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Micro Structured Optical Fibers and Devices

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1. Introduction

Structures in waveguides with radial dimensions of the order of the wavelength of light, comprising of materials with significantly different refractive indexes, has increased the design flexibility and functionality of optical fibers. Examples of microstructured optical fibers (MOF) and related devices with enhanced flexibility over conventional fibers include new dispersion compensating fibers [1], highly birefringent fibers [2] and a new family of micro-fluidic fiber-based devices [3]. The microstructured advantage also enables, a novel mechanism of confinement that allows for guidance of light in a photonic crystal within a lower index defect such as air [4], and designs such as endlessly single moded behavior [5], efficient supercontinuum generation [6] and fibers with high air fill fractions that enable new types of fiber sensing devices [7].

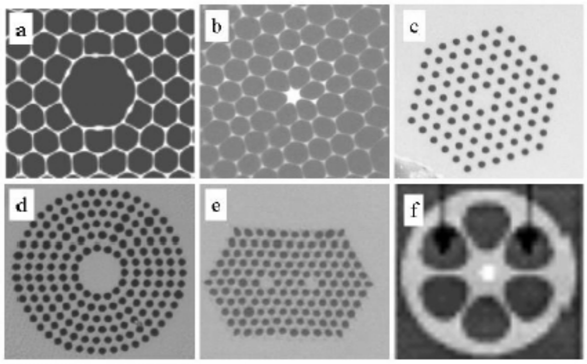

Figure 1 Adapted from Fini and Bise [8] a picture gallery of cross-sections of different MOF designs.

2. Fibers

A few examples of MOF are shown in Figure 1 [8]. Figure 1a [4] shows the thin web type sturcture characteristic of a silica-air, air-core photoinc bandgap fiber. The optical attenuation of this class of fibers has rapidly decreased from over a 1000 dB/km in 2000 to currently 1.7 dB/km [9]. This type of fiber has revolutionary potentials. Modeling has predicted nearly material-independent attenuation (<0.01 dB/km) and material-independent dispresion yielding opportunies not only in long haul transmittion but also in very high power applications. The relatively larger low index core (>7 um diam) has been shown to be useful in sensing gasses.

The small silica core fiber sturcture in Fig 1b, by virture of its small core (~ 2 um), can be used in nonlinerar optics applications. In addition the large void fraction surrounding the core makes it efficient in some sensing applications. In contrast the fiber in Figure 1c is an example of a single moded MOF fiber with mode field diameter matching standard single moded fibers but with cutoff wavelength that can reach the visible. In this case the light in the core does not interact strongly with the voids ans is well confined to the core, making the fiber less sensitive the to the environment. One advantage of this type of fibers is its ultra low bend-loss, which has lead to its consideration for use in access wiring; enabling easier fiber installations and less expensive fiber packaging [10].

A casting method [7] was developed at OFS Labs to enable production of structrures that are not easily achieved by the conventional stacking of capliaries or by hole drilling. Figure 1d is an example of a ring pattern of holes with a large silica core made using this method. A multiple core structures is another example shown in Figure 1e.

Figure 1f is a picture of a flexible device fiber named "grapefuit fiber". This fiber is comprised of a germanium doped standard single mode fiber core surrounded by a thin clad region which is further surrounded by a outer clad of large holes. The large holes can be easily filled with polymers and or fluids. The structure is designed so that only when the fiber is tappered to smaller diameters does the light interact strongly with the fiber core. This fiber is the work horse of the micro-fluidic fiber-based devices including variable attenuators and tunable filters[3, 11].

3. Devices

MOF has been used to enhance functionality in many conventional fiber devices such as dispersion compensation fibers, lasers/amplifier fibers, attenuators, filters and switches. Novel functionality has been developed by taking advantage of the ability to integrate different material into or near the waveguide and by use of photonic band gaps in place of index guidance. The structural sensitivity of photonic crystal band gaps adds additional capabilities to fiber device designs. Figure 2 demonstrates the importance of the dimensional periodicity [12]. In these arrays of high index oil filled holes in a silica background, the quality of the transmission bands clearly shows the importance of the higher quality structure. The temperature dependence of the refractive index of the oil used in this device enables tuning of band gap positions. Although transmission across band gaps is relatively flat the dispersion for a specific

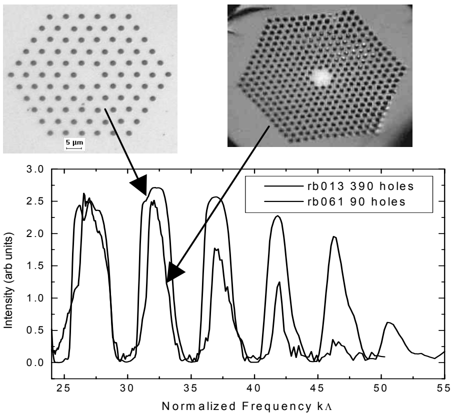

Figure 2 Adapted from [7] End views and normalized relative transmission spectra of two Photonic Band Gap fibers, light guided in the silica core and the holes filled with higher index oil.

mode can have many ±1000 ps/nm/km [13] variation. Although this greatly exceeds that of conventional fibers a fraction of the band still retains a values.

4. Sensors

Optical fibers offer distinct advantages in designing sensors compared to discrete optical components. They are compact, robust and have many integrated optical functions. The tool kit is continuing to expand including for example Bragg gratings, amplifiers, and super-continuum sources. The length of a sample in weak absorption is limited by the optical system design and rarely exceeds a few centimeters in discrete systems. MOF fibers enable meter to kilometer long paths lengths with the ability to sample gases and low viscosity liquids. A proposed water core single moded fiber using an MOF structure should extend the limits of trace absorption measurements in aqueous and biological systems [**14**]. In addition to having long path lengths the surfaces of inner holes of the fiber can be designed to interact with the light guided in the fiber core. An example of this design is shown in Figure 1b. Figure 3 shows the result of exposing this MOF to water vapor. The absorption observed is associated with surface hydroxyl species. The dotted line

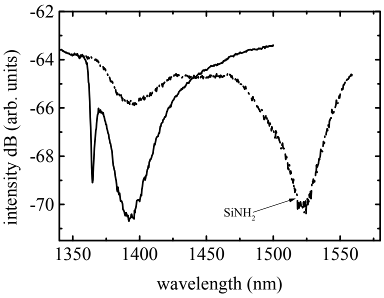

Figure 3 Adapted from Bise and Trevor [7] shows the transmission spectrum of short length fiber with the structure in Figure 1b that is partially reacted with water vapor. The dotted line is the result of reaction with ammonia vapor.

shows the same fiber after reaction with ammonia vapor. The silica surface can also be chemically modified to react with specific chemical species adding additional flexibility to sensor designs.

5. Conclusions

Optical waveguides made with variations in structure on the order of the wavelength have interesting properties and the potential to make novel fibers, fiber devices and sensors. Rapid progress is being made in improving quality and attenuation with an ever-widening variety of designs.

6. References

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