Fabrication of photonic crystal fibre

Conventional communication optical fibres are typically made from two different layers of silica glass: an inner core that is ‘doped’ by adding small amounts of germanium, and an outer cladding of pure silica. Dopsants such as germanium raise the refractive index of the core relative to the cladding region. This difference in refractive index confines light to the core via total internal reflection. Light is then channelled down the core, only emerging when it reaches the end of the fibre.

In recent years, two new types of optical fibres having the potential to revolutionize the communication and sensing industry have been developed, bringing with them a wide range of novel optical properties. These new fibres, known collectively as microstructured fibres, can be made entirely from one type of glass, as they do not rely on dopants for guidance. Instead, the cladding region is peppered with many small air holes that run the entire fibre length. These fibres are typically separated into two classes, defined by the way in which they guide light:

- Holey fibres, in which the core is solid and light is guided by a modified form of total internal reflection as the air holes lower the effective refractive index of the cladding relative to that of the solid core.
- Photonic band-gap fibres, in which guidance in a hollow core can be achieved via photonic band-gap effects. The many varieties of microstructured fibres are discussed in more detail in the following sections.

Photonic crystal fibre (PCF), also known as microstructured fibre, has arrays of holes running along its length. Microstructured fibres guide light due to modified total internal reflection. The holes act to lower the effective refractive index in the cladding region, and so light is confined to the solid core, which has a relatively higher index. Unlike conventional fibres, PCFs can be made entirely from a single material, typically undoped silica. The effective refractive index of the cladding can vary strongly as a function of the wavelength of light guided by the fibre. For this reason, it is possible to design fibres with spectrally unique properties, not possible in conventional optical fibres. Microstructured optical fibres can guide light by an alternative guidance mechanism if the air holes that define the cladding region are arranged on a periodic lattice. The first PCF was fabricated in 1996, and since then progress in this field has been rapid. PCF have matured into a technology with the potential to revolutionize many areas of communication. However in India, to the best of our knowledge, no laboratory has reported the manufacturing of PCF. Hence we have taken an initiative to draw such a type of fibre. In a PCF, the number of holes and their sizes, shapes, orientations and placements can provide degrees of freedom and hence unique properties, which are not available in conventional optical fibres. They could serve as a fibre host for developing a wide range of fibre devices for high power fibre laser, second harmonic generation, super continuum generation, radiation detection, etc.1-6.

Fabrication of PCF, like in conventional fibre fabrication, starts with a fibre preform. Conventional preforms are formed using either modified chemical vapour deposition or vapour axial deposition process. Microstructured preforms are formed by stacking a number of capillary silica tubes and rods to form the desired air/silica structure, fusing the stack into a preform, and then pulling the preform to a fibre at a sufficiently low temperature (~1950°C) to avoid collapsing of the hole (Figure 1). When the desired preform has been constructed, it is drawn to a fibre in a conventional high-temperature drawing tower and hair-thin PCFs are readily produced in kilometre lengths. This way of creating the preform allows a high level of design flexibility, as both the core size and shape as well as the index profile throughout the cladding region can be controlled. This is useful for fabrication of polarization-maintaining fibres with highly asymmetric core regions. Through careful process control, the air holes retain their arrangement all through the drawing process and even fibres with complex designs and high air-filling fraction can be produced. Finally, the fibres are coated to provide a protective standard jacket that prevents micro bending and also allows robust handling of the fibres. The final fibres are comparable to standard fibre in both robustness and physical dimensions and can be both stripped and cleaved using standard tools.

PCFs of various hole sizes have been fabricated (25–2.5 μm). In a typical case, we could fabricate a hole of 4 μm in a 125 μm fibre with fibre length of few tens of metres. In most of the cases, the PCF fibres showed endlessly single-mode behaviour from 544 nm to 1.55 μm. Fibres with large air-holes showed high sensitivity to pressure. Since making of micrometer size air-holes uniform along the lengths is a significant technological challenge, our efforts were directed to develop this part. Figure 2 depicts the microscope image of cross-section of such a PCF fibre developed in our laboratory. The drawn fibre was tested for attenuation using cut-back method. Figure 3 shows attenuation measured at different lengths. The fibre was also tested for attenuation while transverse load was applied. Figure 4 shows attenuation induced because of pressure on the fibre. These fibres have

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Figure 1. Fabrication process of microstructured fibre (see text for details).

Figure 2. Photonic crystal fibre drawn at RRCA, Indore. Diameter of fibre is 125 μm, with air-holes of 4 μm running across it.
Differential expression of two metallothionein encoding genes during heavy metal stress in the mangrove species, *Avicennia marina* (Forsk.) Vierh.

Industrialization and urban development lead to continuous release of heavy metals into the environment and pose a serious threat to living organisms including human beings. The marine environment in particular is highly polluted, with effluents from industrial sources and urban run-off that contain toxic concentrations of heavy metals such as cadmium, copper, zinc and nickel. Mangroves are plant communities, which form a part of this marine environment and possess great tolerance to high levels of heavy-metal pollution. Mangroves have the capacity to act as a sink or buffer, and remove or immobilize heavy metals before they reach the nearby aquatic ecosystems. The mangrove plants have developed various mechanisms like exclusion, chelation, compartmentalization and sequestration for heavy-metal tolerance. In the mangrove plant community, *Avicennia sp.* in particular are considered to be extremely robust to heavy metals and accumulate metals to greater quantities than other mangrove species, before any visible signs of toxicity are evident. In a study conducted by Macfarlane, *A. marina* was found to be highly tolerant to heavy metals like copper, lead and zinc.

Among all the detoxification mechanisms, chelation by various ligands or proteins like metallothioneins (MTs) or phytochelatins provides greater resistance to the toxic effects of the heavy metals. MTs are low molecular weight, cysteine-rich proteins that bind to heavy metals like Cu, Cd and Zn with greater affinity in a stoichiometric ratio of 7:1 for metal and MTs. It has been suggested that the induction of the MT gene is observed primarily at the transcription level. Therefore, studies on the regulation of genes encoding MT in response to heavy-metal stress would be better understood by monitoring the mRNA accumulation of these genes during heavy-metal stress conditions. The present study reports the isolation and differential expression of two MT cDNAs in response to heavy-metal stress in *A. marina* (Forsk.) Vierh.

The cDNA library was constructed from mRNA isolated from leaf tissue of salt-stressed *A. marina* seedlings. Two MT cDNA clones were isolated from the cDNA library through partial sequencing of ESTs. Both the cDNA clones were se-