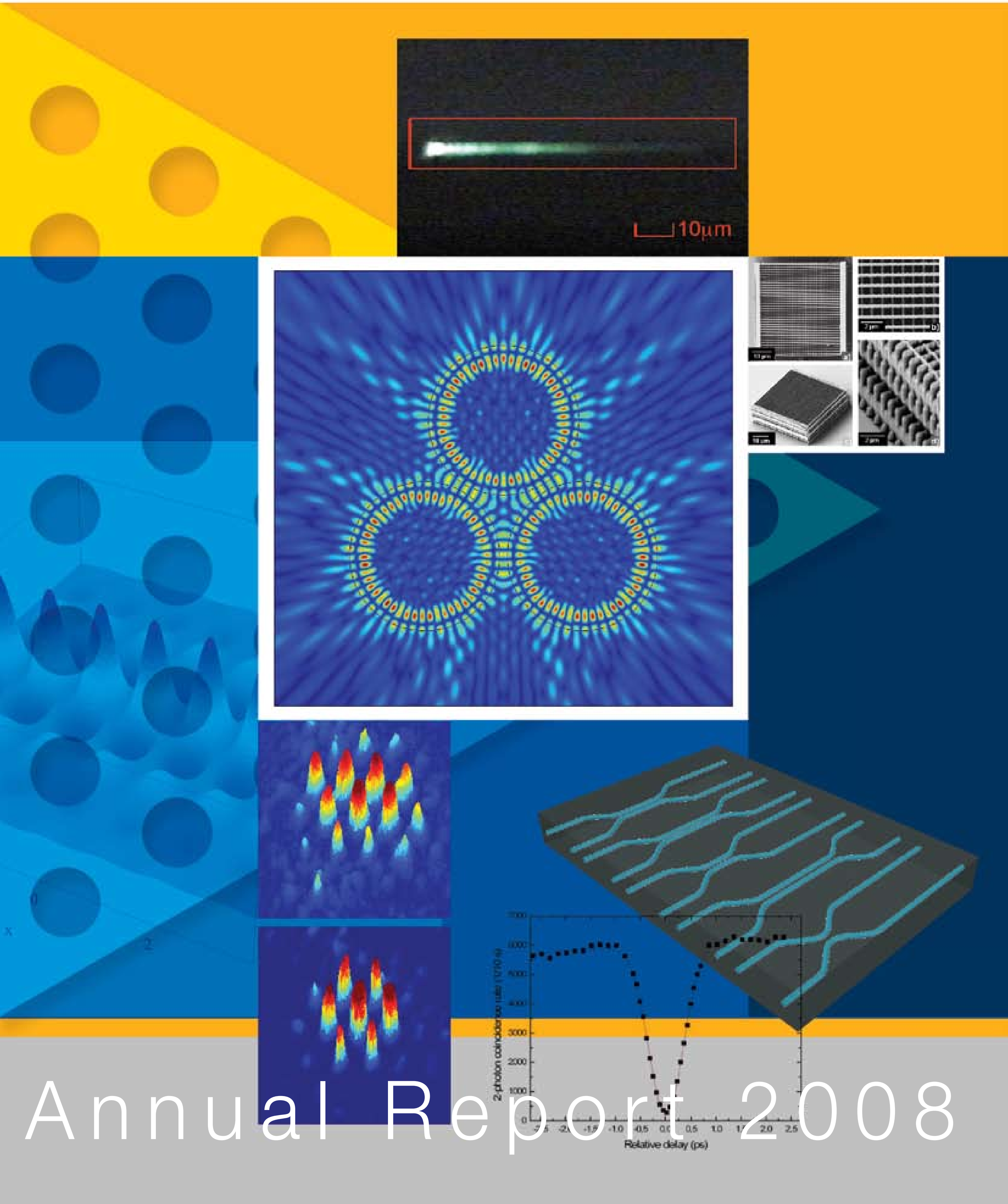
CUDOS

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



Annual Report 2008

CI short biography

Martijn de Sterke received the M.Eng degree from the University of Delft in the Netherlands and his PhD in Optics from the University of Rochester in the USA. After postdoctoral work at the University of Toronto, he joined the School of Physics at the University of Sydney, where he is now a Professor in Physics working in the area of optics and photonics. He has been Editor in Chief of Optics Express, a refereed optics journal, since 1 January 2007.

Awards, honours, major international visits

Martijn de Sterke was the 1999 winner of the Pawsey Medal of the Australian of Sciences. He is Fellow of the Optical Society of America. During 2008 he hosted Prof. Rafael Piestun (University of Colorado) and A/Prof Ole Bang Technical (University of Denmark) for extended sabbatical visits.

Key areas of research contribution within the Centre

Martijn de Sterke contributes to the following Flagship projects: Slow Light (as Science Leader), Three-Dimensional Photonic Bandgap Materials, and Chalcogenide Photonic Crystal All-Optical Switch. He also works on the general theoretical description of wave propagation in complicated media, be they a waveguide, nonlinear, periodic, or random.

