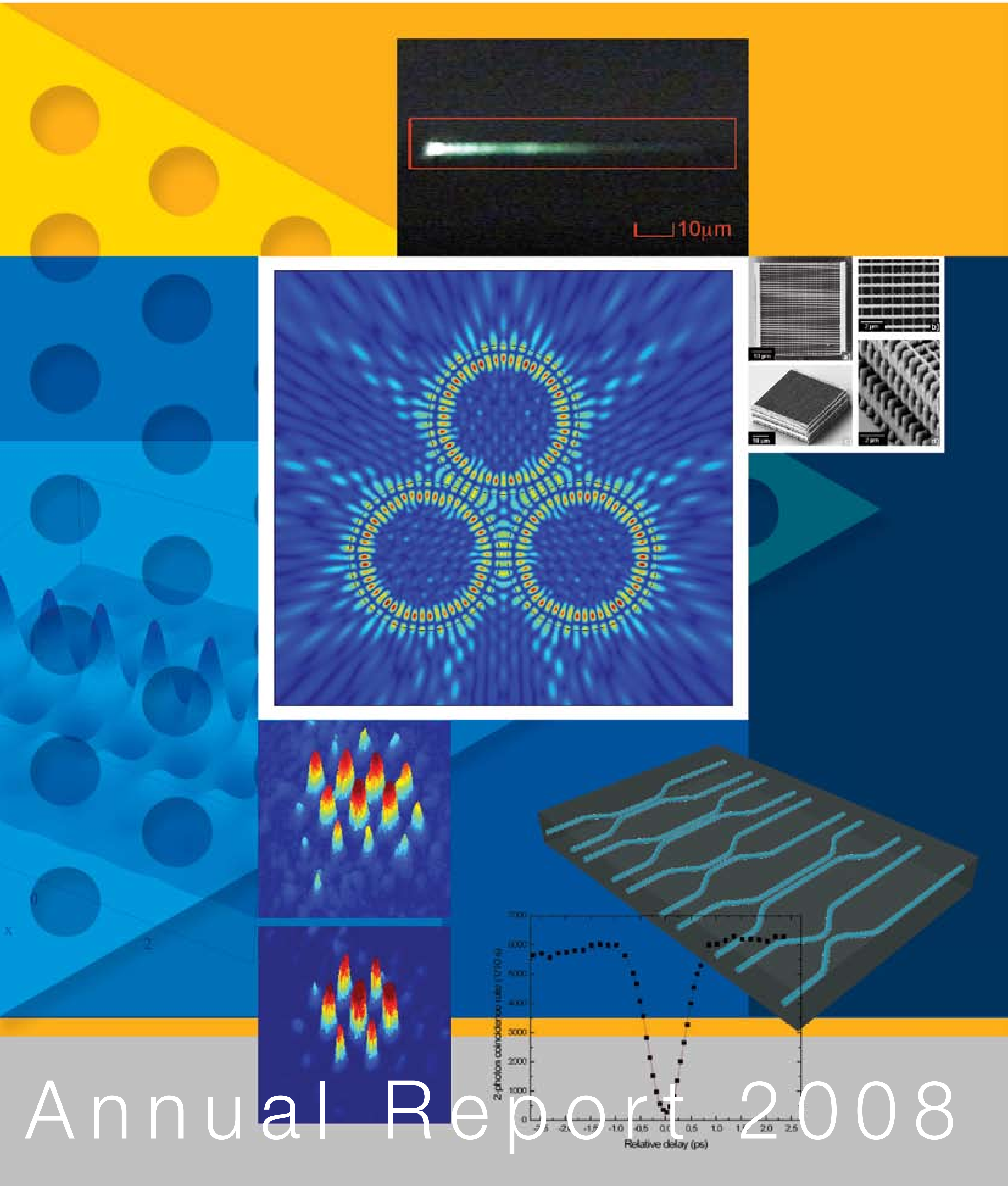
CUDOS

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



Annual Report 2008

CI short biography

Min Gu, a University Distinguished Professor in optoelectronics, is a Node Director of CUDOS and the Director of the Centre of Micro-Photonics at Swinburne University of Technology. His research interests include nanophotonics and biophotonics with internationally renowned expertise in photonic crystals, optical data storage, optical endoscopy, and multi-dimensional optical data storage. 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, the International Society for Optical Engineering, the Institute of Physics and a Senior Member of International Institute of Electric and Electronic Engineers. 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 2008, 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, and a member of International Committee, Australian Academy of Science. He presented 6 (CUDOS related) invited talks at international conferences during 2008. 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 photonics 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, a coordinator of the Flagship project entitled 3D bandgap confinement. Dr. Baohua Jia is the manager of this project.

Awards, honours, major international visits

From 2008, Prof. Gu served as a member of the International Science Linkages (ISL) Assessment Panel, Department of Innovation, Industry, Science and Research (DIISR) and the Sectional Committee on Applied Physical and Engineering Sciences, Australian Academy of Science (2008-2011). In 2008, he became a Senior Member of IEEE and a Fellow of the Institute of Physics, UK.

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

- Singapore National University, Singapore, 6-9 January 2008.
- National Taiwan University, 9-11 June 2008
- Shizuka Unievrsity, Shizuoka, Japan, 17-18 Novermber 2008
- Shanghai JiaoTong University, China, 5 March 2008
- IEEE Chapter in Gainesville, FL and University of Florida, USA, 14 March 2008
