A specialty optical fiber has potential in both sensing applications and communications.

In a fiber draw experiment, we noticed that rings of shrinking thickness naturally appeared in the cladding region, and the cladding rings maintained the same cross-sectional area. This type of fiber—a Fresnel fiber—is analogous to a Fresnel lens, which is made of glass layers with equal area. And just as the Fresnel lens has special transmission properties, so too does the Fresnel fiber: they can be used as sensors for measuring temperature and pressure of gases and liquids, and—properly designed to possess large effective area with flat dispersion—they can be useful in long-distance wavelength-division-multiplexed (WDM) fiber-optic communication links.\(^1\) If designed with a small effective area, then they are suitable for use in such applications as solitons and nonlinear fiber devices.\(^2,3\)

To explore the Fresnel fiber’s capability in sensing certain gases and liquids, we designed several hollow-core Fresnel fibers and filled up the core region with a gas or liquid. Doing so changes the propagation constant, which then can be detected using phase detection techniques. In one experiment, we simulated a Fresnel fiber with core radius of 1\(\mu\)m, \(\Delta = 0.0339\), ring area = 10\(\mu\)m\(^2\), and with 11 cladding layers. The core region is assumed to be initially filled with air. Then, the core is filled with a gaseous material, such as carbon dioxide (CO\(_2\)) at 32\(^\circ\)F (dielectric constant = 1.6), or filled with a liquid, such as kerosene at 70\(^\circ\)F (dielectric constant = 1.8). We then calculated the normalized propagation constant of the fundamental modes for the three cases (see Figure 1). The changes in propagation constant can be quantified using an interferometric technique and then related to the substance filling the core.

These same Fresnel fibers are also sensitive to temperature and pressure. The propagation constant changes with temperature because the refractive indices of the material inside the core region as well as those of the solid layers change with temperature. In pressure applications, the normalized propagation constant is changed because pressure disturbs the thicknesses of cladding layers and their refractive indices due to the elastooptic effect.

In fiber-optic communication systems, where it is important for the fiber to provide both minimum attenuation and dispersion, typical dispersion-shifted fibers provide nearly zero chromatic dispersion at 1.55\(\mu\)m, which is the wavelength of minimum attenuation in silica-based fibers. Fresnel fiber designs also are capable of providing nearly zero dispersion at 1.55\(\mu\)m with effective areas ranging from 15.6\(\mu\)m\(^2\) to 152.7\(\mu\)m\(^2\). Several such single-mode Fresnel fiber designs are characterized in Figure 2.

In wavelength-division-multiplexed (WDM) optical fiber systems, typical dispersion-flattened fibers provide the required small and relatively flat (nearly constant) chromatic dispersion over an extended range of wavelengths. Fresnel fibers designed as dispersion-flattened single-mode fibers also exhibit the required characteristics; Figure 3 shows the dispersion characteristics of two such fibers. The first has a chromatic dispersion of 0.26ps/nm.km and a dispersion slope of 0.004ps/nm\(^2\).km at 1.55\(\mu\)m wavelength. In addition, the dispersion is within \(\pm\)5ps/nm.km over a wide wavelength range (1.32\(\mu\)m to 1.97\(\mu\)m), as shown in Figure 3(a). The second fiber

\(\text{Continued on next page}\)
Figure 2. Effective area for ten different Fresnel fiber designs.

Figure 3. Dispersion characteristics for two different dispersion-flattened Fresnel fiber designs.

Figure 4. Dispersion characteristics for a dispersion-compensating Fresnel fiber design.

Author Information

Rachad Albandakji
Electrical Engineering
Louisiana Tech University
Ruston, LA

Ahmad Safaai-Jazi and Roger Stolen
Electrical and Computer Engineering
Virginia Tech
Blacksburg, VA

References