Researchers and students

During 2007 I worked directly with Research Fellows Kokou Dossou, Snjezana Tomljenovic-Hanic, PhD students Neil Baker, Sam Campbell, Parry Chen, Irina Kabakova, Mike Lamont, Felix Lawrence and Sahand Mahmoodian, and honours students Tom Grujic and Hugo Dupree. I also work closely with Ben Eggleton, Boris Kuhlmey, Ross McPhedran, and (University of Sydney), Lindsay Botten and Chris Poulton (UTS), and Mike Steel (Macquarie).

Research achievements during 2008

Much of my research was carried in the context of one of the Flagship Projects, particularly Slow Light and All-Optical Switching. This work is well described in the associated part of this Annual Report and is not mentioned here. The work of postgraduate students Sam Campbell and Felix Lawrence is described in Lindsay Botten's report, while that of Parry Chen is included in Ross McPhedran's. Here I describe some of the work not covered elsewhere in this Report.

Performance limits of devices

Upper limits to performance play an important role in physics and engineering. The most famous of these are the Shannon limits for the capacity of information channels. However, similar limits have been established for other classes of devices as well. Typically these very general and do not depend on the details of the device, but only on some of the most basic properties such as the volume or the length. With Prof Rafael Piestun from the University of Colorado, we have determined the performance of two-dimensional devices that are meant to separate channels spatially. A particular example of such a device is a superprism, which relies on the dispersion of a photonic crystal (PC), a structure with periodically variations in the refractive index. According to results in the literature, the area of these devices is proportional to N^4, where N is the number of channels that are to be separated. Our general analysis shows that the area is proportional to N^2, a much more favourable scaling. Though the analysis does not indicate how to achieve this scaling, we note that our general result does not assume that the refractive index varies periodically – in fact, it only depends on the range of the refractive in the structure [1].

Photonic crystal cavities

In the last three years we pioneered three novel designs of high quality factor microcavities designs in diamond, chalcogenide glasses, silicon and polymer-based two-dimensional PCs, shown schematically in Figure 1. In these designs we use new ways to achieve light confinement in PCs. The ability to control light by a light induced change, infiltration or depositing an additional layer is a powerful tool that has not been used for the PC design so far. As the microcavity is post-processed efficient techniques to generate cavities are achievable, improving prospects for defect-tolerant optical microcavities.

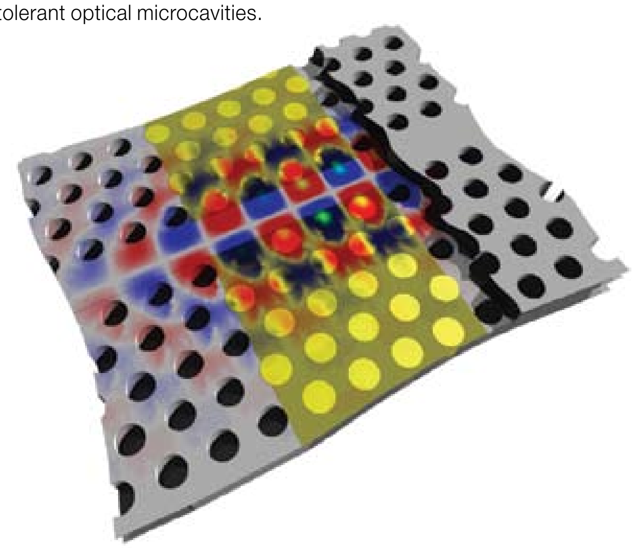


Fig 1. Schematic of the photonic crystal cavity we are considering with the field (in blue and red) superimposed.

Most recently, in collaboration with Prof. Steven Prawer and his group group from University of Melbourne, we designed ultrahigh-Q diamond-based double-heterostructure photonic crystal slab cavities by modifying the refractive index of the diamond. The refractive index changes needed for ultrahigh-*Q* cavities with $Q \sim 10^7$, are well within what can be achieved ($\Delta n \sim 0.02$). The cavity modes have relatively small volumes V<2 (λ/n)3, making them ideal for cavity quantum electro-dynamic applications [2,3].

Whereas the realization of existing diamond-based PC structures relies on a fabrication process with high precision measured by nanometers, our methods rely on post-fabrication processing with a 100 times larger cavity fabrication tolerance. Most importantly for realistic fabrication these novel designs are feasible and extremely flexible because the range of parameters that enable an ultrahigh-*Q* microcavity is quite broad.

We introduced an efficient procedure for high-*Q* cavity design in photonic crystal that relies on the observation that the relative position of the resonant frequency within the mode-gap is a key parameter in the design of such cavities [4]. This allows us to replace many of the FDTD numerical calculations by calculations of the bandstructure that are very fast and require little memory. In this way the total optimization of a high-*Q* microcavity may be sped up by a factor 2-4.

