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All-polymeric photonic bandgap polystyrene/polymethyl methacrylate Bragg fibers

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A novel and efficient method of making waveguides based on alternating polymer layers promises better control of the fabrication process and fewer defects.

As materials for waveguide fabrication, polymers offer several advantages over glass, including low cost, low processing temperatures, and compatible combinations. In particular, polymeric photonic crystal waveguides have been used in a variety of applications, such as data communication,[1–3] light amplification,[4] and sensing.[5–7] Unlike conventional glass waveguides, which are based on the principle of total internal reflection, in photonic crystal waveguides the wave path is controlled by periodic spatial modification of the refractive index. The repeating pattern forces the wave to scatter and interfere in a way that restricts its propagation only to certain directions and at certain frequencies.[8] One-dimensional photonic crystals consist of multilayer films. The transmission intensity through such films depends on the periodicity of the stack and on its refractive index contrast. Some frequencies are strongly reflected and have almost no transmission: see Figure 1(a)[8]. This range of frequencies is called a photonic bandgap. If the multilayer film is rolled into a tube, the frequencies comprised by the photonic bandgap will be confined to the fiber core and will propagate along its length: see Figure 1(b)[8]. This is the basic principle of multilayer Bragg fibers, which have recently been used in color-changing textiles[9] and in high-bandwidth, short-range telecommunications.[3]

Bragg fibers are produced by drawing macroscopic preforms in a drawing tower to decrease their diameter by a factor of 50–100. There are two ways to produce Bragg fiber preforms.[10] The first uses deposition of alternating layers of two different polymers on the inside of a rotating polymer cladding tube by solvent evaporation. Preforms comprising $\sim$30 layers can be obtained. This method is time-consuming due to the solvent evaporation step, and requires the selection of two orthogonal solvents that do not cross-solve the polymer

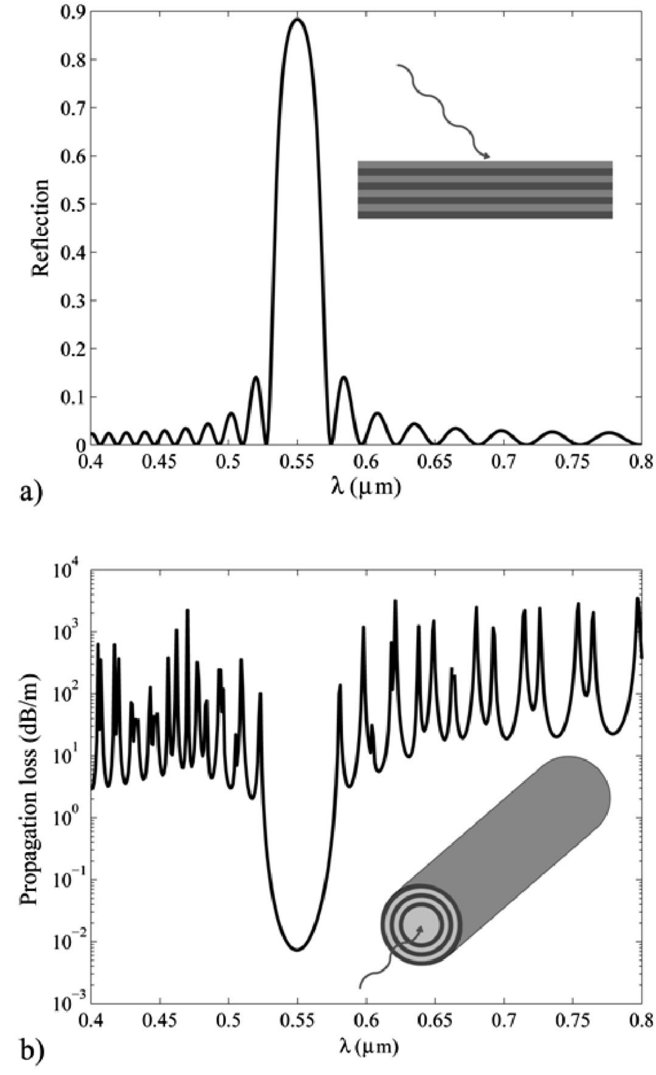

Figure 1. *Wave propagation through (a) a multilayer film and (b) a photonic bandgap Bragg fiber.*[8] *Λ: Wavelength.*

