Tunable Microstructure Fiber Devices

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Abstract *An overview of microstructure fibers and devices is presented. By filling the fiber holes with liquids and manipulating the properties of the liquids, the transmission properties of the fiber can be changed to create tunable devices.*

Introduction

Microstructure fibers consist of a pattern of holes in the cladding region surrounding the core that run uniformly along the length of the fiber. By filling the holes with different materials and manipulating their properties, the cladding of the fiber can be changed to tune the transmission properties of the fiber. This can be used to make tunable all-fiber devices.

Photonic bandgap guidance has been demonstrated by filling the cladding holes with a high index liquid. The location of the bandgaps and their associated properties can be tuned by temperature tuning the index of the liquid. This opens the path to realizing tunable photonic devices.

Microfluidics in microstructure fibers

Figure 1 shows the grapefruit microstructure fiber. The outer regions of the cladding contain air holes. These holes can be selectively filled with either a polymer or a liquid over part or the entire length of the fiber /1/. Temperature tuning the index of the liquid/polymer changes the cladding index. The light in the fiber can be made to interact with the liquid/polymer in two ways, (a) by exciting higher order modes via a long period grating (LPG) written in the fiber core, or (b) by tapering down the fiber which spreads the mode out further into the cladding resulting in a significant overlap between the mode and the liquid/polymer region.

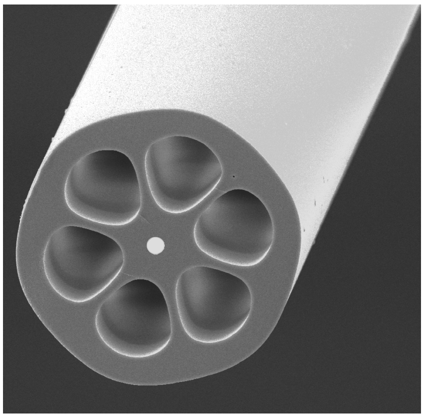

Figure 1. SEM photograph of the grapefruit fiber.

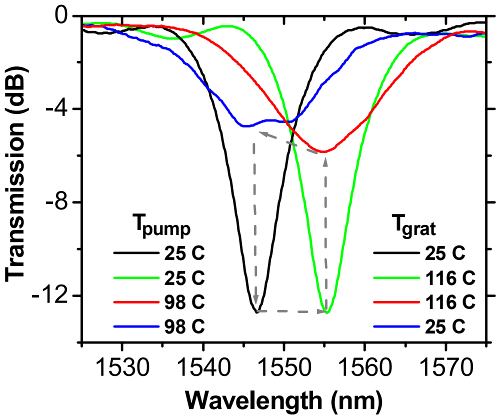

Figure 2. The strength and peak absorption wavelength of a LPG is tuned with heaters.

Figure 2 shows the results of a tunable filter/attenuator using a LPG and two different index liquids. The fiber ends were sealed off during splicing. One heater controlled the peak absorption wavelength by tuning the index of the cladding around the grating with a liquid that has an index similar to silica. A second heater controlled the overlap of a high index liquid with the grating by changing the temperature of the air in the fiber. The grating coupling efficiency to higher order modes decreases as more of the high index liquid overlaps the grating.

Microstructure fibers can be made birefringent by selectively filling some holes /2,3/. Figure 3 shows the difference in the resonant wavelength of the LPG written in the core as a function of temperature for the two orthogonal polarizations.

