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MULTI-WAVELENGTH ERBIUM-DOPED FIBER LASER BASED ON A MICROSTRUCTURE FIBER BRAGG GRATING

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ABSTRACT: *In this paper, a multiwavelength erbium-doped fiber laser based on a microstructure fiber Bragg grating (FBG) is proposed and demonstrated. The fiber Bragg grating is fabricated in a large-air-hole microstructure optical fiber using the phase-mask method. The laser based on this novel grating can be designed to achieve a three-wavelength output at room temperature. The lasing wavelengths of the channels are 1557.84, 1555.07, and 1552.70 nm, respectively, and the wavelength separation is about 2 nm.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 46: 162–164, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20931

Key words: *erbium-doped fiber laser (EDFL); multiwavelength fiber laser; microstructure fiber (MF); fiber Bragg grating (FBG)*

1. INTRODUCTION

Multiwavelength fiber lasers are useful sources in wavelength-division-multiplexed (WDM) fiber-communication systems, fiber sensors, and optical-instrument testing. With regard to wavelength-selection components for lasers, fiber Bragg gratings (FBGs) are ideal ones due to the unique advantage of fiber compatibility. Various techniques have been proposed to realize multiwavelength oscillations by utilizing cascaded FBG cavities [1], polarization-dependent loss element [2], an FBG written in a birefringent fiber [3, 4], a sampled FBG [5], two overlapping cavities composed of two FBGs with a common gain medium [6], and FBG fabricated in a few-mode fiber [7].

Air-silica microstructure fibers are all-silica fibers which contain air voids that run along the length of the fiber. Such novel optical fibers differ from traditional fibers with regard to their optical properties, due to the effect of the structure of the fiber cladding on the spatial distribution and the effective refractive indices of cladding mode, thus increasingly attracting attention to this class of fiber-waveguide structures. Recently, increased interest has focused on the guidance properties of the cladding modes. The inscription of both FBG and long-period grating in microstructure fibers with different geometrical cross sections has been reported [8–11]. In this paper we choose a "grapefruit" fiber, which is a typical large-air-hole microstructure fiber, for fabrication of an FBG in the photosensitive core using the phase-mask method. The grating formed in this novel waveguide shows multiple resonances in both its transmission and reflection spectra, as compared to conventional FBGs in single-mode fibers. This FBG is incorporated into an Erbium-doped fiber-laser cavity as a wavelength-selective component for the first time, to the best of our knowledge. The proposed laser can be made to operate with a three-wavelength output at room temperature. The lasing wavelengths of the oscillations are 1557.84, 1555.07, and 1552.70 nm, respectively, and the wavelength separation is about 2 nm. The output powers for the three wavelengths are −5.2, −3.1, and −4.1 dBm, respectively.

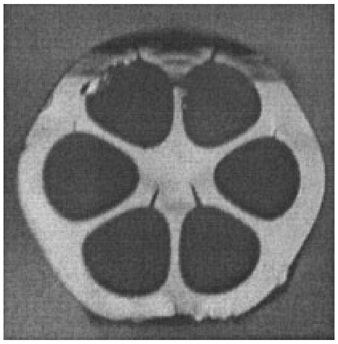

Figure 1 Cross section of the 125-μm-diameter grapefruit fiber

2. FABRICATION OF THE FBG IN MF

An FBG based on microstructure fiber was fabricated using the phase-mask technique. The fabrication setup was not different from that used in the fabrication of a conventional fiber grating. A 248-nm UV beam generated by an EXCISTAR M-100 KrF excimer laser was focused by a cylindrical lens and exposed to the core of the MF through a phase mask. The UV exposure energy density was 40 mJ per pulse and at a repetition rate 10 Hz. The period of phase mask is 1.072 μm.

Figure 1 shows a cross section schematic of the "grapefruit" air-silica microstructure fiber. It incorporates six large air holes that form an approximately 38-μm air annuls around a central silica region 27 μm in diameter. The center of this region contains a germanium-doped, single-mode core of diameter ~6.6 μm and Δ~0.0043, where Δ denotes the index change of the fiber core caused by the germanium doping. Considering the scatting of the UV light caused by these air holes, the fiber was treated in 120 atm of H2 at room temperature for several days in order to enhance the photosensitivity of the germanium region.