Defect formation in PCs

Many of the key applications of PCs derive from the inclusion of defects, region in the PC with slightly changed properties. In collaboration with UTS we have studied the formation of defects in two dimensional PCs. Using a method that we adapted from the condensed matter literature, we have found semianalytic expressions for the frequency and the associated fields of the defect state. It was surprising to find that almost all cases the defect states can be understood using very simple building blocks, and in fact it is very difficult to find really complicated cases! We are currently studying the formation of PC waveguides by the introduction of a line defect. By using this method we are now able to understand the fields associated with these defects well. A typical field profile is shown in Fig 2. While they may look complicated, they can be thought of as being the sum of a limited number of well-understood elements.

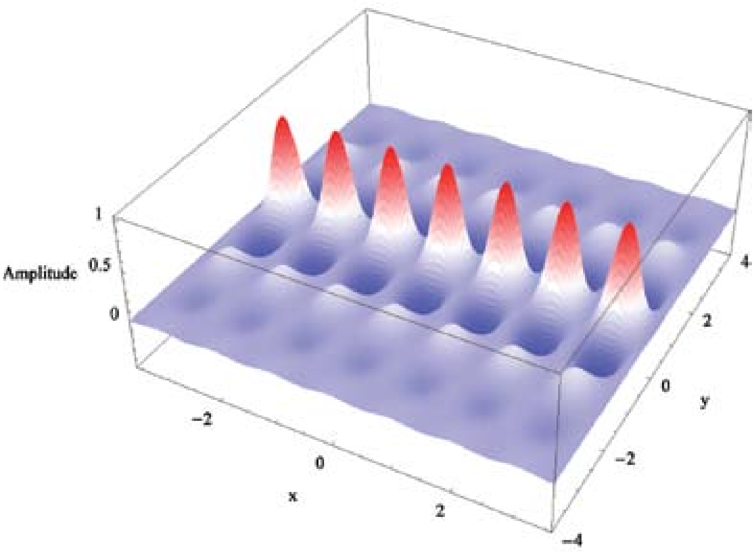


Fig 2. Electric field of a line defect in a two-dimensional photonic crystal.

All-optical switching in fiber gratings

All-optical switching in a fiber grating, the transition between high and low transmission with a change in the incident power, has been discussed in the literature for decades. The theory was developed in 1979 and experimental verification was reported more than a decade later. It has since been pointed out that a fiber grating with a defect should have a lower switching threshold and should thus be easier to switch. We have now performed the first experimental demonstration of all-optical switching in such a grating [5]. The grating was carefully designed to match the incident pulses, and gave more than 5 dB change in the transmission coefficient when the incident power was varied (Fig. 3). The significance of this work is that it is the first step in establishing a range of light processing functions in optical fibers.

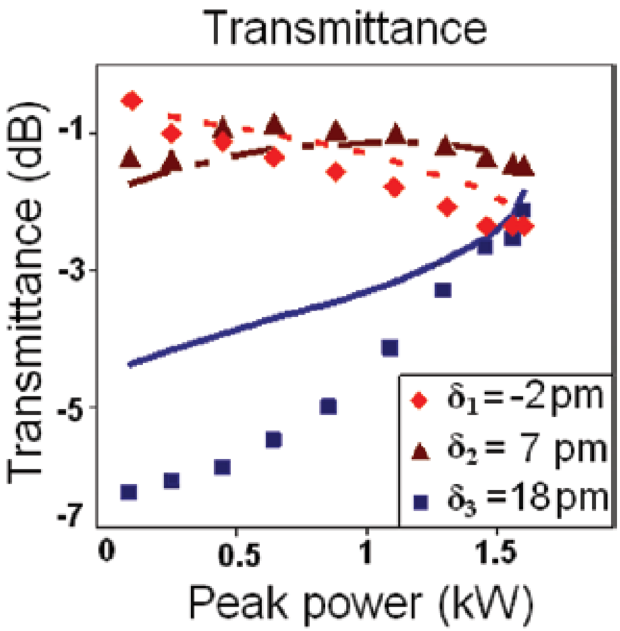


Fig 3. Transmittance versus peak power of the incident pulses for three different frequencies. Symbols and curves indicate experimental and numerical results, respectively.

[1] R. Piestun and C.M. de Sterke, "Fundamental limit for 2D passive devices," in press, Optics Letters.

[2] S. Tomljenovic-Hanic, A.D. Greentree, S. Prawer, and C.M. de Sterke, "Design of high-Q cavities microcavities in diamond-based photonic crystal heterostructures," *Australian Institute of Physics Congress: AIP Congress-QUICC 2008*, Adelaide, Australia, #185.

[3] S. Tomljenovic-Hanic, A.D. Greentree, S. Prawer, and C.M. de Sterke, "Design of ultrahigh-Q cavities microcavities in diamond-based photonic crystal heterostructures," submitted to Optics Express.

[4] S. Tomljenovic-Hanic and C.M. de Sterke: "Design of high-Q cavities in photonic crystal heterostructures," *Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science and Photonic Applications, Systems and Technologies: CLEO/QELS 2008*, San Jose, California, USA, JTu125.

[5] I.V. Kabakova, B. Corcoran, J.A. Bolger, C.M. de Sterke and B. J. Eggleton, "All-optical self-switching in optimized phase-shifted fiber Bragg grating," submitted to Optics Express.