CUDOS

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

ANNUAL REPORT 2006

Professor Min Gu

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 span nanophotonics and biophotonics with internationally renowned expertise in multiphoton induced devices, high density optical data storage, laser tweezers, laser scanning microscopy, nonlinear optical microscopy, and three-dimensional optical imaging theory. Professor Gu is 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. In 2006, he was elected as a Fellow of the Australian Academy of Technological Sciences and Engineering. He has been appointed as the member of the Fellows and Honorary Members Committee of the Optical Society of America. During 2006, Prof. Gu was a Bureau member and the Vice-President of the International Commission for Optics, and a Bureau member and the Past President of the International Society of Optics with Life Sciences. He presented twelve invited talks at international conferences during 2006. He also served on the editorial boards of eight 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
- Photonic crystal based devices such as superprisms and microcavities.
- Nonlinear photonic crystal fabrication
- Inverse high index photonic crystals

Roles and responsibilities within Centre

Prof. Gu is a member of the Executive Committee, Science Leader of the Flagship project Photonic Bandgap materials for Emission Control and the leader of three-dimensional photonic crystals project.

Awards, honours, major international visits

Professor Gu was elected as a Fellow of the Australian Academy of Technological Sciences and Engineering in 2006. He conducted international scientific visit to the following laboratories: University of St. Andrews, UK, (Jan 1-30, 2006); Ecole Polytechnique Federale De Lausanne, Switzerland (Jan 13, 2006); Oxford University, UK (Jan 19, 2006); Fudan University, China (March 17, 2006); Advanced Photonics Institute, Kwangju Institute of Science and Technology (May 8-9, 2006, signed an MOU for collaboration in photonics); Royal Institute of Technology (KTH), Sweden (Sept 12, 2006); National Taiwan University (Dec 1-2, 2006); and Osaka University, Japan (Dec 11, 2006).

Key areas of research activity

The CUDOS group at Swinburne, headed by Professor Min Gu, is located at the Centre for Micro-Photonics (CMP). It includes three researchers, two PhD students and one administrative staff member. Our contributions to the CUDOS include 3D photonic crystal fabrication in polymer and in high refractive index materials, photonic crystal-based devices such as superprisms and microcavities, radiation dynamics of infrared QDs in photonic crystals and nonlinear photonic crystal fabrication in lithium niobate. Some of the activities form a core of the CUDOS Flagship Project “Photonic Bandgap Materials for Emission Control”.

Research achievements during 2006

Novel approach to fabricate diffraction optical elements devices using two photon polymerisation

As the key components in the miniaturisation of optical systems, diffraction optical elements (DOEs) have attracted lots of research interest in recent years. The fabrication of DOEs mainly relies on conventional semiconductor fabrication technologies which are expensive and time consuming. In collaboration with Professor Byoungho Lee’s group from Seoul National University, we have successfully fabricated a novel DOE in an organic-inorganic composite by using the two-photon polymerisation technique, as shown in Figure 1. The tight focusing of the two-photon process allows multi-grayscaled 3D DOEs to be fabricated with a high resolution of approximately 120 nm [1].

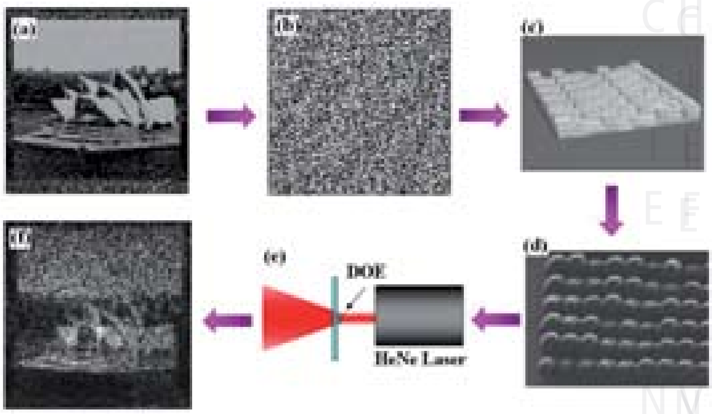
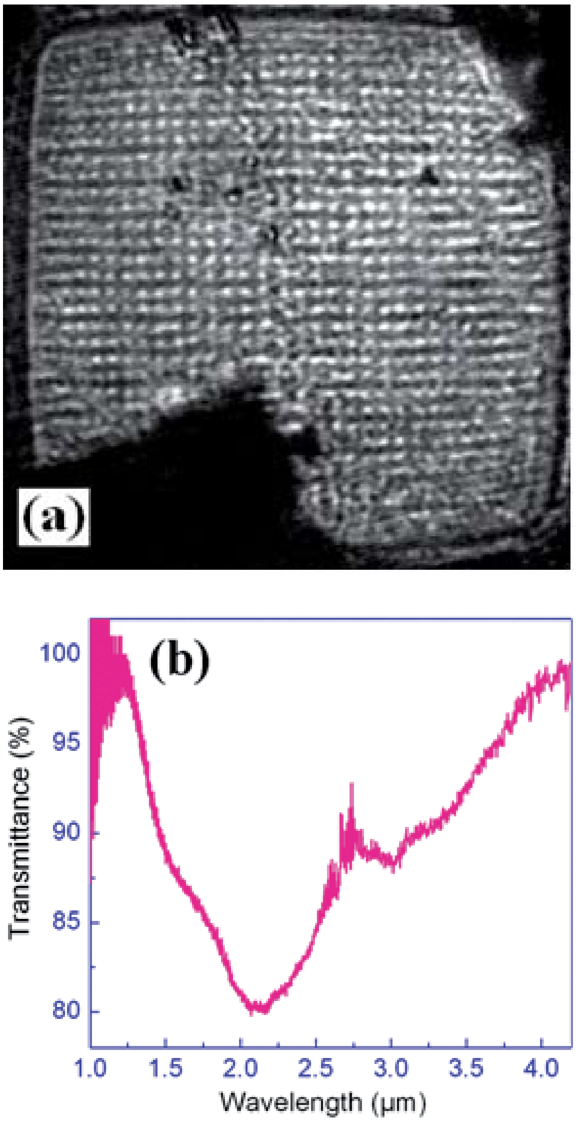