The measured reflection spectrum of the FBG in grapefruit microstructure fiber is shown in Figure 2. As can be seen from the figure, multiresonance peaks are observed, which are different from those of conventional single-mode FBGs. The three resonant wavelengths measured are 1557.84, 1555.07, and 1552.70 nm, respectively. Using a full-vector finite element method, the resonance labeled "A" corresponds to the coupling between the propagating fundamental mode and the antipropagating fundamental mode, while "B" and "C" correspond to the coupling between the fundamental mode and some of the low-order cladding modes.

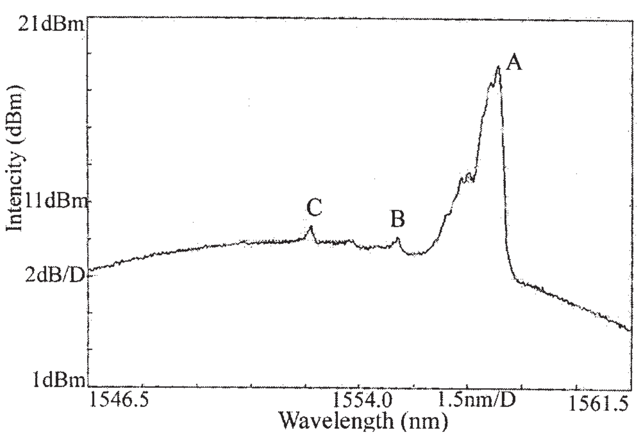

Figure 2 Measured reflection spectrum of the FBG in microstructure fiber

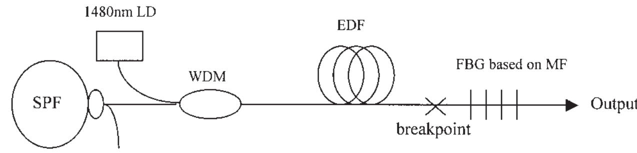

Figure 3 Schematic diagram of the linear cavity Er-doped fiber laser

This is due to the unusual air-silica geometry of MF. In effect, the large air holes form an effective inner cladding and small amount of light from these cladding modes leak out of the webbing between the holes. Consequently, the cladding modes confined in the small-diameter silica region have relatively large overlap with the core mode.

3. LASER CONFIGURATION

The configuration of the proposed laser is shown schematically in Figure 3. The linear cavitey laser is constituted of a sagnac fiber loop (SFL), a WDM couplor, 5 m of EDF with an erbium-ion concentration of 400 ppm, and an FBG in microstructure fiber. The SFL acts as a broadband reflector for signals and the FBG is used for wavelength selection and the output coupler. The fibers in the cavity were all single-mode fibers, except the grapefruit fiber used for FBG fabrication. The 5-m-long Erbium-doped fiber provided the gain media and was pumped by a 1480-nm laser diode via a 1480/1550-nm WDM coupler. At the point marked by a cross in Figure 3, the conventional fiber was not spliced directly to the microstructure fiber, and we adjusted the position of the two segments by fine-tuning the control device. The laser's spectral characteristic was monitored using an ADVANTEST Q8383 optical spectrum analyzer with 0.1-nm resolution.

4. RESULTS AND DISCUSSION

The output spectrum of the proposed laser schematized in Figure 3 is measured. At first, we spliced the conventional fiber directly with the microstructure fiber at the breakpoint marked in Figure 3 and only one lasing wavelength of 1557.84 nm was observed. We thought this was due to the differences of reflectivity between the three reflection peaks, which can be obviously observed from the spectrum shown in Figure 2. In order to resolve this problem, we broke the welding point and used a fine-tuning control device to adjust the fiber's position. Using this method, the cross section between the single-mode fiber and the MF can be slightly offset to form an unmatched mode area, which results in the depression of the reflectivity of the main reflection peak.

