical Society, a member of RQF Journal Ranking Committee, Australian Academy of Technological Sciences and Engineering and a member of International Committee, Australian Academy of Science. He presented 5 (CUDOS related) invited talks at international conferences during 2007. He also served on the editorial boards of the 13 international journals.

Key areas of research contribution within the Centre

3D photonic crystal fabrication in various materials

Radiation dynamics of infrared QDs inside 3D photonic crystals

Photonic crystal based devices such as superprisms and microcavities.

Roles and responsibilities within Centre

Prof. Gu is a member of the Executive Committee, a node leader at Swinburne, and Science Leader of the Flagship project entitled 3D bandgap confinement. Dr. Baohua Jia is the manager of this project.

Awards, honours, major international visits

Professor Gu was elected to the Australian Academy of Science in 2007 for his work on 3D optical imaging theory, biophotonics and

◀ Professor Min Gu

nanophotonics. There were just 16 Fellows elected in Australia in 2007. Prof. Gu was the only Fellow elected in the section of Physics and Astronomy. Professor Gu has joined the elite group of scientists who are Fellows of both the Australian Academy of Technological Sciences and Engineering and the Australian Academy of Science.

Professor Min Gu was awarded a Cheung Kong Scholars Program Guest Professor in the field of Biophotonics from the Chinese Ministry of Education. The Cheung Kong Professorship award is one of the most prestigious academic awards in China. The Guest Professor Award is given to professors who have outstanding academic distinctions abroad to participate in research activities at high-ranked universities in China.

Professor Min Gu conducted international scientific visit to the following laboratories:

- Huazhong University of Science and Technology, China, 29-30 March 2007
- Universidad Autonoma de Madrid, Madrid, Spain, 14-15 April 2007
- Ecole Polytechnique Federale De Lausanne, Switzerland, Sept 7-Oct 7, 2007. During this visit, Prof. Gu was awarded a visiting professorship.
- Padova University, Italy, Sept 21 2007
- Fudan University, China, 3-9 November 2007
- National Taiwan University, Taiwan, 3-4 December 2007.

Dr. Baohua Jia and Mr. Jiafang Li conducted international scientific visit to the following laboratories:

- 4. Physikalisches Institut, University Stuttgart, Germany, 20 -22 June 2007
- Max-Planck institute, Stuttgart, Germany, 21 June 2007

International linkages

- University of Oxford, UK. We have built long term collaboration with Prof. Tony Wilson (CUDOS PI) and Dr. Martin Booth on adaptive optics. Two joint international collaboration grants (Investors: Min Gu, Tony Wilson, Martin Booth, Guangyong Zhou) from the *Leverhulme Trust* (UK) and *ARC Linkage International* have been awarded to support this project for three years.
- Universidad Autónoma de Madrid, Spain. This is a newly initiated collaboration between the CMP and Prof. Daniel Jaque's group on photonic crystal fabrication and characterisation in rare earth ion doped lithium niobate crystals. An Australian Academy of Science *Scientific Visit* grant has been awarded to Dr. Guangyong Zhou to strengthen this collaboration.
- Padova University, Italy. To develop quantum dots-doped chalcogenide glass nanocomposite, we have initiated collaboration with Prof. Alessandro Martucci's group in Padova University. This international linkage is a key step towards the achievement of the complete control of radiation emission with complete bandgap materials.
- Sun Yat-Sen University, China. The collaboration with Prof. Xue-Hua Wang's group will provide strong theoretical support for the photonic crystal project.

- University Laval, Canada. We have initiated collaboration with Prof. Yunlong Sheng's group on the plasmonic effect of photonic crystals.
- Massachusetts Institute of Technology, USA. Prof Barry R. Masters.

Key areas of research

The CUDOS group at Swinburne, headed by Professor Min Gu, is located at the Centre for Micro-Photonics (CMP). It includes three researchers (Dr. Guangyong Zhou, Dr. Baohua Jia and Mr. Michael Ventura), two PhD students (Mr. Jiafang Li and Ms Elisa Nicoletti), one Honours student (Mr. Stephen Weber) and one administrative staff Ms Johanna Lamborn. In May 2007, Elisa joined us for her PhD and works on 3D photonic crystal fabrication in chalcogenide glass. Congratulations to Michael for the submission of PhD thesis and continuing his work as a postdoctoral fellow at CMP. Dr. Shuhui Wu left CMP in the middle of February 2007 to take another position at The University of Melbourne. Thanks for all her contributions during the past three years.

