Tunable photonic band gap fiber

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Abstract: A photonic band gap fiber has been generated by incorporating a high index fluid into a sol-gel derived microstructured fiber. The band gap positions and widths are tuned by adjusting the temperature.

OCIS codes: (230.3930) Microstructure devices; (060.2280) Fiber design and fabrication

1. Introduction

Recently, there has been a surge in interest in microstructured fibers owing to their unique waveguiding properties such as supercontinuum generation[1] and dispersion.[2] One particular microstructured fiber which shows great promise is the Photonic Band Gap fiber first demonstrated by Knight et al.,[3] containing a depressed index core with a honeycomb lattice and subsequently by Cregan et al.[4] and West et al.[5] for an air core fiber with a triangular lattice of air holes. Unlike total internal reflection waveguides, photonic band gap fibers use alternating layers of dielectric material. The periodic lattice gives rise to two-dimensional Bragg scattering forming a photonic band gap in the cladding. Frequencies which lie within the photonic band gap are not allowed to propagate within the cladding and are localized at any defect region, in this case the low index fiber core. Photonic band gap guidance allows light to be guided within low loss core materials such as air or vacuum, potentially minimizing the effects of material loss and dispersion and allowing for high power transmission. In this work, a photonic band gap fiber has been generated by taking a sol-gel derived microstructured fiber with a solid silica core surrounded by a triangular lattice of air holes and then filling the holes with a high index liquid, $n_{589\ nm} = 1.80$. The index of the material within the holes is adjusted continuously by varying the temperature leading to changes in the photonic band gap spectra such as the spacing and widths of the band gaps. The ability to tune the photonic band gap may lead to potential devices such as tunable filters or dispersion compensators.

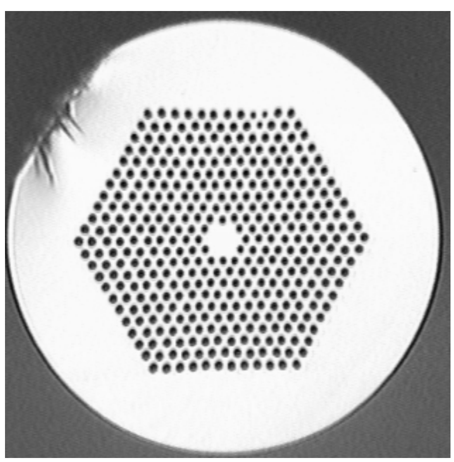

Fig. 1. Cross-section of the sol-gel derived photonic band gap fiber. The dark circles are air holes while the bright regions are silica.

2. Fiber properties and transmission

The microstructured fiber in this study, of which a cross-section is shown in Figure 1, was manufactured by using a sol-gel casting technique. The resulting fiber is shown in Figure 1, with hole diameter, hole spacing and core diameter of 2.4 µm, 4.3 µm and 10.5 µm respectively. To the best of our knowledge, this is the first report of a microstructured fiber made via sol-gel. The sol-gel casting method provides advantages over bundling or stacking methods since the hole pattern, size and spacing can be altered independently and does not create interstitial holes within the lattice.

This fiber consists of a high index solid silica core surrounded by a lower index cladding of air holes. As such this fiber guides light in the higher index core by total internal reflection and does not reveal the photonic band gap properties of the lattice, showing a transmission spectrum similar to silica-based fibers. When a high index fluid is inserted into the holes by vacuum,[6] the core is now a low-index defect within a regular triangular lattice of high index rods separated by silica webs. The only manner in which the light can be guided in the core is via the photonic band gap effect. Upon placing a high index liquid ($n_{589\ nm}$ = 1.80,Cargille Laboratories series M) into the holes a strongly wavelength dependent transmission is osberved, Figure 2, with a series of transmission windows corresponding to photonic band gaps with an energy spacing of ~ 2000 cm^{-1}. The photonic band gap effect has been observed over lengths from 4 cm up to 2 meters with a loss value for band gap regions less than 2.5 dB/m obtained by cutback measurements. Specifically, the band gap centered near 800 nm has a loss of 2 dB/m compared to the reported loss value[7] of 115 dB/m for the high index fluid in this wavelength region, indicating the efficient guiding properties of the photonic band gap. Currently the lengths over which the photonic band gap has been observed is limited by the distance the high index liquid has been drawn into the fiber.