Figure 1. (a) A 2D intensity distribution of a photo of the Sydney Opera House sampled by 128 × 128 points. (b) A designed phase profile for (a) with 256 phase levels by using the iterative Fourier transform algorithm. (c) A sketch showing an overall view of the designed DOE. The pixels are fabricated on a microscope cover glass. (d) A SEM image of the fabricated DOE. (e) Experimental setup for reconstructing the diffraction

High refractive index TiO_2 infiltration towards complete bandgaps

The refractive index of polymer materials around 1.5~1.7 is too low to open complete 3D bandgaps [2]. In order to achieve high refractive index contrast, Dr. Shuhui Wu and Dr. Baohua Jia are developing a novel infiltration technique to fabricate 3D inverse woodpile photonic crystals with high refractive index TiO_2. This technique includes the fabrication of polymer (SU-8) template, infiltration of TiO_2 precursor [$Ti(OR)_4$] into the template, conversion of the precursor into TiO_2 and thermal removal (above 450 °C) of polymer template. Significant progress has been achieved.

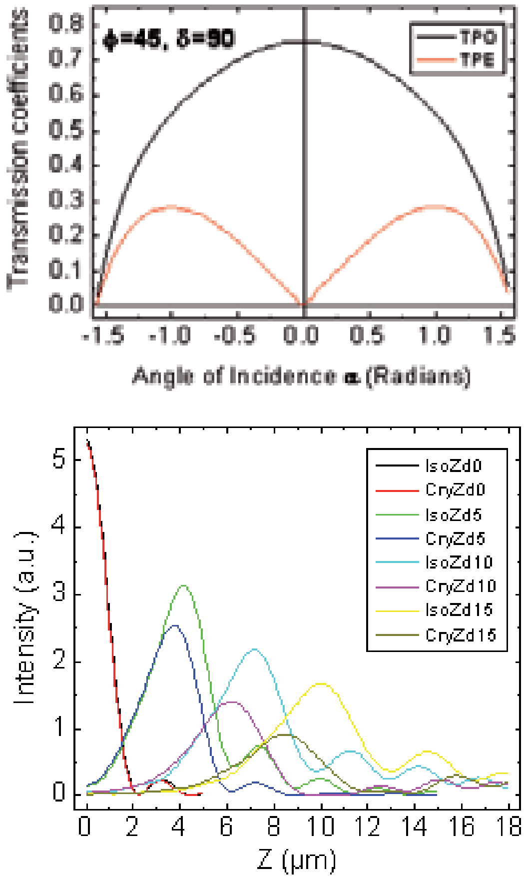
After engineering the polymer template and the infiltration process, they can get crack-free inverse woodpile TiO_2 photonic crystals (Figure 2a). The suppression rate in the transmission spectra can be up to 20% (Figure 2b). In the coming year, they will concentrate on improving the quality of TiO_2 photonic crystal to achieve complete bandgaps. In the meantime, quantum dots will be doped into the matrix in order to study their emission properties in high refractive index contrast photonic crystals.



▲ **Figure 2. Transmission confocal image of an inverse TiO_2 woodpile photonic crystal (a) and its transmission spectra (b).**

Understanding aberration and its compensation in anisotropic lithium niobate for nonlinear photonic crystal fabrication

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. However, the large refractive index mismatch between the crystal and the immersion medium of the objective induces pronounced aberration. The anisotropy of the crystal makes the calculation of the point spread function and aberration compensation even more difficult. Although obvious bandgap effect has been observed in 3D void photonic crystal in lithium niobate by using a threshold fabrication method [3], the repeatability and suppression rate still need to be improved. Dr. Guangyong Zhou, winner of an ARC Postdoctoral Fellowship, has successfully calculated the transmission coefficients of ordinary and extraordinary rays after the refraction on the interface (Figure 3a) and the point spread function for the case where the optic axis is perpendicular to the interface (Figure 3b). Based on this calculation, he is currently working on aberration compensation by using an adaptive liquid crystal phase modulator in collaboration with Professor Tony Wilson's group at Oxford University.



▲ **Figure 3. (a) Transmission coefficients of o-rays and e-rays on the interface. (b) Comparison of the axial cross-section of the point spread function before and after taking into account of the anisotropy of lithium niobate.**

References

[1] Jia B, Serbin J, Kim H, Lee B, Li J, Gu M, Use of two-photon polymerization for continuous gray-level-encoding of diffractive optical elements, APPLIED PHYSICS LETTERS (accepted, 2006)

[2] Wu S, Zhou G, Gu M, Synthesis of high refractive index composites for photonic applications, OPTICAL MATERIALS (in press, 2006)

[3] Zhou G, Gu M, Direct optical fabrication of three-dimensional photonic crystals in a high refractive index $LiNbO_3$ crystal, OPTICS LETTERS 31, 2783-2785 (2006)