- Zhejiang University, China, 20 September 2008.
- Hong Kong Polytechnic University, Hang Kong, 6 November 2008

The following persons in his group has conduct international scientific visit /given invited talks/received Awards:

- **Dr. Jia and Dr. Dario Buso both succeeded in the 2008 round ARC application and received the prestigious ARC APD Fellowship. Congratulations!**
- Dr. Zhou visited University of Oxford, UK, 8-27 June 2008
- Dr. Zhou visited Universidad Automatic de Madrid, Spain, 29 May – 7 June 1 2008.
- Dr. Jia visited Zhejiang University, China, 27 March 2008.
- Dr. Zhou and Dr. Jia, together with Prof. Gu, co-organised a session *Femtosecond Photonics: Two Photon Polymerisation And Optical Data Storage* in the 2008 PIERS conference and gave invited talks separately.

International linkages

- University of Oxford, UK. A long term collaboration with Prof. Tony Wilson (CUDOS PI) and Dr. Martin Booth on adaptive optics has been built and consolidated. With the support from two joint international collaboration grants (Investors: Gu, Wilson, Booth, Zhou) from the *Leverhulme Trust* (UK) and *ARC Linkage International* and mutual scientific visits, significant progress has been made in the experimental adaptive aberration compensation.
- Universidad Autónoma de Madrid, Spain. This newly initiated collaboration has been consolidated through a scientific visit by Dr. Zhou to Dr. Jaque's group with the support from Australian Academy of Science under the Scientific Visit to Europe Scheme. Strong modification of erbium ion emission has been observed in photonic crystals fabricated in Erbium doped lithium niobate crystal.
- Sun Yat-Sen University, China. The collaboration with Prof. Xue-Hua Wang's group will provide strong theoretical support for the photonic crystal project. A joint ARC Discovery grant has been awarded to Dr. Baohua Jia and Prof. Wang (PI) to support this project for three years (2009-2011).
- Institute of Optics and Electronics, Chinese Academic of Sciences, China. This is a newly initiated collaboration in the