Our contributions to the CUDOS include 3D photonic crystal fabrication in various materials, photonic crystal based devices such as supreprisms and microcavities, radiation dynamics of near-infrared QDs in photonic crystals. Some of the activities form a core of the CUDOS Flagship Project of *3D bandgap confinement*.



Research achievements during 2007

Successful measurement of inhibition and enhancement of spontaneous emission of QDs in polymeric 3D PCs in telecommunication wavelength

One of the most outstanding outcomes in 2007 is that for the first time **Mr. Michael Ventura** and **Mr. Jiafang Li** have successfully measured the radiation dynamics of PbS and PbSe QDs incorporated into 3D photonic crystals in telecommunication wavelength region by using the direct doping method and the infiltration method, respectively. This is a crucial step towards integrated active photonic devices and contributes significantly to the overall goal on photonic chip. These important results have been published in one of the most highly cited journal: *Advanced Materials* [1-3]. More details on this project can be found in the *Flagship project: 3D bandgap confinement*.

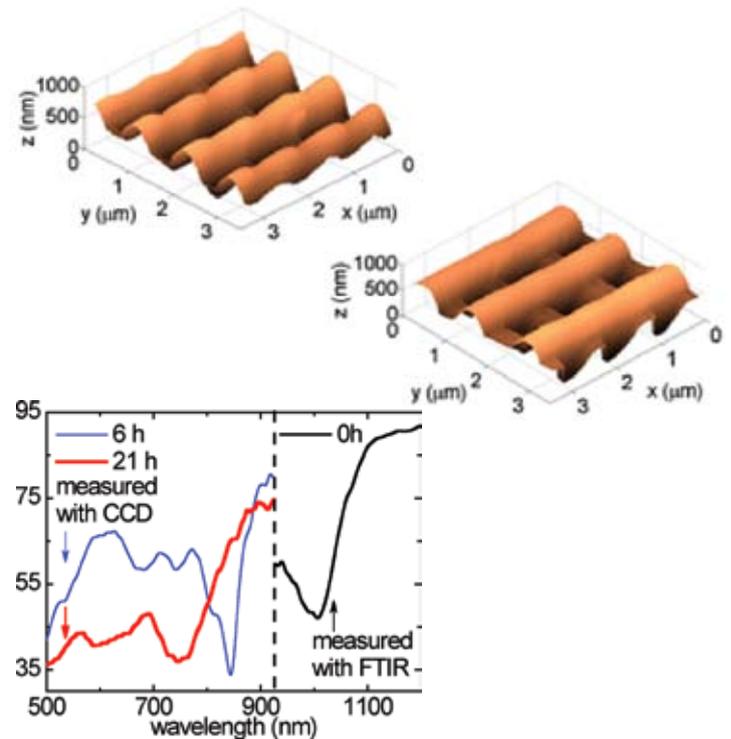
3D photonic crystals in Chalcogenide glass with higher order band gap

Another important milestone achieved in 2007 is that, Miss Elisa Nicoletti has successfully fabricated 3D woodpile photonic crystals in arsenic trisulphide (As_2S_3) thin films, which were prepared by Prof. Luther-Davies's group at ANU, by using the direct-laser-writing method [4]. Not only the fundamental bandgaps but also

the higher order band gaps were observed indicating the high quality of the photonic crystals. This significant achievement promises to enable a variety of nonlinear functional devices based on 3D high index photonic crystals and is strategically important for the entire CUDOS vision on a photonic chip. More details can be found in the Flagship project: *3D bandgap confinement*.

Visible photonic band gap in polymer based woodpile photonic crystals

Mr. Jiafang Li and **Dr. Baohua Jia** has made a significant breakthrough in the two-photon polymerisation method. They can tune the photonic band gap from 1050 nm to 720 nm and improve the quality of the structures by engineering the post treatment conditions. This significantly expands the potential applications of direct laser writing method and leads to potential photonic devices in visible wavelengths.

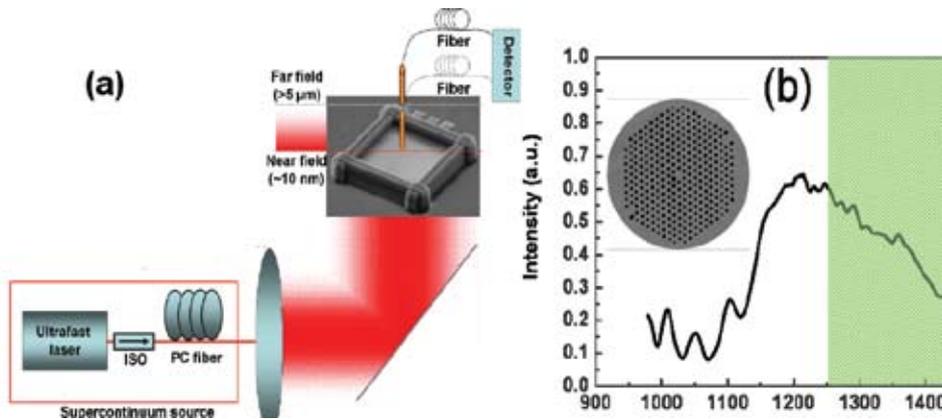


Top left: Atomic force microscope image of structure before post treatment; top right: after post treatment; bottom: transmission spectra of a woodpile PC showing a bandgap moving towards visible wavelength after the post treatment