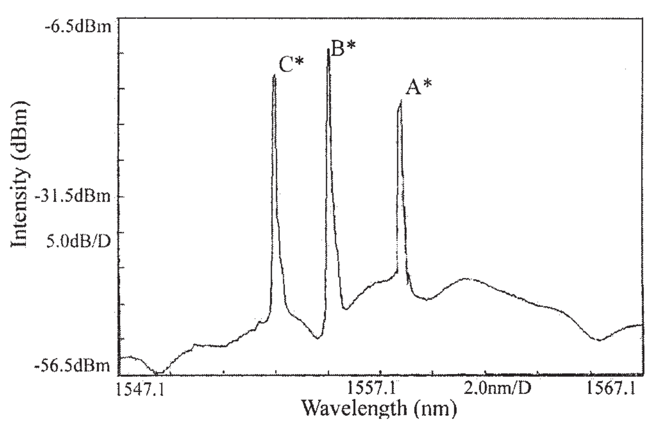

Figure 4 Output of Er-doped fiber laser based on microstructure fiber

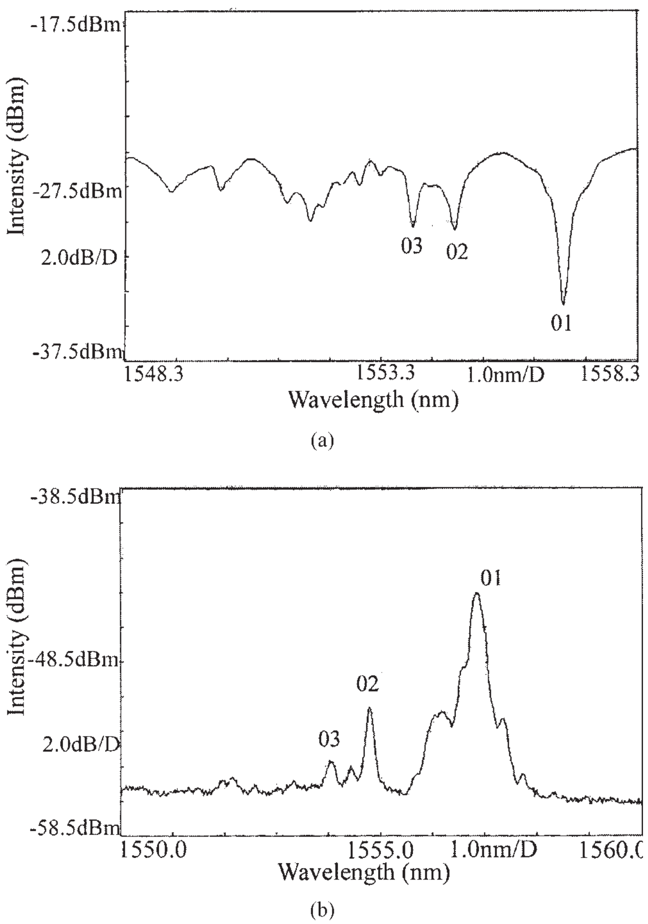

Figure 5 Measured transmission spectrum and reflection spectra of the FBG inscribed in grapefruit microstructure fiber: (a) transmission spectrum; (b) reflection spectrum

As can be seen from Figure 4, when the position of the fiber was adjusted appropriately, the multiwavelength operation of the EDFL at room temperature was obtained. The wavelengths of lasing outputs were 1557.84, 1555.08, and 1552.92 nm, respectively. We found the lasing oscillations marked by "A*" and "B*" were consistent with the reflection peaks of the FBG with the mark of "A" and "B," but a slight wavelength drift could be observed with regard to the third wavelength output. This may be due to the change of the coupling cladding-mode's order caused by the unmatched mode area. The output powers were about 0.30, 0.49, and 0.39 mW, respectively, and there was no obvious variation in each resonance wavelength. We considered the principle to be analogous to multiwavelength Erbium-doped fibers based on multimode-fiber gratings, which have been widely studied [12–14].

By improving the fabrication technology, another FBG was formed successfully in the same fiber. Figure 5 shows the measured transmission and reflection spectra written for the second time. As compared to the first one, the phenomena of multiple resonant peaks were more obvious and the wavelength differences between the two gratings was attributed to the error introduced in the process of grating inscription and the tiny inhomogeneity of the fiber. These results will be used in further research.

5. CONCLUSION

In conclusion, a multiwavelength Erbium-doped fiber laser based on a microstructure-fiber grating has been proposed and demonstrated. The novel FBG can be conveniently fabricated using the traditional phase-mask method, the laser can operate with a three-wavelength laser output at room temperature, and the wavelength separation is about 2 nm. This method has a simple configuration, as compared to many other techniques.

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