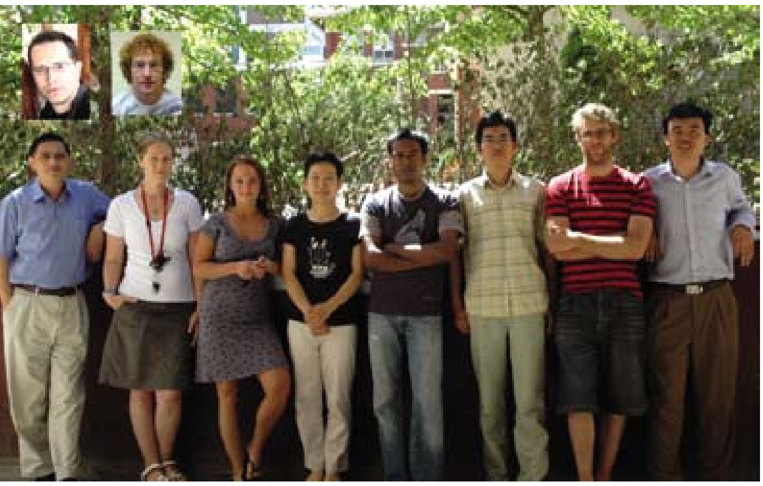
field of plasmonics. Prof. Chunlei Du has well recognized reputation in the field of micro/nano fabrication, optical components/ systems design. Prof. Du visited Centre for Micro-Photonics for three months in the second half of 2008.

- 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.

Describe key areas of research activities

The CUDOS group at Swinburne, headed by Professor Min Gu, is located at the Centre for Micro-Photonics (CMP). It includes four researchers (Dr. Guangyong Zhou, Dr. Baohua Jia, Dr. Michael Ventura and Dr. Dario Buso), three PhD students (Mr. Jiafang Li, Ms Elisa Nicoletti and Ms MD Muntasir Hossain), one Honours student (Mr. Benjamin Cumming) and one administrative staff Ms Johanna Lamborn. In April 2008, Muntasir joined us as a PhD student in the field of radiation control by metallic photonic crystals. Dr. Dario Buso joined CUDOS group at the beginning of 2008 as a Visiting Postdoctoral Fellow working on novel co-shell quantum dots synthesis. After one year of work, he left us and took up a research position at CSIRO. Thanks for all his excellent contributions in the past year.

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



Research achievements during 2008

3D photonic crystal fabrication in chalcogenide glasses (by Miss **Elisa Nicoletti**) and adaptive aberration compensation in high refractive index materials (by Mr. **Ben Cumming** and Dr. **Guangyong Zhou**) are reported in detail in the *Flagship project: 3D bandgap confinement.* The following is the highlights of other achievements in 2008.

Band gap engineering of different higher order band gap for spontaneous emission control

The ability to control spontaneous emission, in particular quantum dot (QD) radiation in three-dimensions (3D) allows for a method towards the development of the next generation of active photonic devices [1,2]. To make a comparison between the fundamental, main and higher orders stop-gaps, band calculations were conducted by Dr. **Michael Ventura** on polymer woodpile lattices

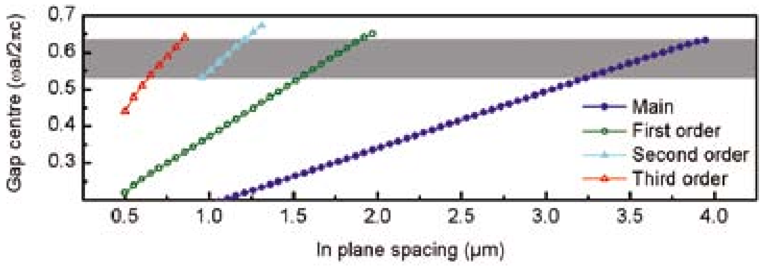


Fig 1. The mid-gap position for different order band gap as a function of the in-plane spacing.

using experimentally achievable in-plane and layer-spacing. A regime has been found in (fig. 1) which the in-plane spacing of the PC can be varied while keeping the layer spacing and channel cross sections fixed allowing for the main (solid blue circles), the first (hollow green circles), the second (solid light blue triangles) and the third higher order stop gaps (hollow red triangles) to fall in the same frequency band (grey region) via careful selection of in plane spacing. PCs will now be fabricated using these parameters and time-correlated single-photon counting (TCSPC) techniques will be applied to further understand the effects of stop-gap order on spontaneous emission. Dr. **Ventura**, together with Mr. **Jiafang Li**, has set up an automatic 3D lifetime/fluorescence measurement system at CMP. This system can record fluorescence and lifetime at each point and later re-construct into 3D lifetime distribution across 3D structures. This instrument enables us to study the local density of state inside 3D photonic crystals.