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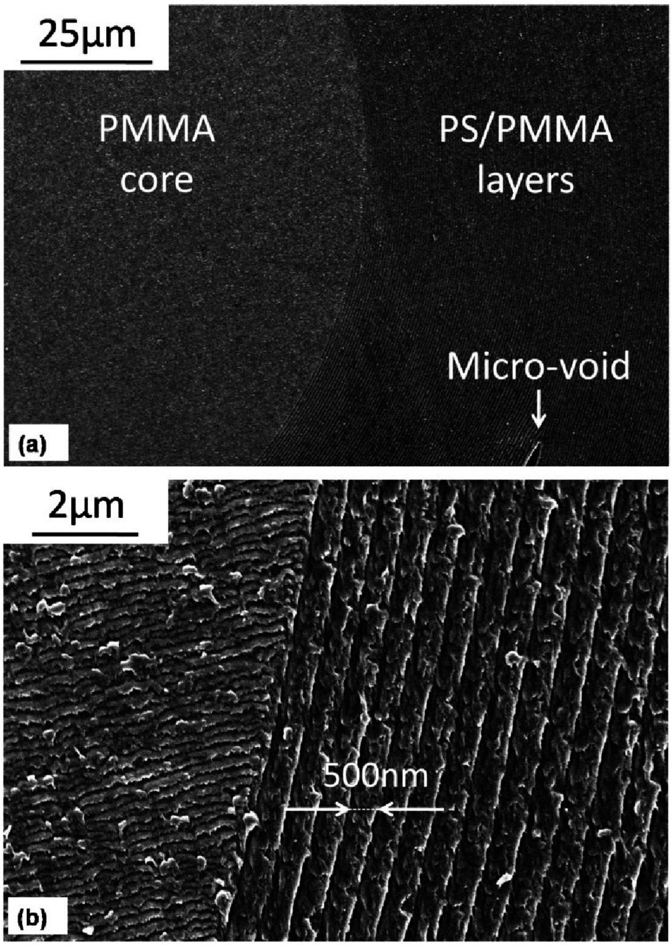

Figure 2. *Microstructure of a Bragg fiber of external diameter 500μm. (a) Low magnification. (b) First 15 alternating layers at high magnification.*[11] *PS: Polystyrene. PMMA: Polymethyl methacrylate.*

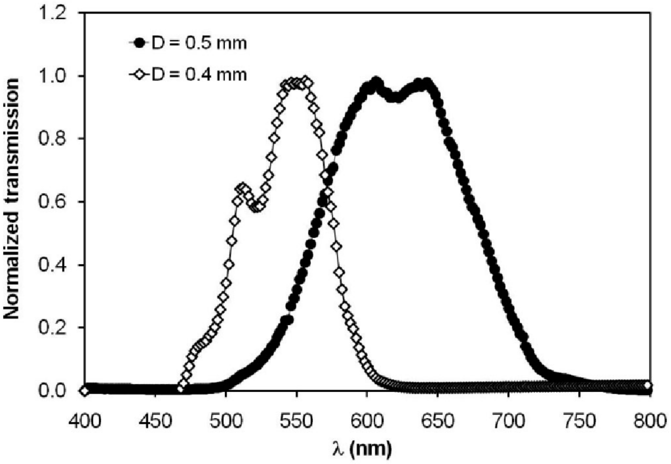

Figure 3. *Transmission spectra of two PS/PMMA Bragg fibers of different diameters.*[11]

during deposition. An alternative approach is that of co-rolling, which consists of rolling two different polymer films around a plastic mandrel. This method allows fabrication of preforms containing ∼100 individual layers. However, this technique leads to trapping of microvoids inside the multilayer structure. Such defects strongly affect the optical properties of the fibers, especially when they are located within the layers closest to the fiber core.

We describe in detail elsewhere a novel method of preparing multilayer preforms.[11] To minimize the formation of microvoids, we chose to roll a single multilayer film around the mandrel rather than co-rolling two monolayer films. We used polystyrene (PS) and polymethyl methacrylate (PMMA) to produce a four-layer PS/PMMA film by co-extrusion. This multilayer PS/PMMA film was then rolled around a PMMA mandrel. The resulting preform was drawn in the draw tower.

To vary the spectral position of the photonic bandgap, we used various drawing velocities, and obtained Bragg fibers with external diameters ranging from 300 to 500μm. Scanning electron microscopy shows that those fibers consist of ∼150 layers with a uniform thickness of 500–550nm (see Figure 2).

Figure 3 shows the transmission spectra of the Bragg fibers in the visible region as a function of their diameter. The transmission range is 475–625nm (green to yellow) for fibers of diameter 400μm, and 500–725nm (yellow to red) for fibers of diameter 500μm. This result confirms that the transmission properties of the Bragg fibers can easily be modified by controlling the drawing ratio, and thereby the thickness of the alternating PS/PMMA layers.

In summary, we produced solid-core PS/PMMA Bragg fibers according to a new process in which a multilayer co-extruded film was rolled around a PMMA mandrel to make a preform that was subsequently drawn into a fiber. Compared to classical processes, this new method makes it possible to significantly reduce the number of defects that can occur during fabrication and to accurately control the thickness and uniformity of the alternating layers. In addition, many layers can be achieved within a reasonable amount of time. The resulting Bragg fibers were shown to guide specific wavelengths in the visible range depending on their diameter. Next steps will aim at enhancing the control of fiber diameter and at expanding the co-rolling technology to other polymeric systems.

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