Photonic bandgap microstructure fibers

Figure 4 shows the cross section of our photonic bandgap fiber. It has a solid silica core and the air holes are filled with a high index liquid (n = 1.7) that raises the effective cladding index to above that of the core. Light is guided in this fiber by coherent Bragg reflections off the periodic crystal structure surrounding the core. Wave vector matching between the reciprocal lattice of the crystal structure and the

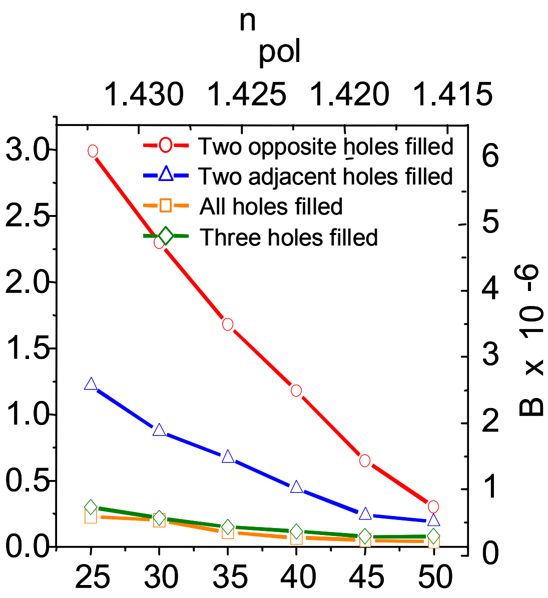

Figure 3. Plot of wavelength difference between thw two orthoginal polarizations as a function of temperature.

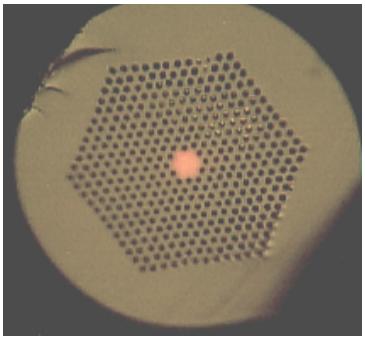

Figure 4. Photonic band gap fiber filled with high index oil.

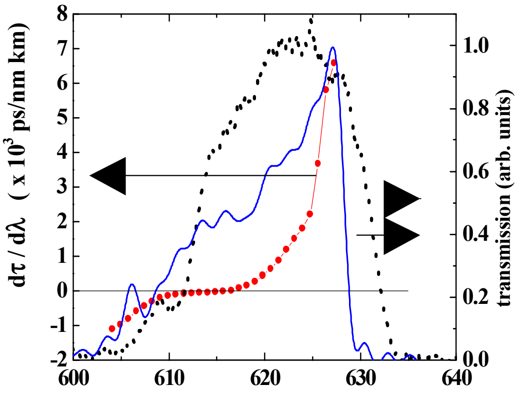

Figure 5. The dotted line shows all the transmited light. The solid line is the transmission of the fundamental mode. The line with circles is the corresponding dispersion.

light in the core is crucial for guidance and only the resonant frequencies are guided (Fig. 5) /4/.

Changing the temperature of the liquid changes the wave vector matching requirements leading to a shift in the location of the bandgap. The bandgap fiber shows strong variations in the modal and dispersion properties across the bandgap. The transmission of the fundamental mode of the fiber has a very sharp cutoff on the long wavelength edge (arising from mode cutoff conditions), and at longer wavelengths only the higher order mode is supported /5/. The dispersion across a bandgap switches from negative values at short wavelengths to large positive values at the long wavelength edge (Fig. 5). The dispersion of the fiber near the long wavelength cutoff is ~ 5000 ps/nm-km which is orders of magnitude higher than that of standard fibers. The dispersion curve and the long wavelength edge of the bandgap shift linearly with temperature and index of the liquid highlighting the wave vector matching requirements between the light and the fiber structure. Hence the dispersion and the relative-dispersion-slope can be temperature tuned over a wide range.

The dispersion and modal properties of the fiber suggest that the longitudinal component of the wave vector decreases with an increase in wavelength so that the transverse component can satisfy the Bragg condition with the crystal structure. In the ray picture, this implies that the light makes more bounces in the core at longer wavelengths, which slows it down considerably. This property can be exploited in future devices such as amplifiers where a longer interaction time of light with medium is required.

Conclusions

Microstructure fibers provide a direct means to manipulate transmission properties by affecting the cladding structure and hence are ideally suited for making tunable fiber devices.

References

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