Photonic band gap tuning through chalcogenide glass coating

High refractive index and high nonlinearity are desirable materials for functional photonic crystal based devices. Compared with the direct laser fabrication in high refractive material in which the strong aberration is always a problem, polymer template infiltration is a relative easier way to achieve the same goal. Dr. **Dario Buso** invented a controllable CdS deposition method from an aqueous solution. The very low solubility product of CdS is the driving force that minimizes the homogeneous precipitation of CdS crystals in the liquid, hence promoting the chalcogenide formation directly on the Ormocer surface. Each circle of deposition can produce a layer of CdS with a thickness of approximately 230nm with a refractive index of 2.28 at 850 nm. Multi step deposition can produce thicker CdS film. 3D photonic crystal templates were fabricated by Mr. **Jiafang Li** with hybrid sol-gel Ormocers by using a direct laser writing technique. SEM characterisation shows homogeneous CdS deposition can be deposited on the woodpile structure's pillars. Smooth surfaces are obtained tuning the deposition conditions, such as temperature, PH value and precursors concentration. A 375 nm band-gap shift was obtained after deposition of 4 layers and a 5% increase of the band-gap amplitude is also obtained after deposition of 2 CdS layers, a result consistent with presence of higher refractive index CdS on the structure's pillars.

Photonic crystal fabrication using radially polarised beam

A radially polarised beam [Fig.2(a)] has attracted much interest in recent years due to its capacity to dramatically increase the resolution. As such, various applications including microscopic imaging, optical laser trapping have been demonstrated. Indeed, radially polarised beam showed many superior properties compared with linear or circularly polarised beams. However, so far the utilisation of such a beam in femtosecond laser fabrication has yet to be demonstrated. By combining the radially polarised beam with the two-photon polymerisation (2PP) technique, 3D photonic crystals (PCs) have been fabricated by Dr. **Baohua Jia**, as shown in [Fig.2(b)]. As expected, the lateral resolution of

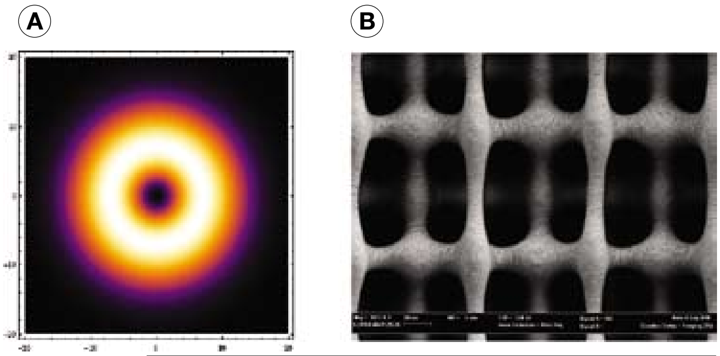


Fig 2. (a). Radially polarised beam (b). SEM image of 3D woodpile structure fabricated using the radially polarised beam.

a single rod in the fabricated PC has been greatly improved by 60 nm compared with linearly polarised beam under the same fabrication condition.

Radiation control of Erbium ions by active photonic crystals fabricated in Er-doped 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 Er^{3+} and Tm^{3+}, whose emission can match the telecommunication wavelength. In collaboration with Universidad Autonoma de Madrid, Dr. **Guangyong Zhou** investigated the radiation control of Er^{3+} ions by the photonic crystals. High quality photonic crystals with band gap covering the wavelength of 1.6-2.4 μm in rare earth ion doped lithium niobate crystal were fabricated. Fluorescence measurement shows that the emission of Er^{3+} is significantly inhibited by the photonic band gap which matches the wavelength of Er^{3+} emission [3]. (Fig. 3) Laser induced material modification has also been investigated [4]. By further improving the quality of photonic crystal and optimising the level of doping, active photonic devices like low threshold lasers are possible.

