Chapter 4

MICROSTRUCTURE FIBER AND WHITE-LIGHT GENERATION

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Abstract: Microstructure fibers have played a key role in the production of coherent frequency combs that span more than an octave of bandwidth. In this chapter, we review the fabrication process for such fibers and their linear and nonlinear optical properties. We also discuss the underlying physical processes that give rise to supercontinuum generation.

Key words: microstructure fiber, supercontinuum generation, ultrashort pulse propagation, fiber dispersion

1. INTRODUCTION

The unlikely merger of ultrafast optics, microstructure fibers, and nonlinear optics with frequency stabilization techniques has led to a revolution in frequency metrology. Development over the past decade of ultrafast solid-state laser systems, such as Ti:sapphire, has resulted in laser oscillators that can produce sub-100 fs, nanojoule-energy mode-locked pulses in the near infrared (IR). In parallel, novel single component fibers with cross sections consisting of regularly spaced air holes were created [1] that for large air holes allowed the creation of waveguides that strongly confine the light field to a small area and shift the zero dispersion point of the fiber close to the operating wavelength of the Ti:sapphire oscillators. The combination of the high peak intensities due to strong light confinement and the large effective interaction lengths in the fibers results in a highly intense, nonlinear interaction that can generate a remarkably broad-bandwidth spectrum spanning more than an octave of the central laser frequency [2].
This coherent white-light spectrum is precisely what is needed to stabilize the underlying frequency comb of the mode-locked laser oscillator. It has also led to other applications such as optical coherence tomography [3].

In this chapter, we review the basic properties of microstructure fibers, how they are fabricated, and the underlying physics of supercontinuum generation using ultrashort laser pulses in these fibers.

2. MICROSTRUCTURE FIBER FABRICATION

Microstructure fibers have unique properties and can deliver functionalities superior to many of the best transmission and specialty fibers. Their unique properties are obtained from an intricate cross section of high- and low-index regions that traverse the length of the fiber. The vast majority of these fibers consist of silica for the high-index region and air for the low-index region. These fibers are known by several different names including microstructure fiber, holey fiber, and photonic crystal fiber.

The index profiles that make these fibers unique can also lead to inherently high loss. Loss occurs at connections launching light in and out of the fiber and along the length of the fiber. Light is launched into these fibers by free-space optics, low-temperature fusion splicing, or butt coupling. For microstructure fibers with small cores, coupling with free-space optics produces the smallest insertion loss. Loss due to significant mode mismatch occurs when splicing or butt coupling standard fibers to small-core microstructure fibers. Attenuation along the fiber length can occur because of impurities, hole surface roughness, or poor confinement but is presently low enough that it is not important for most device applications.

Like traditional fibers, microstructure fibers are fabricated in a two-step process. First, a large-scale template of the fiber, called a preform, is fabricated. Second, the preform is drawn (stretched) into a fiber, typically kilometers in length. However, new preform fabrication and draw techniques had to be developed to incorporate air holes in the preform and have them remain through draw.

2.1 Preform fabrication

Preforms are long cylinders, typically less than a few centimeters in diameter, that closely match the structure of the desired fiber. Their large scale, compared to fiber, makes them easy to handle when assembling the desired microstructure pattern. They are typically composed of silica with air holes running uniformly along their length. Other amorphous materials are