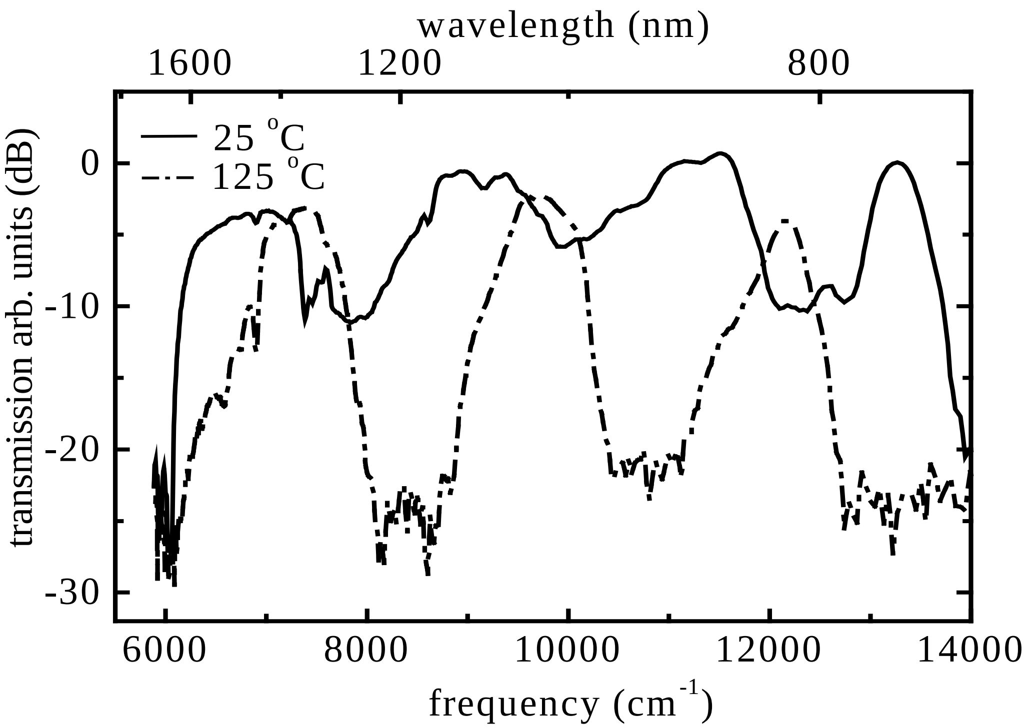

Fig 2. Tranmission spectra of the Photonic Band Gap fiber show in Fig 1. when the air-holes are filled with a liquid having an index of 1.80. The spectrum taken at 25°C and 125 °C are shown with solid and dot-dashed lines respectively.

For the temperature dependent measurement, a photonic crystal fiber with a total length of 1.5 m is filled with high index fluid for a distance of ~10 cm using vacuum. This liquid is then positioned into the middle of the fiber using both air pressure and vacuum. The 10 cm section filled with high index liquid is placed into a Lindberg digital oven. An overfilled launch from a white light source is coupled into one end of the fiber while the opposite end is fed directly into an ANDO optical spectrum analyzer. Three 3 cm diameter loops are placed between the input end and the liquid filled region to confine the light to the core region. Transmission spectra were recorded from 25°C to 150°C and then back down to 25°C at 25° intervals. No noticeable hysterisis was observed. Figure 2 displays the transmission spectra at both 25°C and 125°C. Changing the temperature the of the high index liquid leads to a large change in index ($dn/dT = -6.8*10^{-4}$) within the holes creating noticeable changes in both the photonic band gap spacing as well as the band gap width. Figure 3 shows the plot of the spacing of the band gaps as a function of temperature. The

3 dB bandwidths for band gaps near 1400 nm are displayed in terms of the gap:midgap ratio, defined as the width divided by the band gap center wavelength, and are also plotted as a function of temperature and index. The photonic band gap spacing is inversely proportional to the index value while the width of the band gaps is directly proportional to the index. The decrease in the width of the photonic band gaps as the index decreases is entirely expected as the index contrast between the high index rods of the triangular lattice and low index silica webs decreases.[8] Only wavelengths which match the phase conditions of the lattice structure will undergo Bragg reflection and give rise to photonic band gap structure. Therefore, with a larger index of refraction, longer free space wavelengths are able to satisfy the phase matching condition of the lattice and hence the energy spacing between the various Bragg reflections is less when the index of the material inside the holes increases.

The ability to change the photonic band gap structure continuously and reversibly by modifying the index thermally allows the band gap features to be sensitively tuned, allowing for a thorough investigation of the various band gap guiding properties. Furthermore, it may be possible to use this type of band gap fiber as a tunable filter. Investigations of the dispersion properties of this fiber have been examined recently in our laboratory showing a change in dispersion $> 10^3$ ps/nm km across the band gap region suggesting that controlling the band gap position and width may also provide a sensitive method for tunable dispersion compensation.

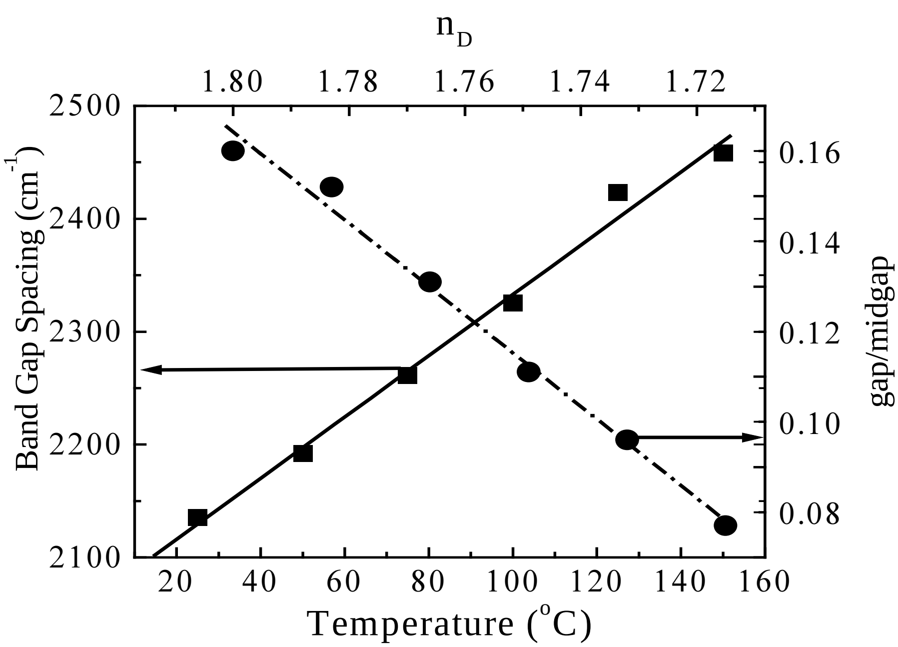

Fig 3. Dependence of the Photonic Band Gap spacing and width on index of refraction. The band gap spacing is shown with squares and the width as given by the gap:midgap ratio is displayed with circles.

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