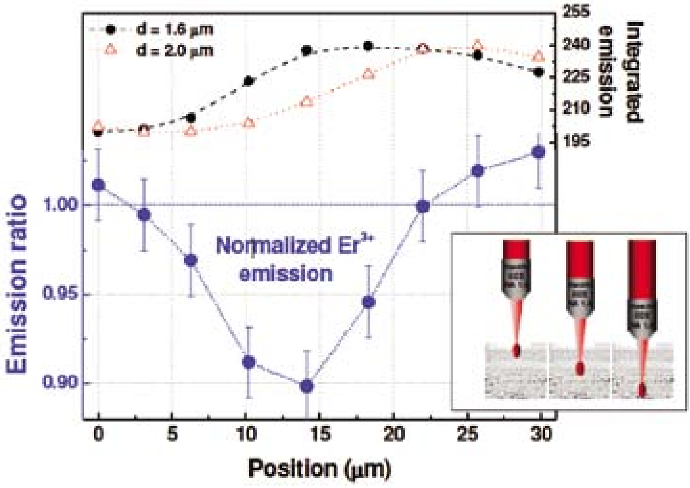


Fig 3. Spontaneous emission control of Er^{3+} by using 3D lithium niobate based photonic crystals.

Active photonic structures in Nd-doped yttrium aluminium garnet laser ceramics (Nd:c-YAG) for microlasers

Nd-:cYAG is one of the most promising materials in the field of photonic laser technology since it combines the unique laser properties of Nd:YAG crystals with the large-scale, flexible, and cost-effective production processes of ceramics. We fabricated a 3D photonic structure by using the direct laser writing technique, showing a stop band centered at 2.4 μm, in a Nd:YAG transparent laser ceramic [5]. (Fig. 4) The submicron voxels constituting the 3D structure have been characterized by a combination of CLSM and confocal luminescence experiments. We have found that the modulation of the refractive index is accompanied by a slight modulation of the luminescence intensity of neodymium ions located inside the voxel structures. Furthermore, we have also reported on the modifications that the direct laser fabrication process imposes over the spectral and dynamical properties of the Neodymium ions inside the photonic structure. The results also make Nd:c-YAG ceramics, in combination with the DLW technique, a very promising candidate for applications such as low-threshold lasers, based on the manipulation of the spontaneous emission of the Nd^{3+} ions.

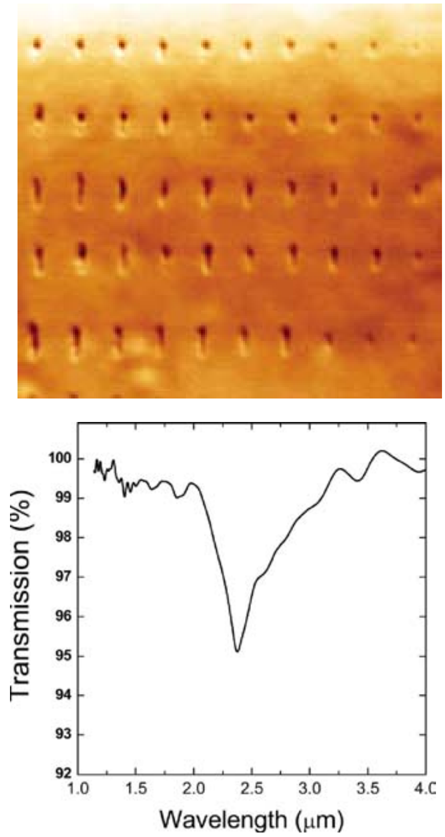


Fig 4. Transmission microscopy image of the side view of fabricated voids in YAG ceramics (top) and measured transmission spectra showing an obvious bandgap (bottom).