Near-field mapping 3D photonic crystal to understand fundamental physics

During the past few years, great efforts have been spent on understanding the light-matter interaction within 3D photonic crystals. However the experimental attempts were hindered to some extent due to the limitation of far-field optics, which capture only the averaged signals. To overcome this problem **Dr. Baohua Jia** has been working on characterising the detailed local intensity distributions in three-dimensional (3D) photonic crystals (PCs) by utilising a scanning near-field optical microscope (SNOM) (see the setup below). Highly correlated topographic and optical signals of the PCs can be simultaneously obtained with sub-wavelength resolution. The optical signals from the SNOM, particularly the near-field part, reveal the variations of the mode confinement and light propagation in the PCs at different wavelengths. To cover the near infrared bandgap of the PCs supercontinuum generation in a polarization maintaining PC fibre (the cross-section of which is shown in the inset in (b)) has been employed as the broad band source. The supercontinuum spectrum spans from 500 to 1700 nm, which covers the bandgap region of the PCs ranging from 1200

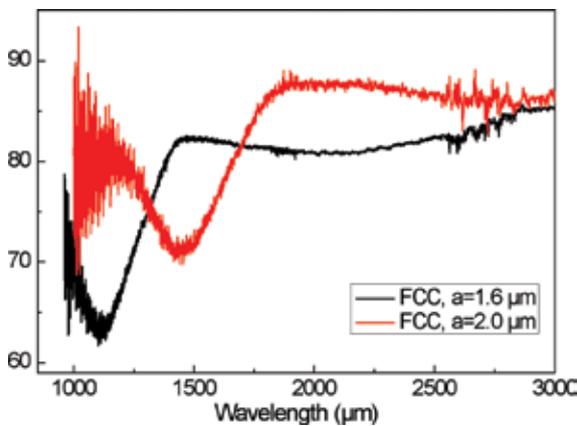
nm to 1500 nm. Characterization of local mode distribution and photonic bandgap has been undertaken by precisely positioning the near-field probe with respect to the 3D PCs.



(a) Schematic of the experimental setup for characterising 3D PCs with a SNOM under supercontinuum illumination. (b) Supercontinuum spectrum generated by exciting a nonlinear PCF with femtosecond pulses. Shaded area indicates the position of the stop gap. The top inset is a SEM image of the cross section of the PCF.

Photonic crystals in active lithium niobate

Lithium niobate is considered to be a good candidate for nonlinear photonic crystal fabrication due to its high refractive index of 2.2, large transparent range of 0.5-5 μm and large nonlinearity. Another advantage is that it can be easily doped with rare earth ions, for example Nd^{3+} and Tm^{3+} whose emission can match the telecommunication wavelength. Airán Ródenas Seguí, a visiting PhD student, together with **Guangyong Zhou** has successfully fabricated 3D face-centered-cubic void based photonic crystals in Nd^{3+} doped lithium niobate crystal by using femtosecond laser induced micro-explosion method. One can see that for a fabricated photonic crystal with a lattice constant of 2 μm , the band gap exists at the telecommunication wavelength of 1.5 μm which exactly matches the emission from the Nd^{3+} . This will allow us to study the emission control by using photonic crystals and design functional devices including a low threshold laser.



FTIR transmission spectra of fcc PhCs with lattice constants of 1.6 μm and 2 μm fabricated in Nd^{3+} doped lithium niobate

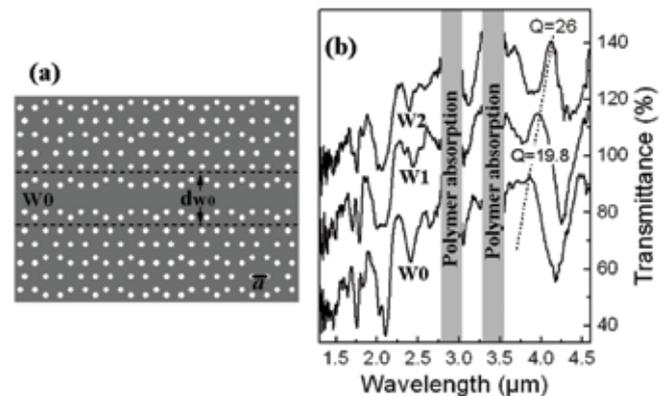
Photonic quasi-crystal – another platform to control light

Apart from periodic photonic crystals, another class of structures with quasi-periodic lattice, called photonic quasi-crystals (PQCs),

has attracted a considerable attention. PQCs have neither a true periodicity nor a translational symmetry, but have a quasi-periodicity that exhibits a long-range order and an orientational symmetry.

