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W-type fiber design for application in U- and S-band amplifiers by controlling the LP_{01} mode long wavelength cut-off

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Abstract

We propose a novel passive band-pass filtering scheme to obtain a net gain in a band-competing system using a W-type fiber waveguide, slicing a shorter wavelength gain band out of a given stimulated emission cross-section. By controlling the location of the LP_{01} mode cut-off, fiber design parameters are presented for obtaining a U-band gain from Tm ions and S-band from Er ions. The tolerance of the LP_{01} mode cut-off wavelength and the accompanying bending loss are theoretically analyzed in terms of waveguide parameters.

Keywords: Fiber amplifiers; W-type fiber; S-band amplifier; U-band amplifier

1. Introduction

The increasing demand for wider communication bandwidth has brought in extensive expansion of conventional communication bands into neighboring windows such as S-band (1450–1530 nm) and U-band (1625–1675 nm), and amplifiers for the corresponding bands

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are essential for optical networks. The optical fiber amplifiers for S-band were initially developed by gain shifted Tm-doped fluoride fibers using the up-conversion pumping schemes [1]. Recently S-band Er-doped fiber amplifiers (EDFAs) have been reported by suppressing the emission in C-band at longer wavelengths [2,3]. Silica glass host and commercially available components make the S-band EDFA highly competitive yet special waveguide designs or filtering methods are required since the emission cross section of C-band is several times greater than S-band in Er ions. Tm ions show the peak emission cross section near 1.8 μm in a direct three level transition in silica glass [4], and a weak optical gain around 1600–1700 nm covering U-band have been reported in silica based glass fibers [5]. However the competing emission was not effectively suppressed in the report and a higher gain could be expected after filtering out the 1.8 μm band with a special fiber design. Consequently, it is essential to implement versatile methods for suppressing longer wavelengths above S- or U-band in order to achieve optical fiber gain blocks in the bands of interest.

In contrast to conventional step index single mode fibers, W-type fibers have the fundamental LP_{01} mode cut-off at a long wavelength to provide a short wavelength pass filter characteristic as well as negative chromatic dispersion [6–11]. In particular, parametric analysis on waveguide structure and bending loss studies have been established in the silica glass window around 1550 nm for the application of low loss, passive transmission fibers. We will extend the application of W-type fibers to active devices such as fiber amplifiers, where the unique feature of W-fiber, LP_{01} cut-off, is applied in a rare earth doped fiber in order to effectively filter out the competing longer wavelength emission band and achieve a net gain in a shorter wavelength band. In this paper, we present detailed theoretical analyses on W-type fiber designs to obtain S-band out of Er and U-band out of Tm emission cross sections adopting unique short pass characteristics of W-type fibers. Parametric studies on the impact of fiber structural deviation over the location of the LP_{01} mode cut-off wavelength and bending loss of a W-type fiber are theoretically analyzed, for the first time to the best knowledge of the authors. The sensitivity of the cut-off wavelength and bending performances over the W-type fiber parameter variations will provide practical information for design and fabrication of active fibers.

2. Waveguide design for U- and S-band amplifiers

The structure of W-type fiber is illustrated in the inset diagram at the upper left of Fig. 1. It is composed of three layered structure, high refractive index core, depressed inner cladding, and silica cladding. The depressed index cladding is usually achieved by doping fluorine or boron in silica, while the core index is raised by germanium or aluminum. The refractive indices of core, depressed cladding, and outer cladding are denoted as n^+, n^-, and n_0, respectively. The refractive index differences are expressed as $\Delta n^+ = (n^+ - n_0)$ and $\Delta n^- = -(n^- - n_0)$. The core radius is a and the depressed cladding radius is b. These are the key waveguide parameters of a W-type fiber and they will determine guiding properties of the W-fiber.

One of unique properties of W-type fibers is existence of the fundamental LP_{01} mode cut-off [6,8]. As the wavelength increases, the effective index of the fundamental LP_{01}