3D metallic photonic crystals with near infrared band gap

Metallic photonic crystals (MPCs) can offer more advantage over conventional dielectric photonic crystals for specific nanophotonics applications e.g. spontaneous emission control, waveguides etc. due to their complete, strong and large photonic band gaps. Significant progress has been made in both experiments and theoretical simulation on this topic. Mr. **Jiafang Li** has successfully fabricated three-dimensional (3D) metallodielectric photonic crystals (MDPCs) in the near-infrared wavelength (NIR) range. The realisation of 3D MDPCs starts from woodpile PC templates [Fig.5(a)] fabricated with two-polymerisation (2PP) technique. Subsequently, the surfaces of the woodpile PCs are chemically functionalised and thin layers of silver nanoparticles are deposited on the surfaces of the woodpiles with an electroless silver deposition method [Fig.5(b)]. The high quality of the silver-coated woodpile [Fig.5(c)] has an enhanced reflection of more than 90% at 1.66 μm. Further studies with this deposition method would result in complete photonic band gaps and lead to promising photonic

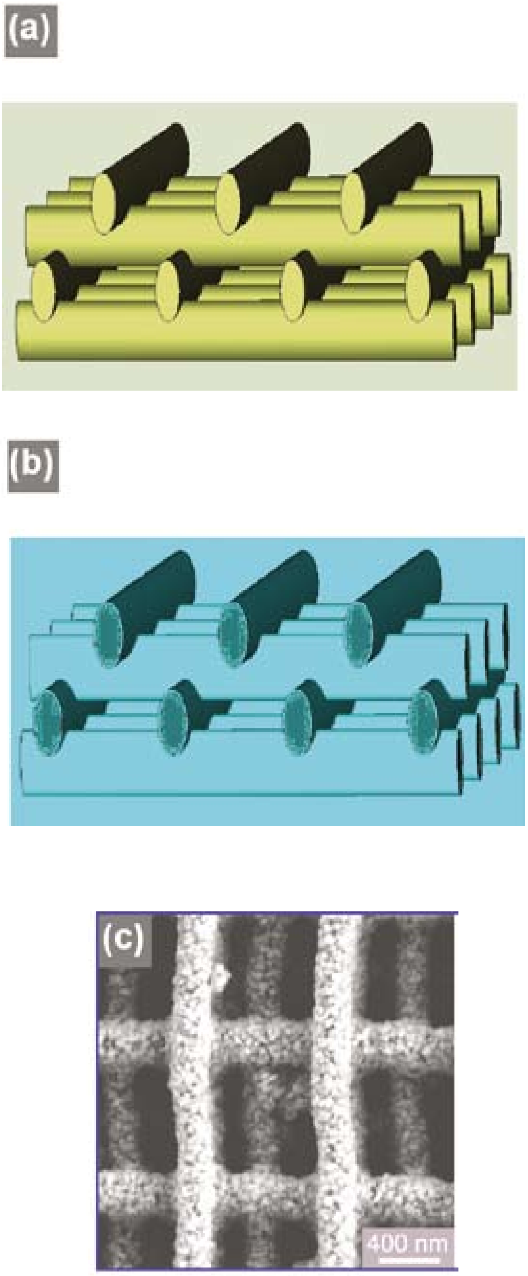


Fig 5. The cartoon of 3D woodpile photonic crystals before (a) and after (b) the infiltration. (c) The SEM image of sliver nanoparticle coated woodpile PhCs.

applications such as complete control of spontaneous emission. Mr. **MD Murtasir Hossain** has done rigorous theoretical calculations to investigate the photonic band gap properties of possible MPC structures based on a proposed fabrication technique. MPCs can be fabricated by infiltrating metal by electrodeposition method into polymer photonic crystal template fabricated by using two-photon polymerization method. For a structure infiltrated with silver, a strong band gap starting from 1.0 µm with reflection up to over 95% has been predicted by theoretical simulation.

References

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