2D PQCs have high-order rotational and mirror symmetries. Recent studies have demonstrated that 2D complete PBGs can also exist in several quasi-periodic patterns. Compared with PhCs, the main advantage for the PQCs is that they can open a complete PBG with much lower refractive index contrast. **Dr. Guangyong Zhou** has fabricated 2D 8-fold photonic quasicrystal in a polymer material by using two photon induced microexplosion method.

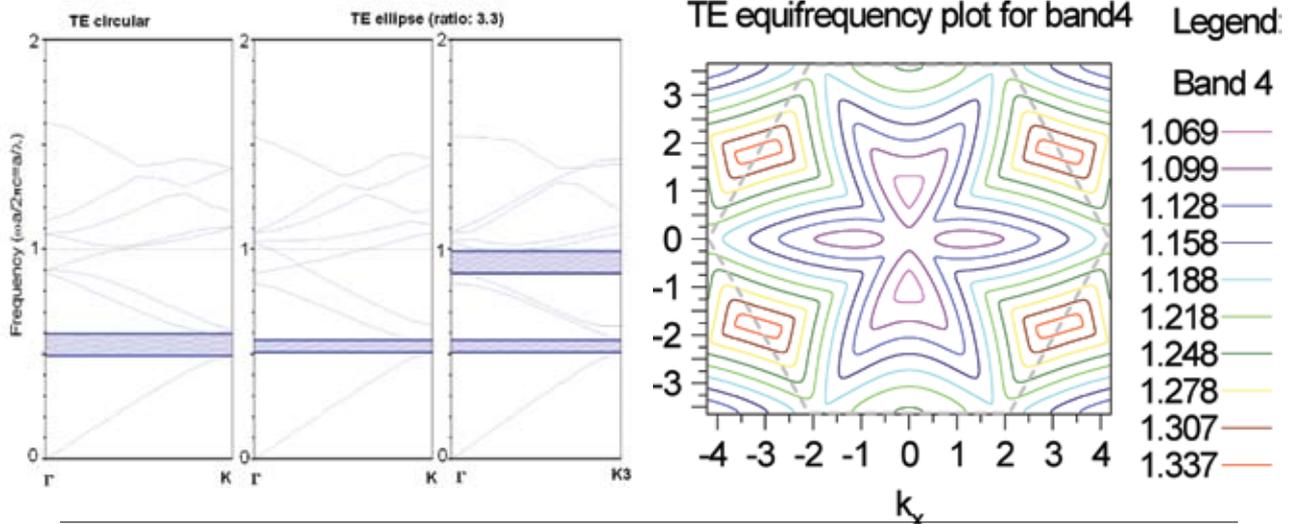
Substantial photonic band gaps have been observed. A planar waveguide has been introduced and multi-order F-P cavity modes have been observed. The effective waveguide, which is wider than the physical width, can be inferred from the position of waveguide modes for different sizes of waveguide [5].



Sketch of the planar waveguide in the middle of the PQC (a); waveguide modes with different size of waveguides (b)

Engineering the photonic band gap and superprism effect of 2D photonic crystals by changing the element shape

Although 2D photonic crystals fabricated in low refractive index materials do not have a complete photonic band gap, they have some unique properties. For example polarisation-dependent superprism [1] could be widely used in all-optical chips. The band gap and hence the superprism can be optimized by engineering the shape of the element. Stephen Weber picked up the task as his Honours project with us. By using the R-SOFT program, he observed an enhanced higher order band gap which is even wider than the fundamental gap at Γ -K3 direction after changing the shape of rod from circular to ellipse. This observation is particular important because one aims at getting band gap at visible wavelength at this direction. As the elliptical rod has reduced symmetry compared to the circular one, the equal frequency contours and therefore the superprism effect are also changed. He also fabricated 2D photonic crystals with horizontal rods by using the two-photon polymerization method and obtained good structures with an obvious band gap.



Left: Band gap splitting at Γ -K direction; right: Equal frequency contours for photonic crystal with ellipse rods

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