A novel dual-wavelength fiber Bragg grating and its application in fiber ring laser

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A novel method for fabricating dual-wavelength fiber Bragg gratings (FBGs) by using one phase mask is developed. The method is based on a double-exposure technique. Our technique lends itself to writing gratings with controllable reflectivity and separation of two Bragg wavelengths. A grating with two equal transmission peaks of 20.25 dB is obtained by this method and the separation of the two Bragg wavelengths is about 0.8 nm. With the grating, we demonstrate a dual-wavelength erbium-doped fiber ring laser whose interval of the two peaks is 0.8 nm. The laser's peak powers can get 3.1 mW above and have a good stability.

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Since the discovery of photosensitivity of Ge-doped optical fibers, fiber Bragg gratings (FBGs) have been considered as important fiber components in fiber-optic communication and sensor systems[1−3]. To satisfy numerous applications, various special fiber gratings have emerged, one of which is the dual-wavelength FBG. This kind of grating can be used to make dual channels optical add/drop multiplexes (OADMs), dual-wavelength filters, dual-wavelength fiber lasers, and to solve the problem of temperature-strain cross sensitivity of FBG sensors[4]. The dual-wavelength FBGs used to be made by using two phase masks. The interval of the two wavelengths is limited by the phase masks while the process of exchanging mask is not convenient. We develop a novel method to make the dual-wavelength FBGs. The dual-wavelength FBGs can be fabricated by using double-exposure with only one phase mask. The technique lends itself to writing gratings with controllable reflectivity and separation of two resonant wavelengths. As an application of the fiber grating, we demonstrate a dual-wavelength erbium-doped fiber (EDF) ring laser. The experimental results indicate that the peak powers of the laser can attain 3.1 mW above, the interval of the two peaks is 0.8 nm and the output spectrum has a good stability.

The experimental setup to fabricate the fiber grating is shown in Fig. 1. It comprises a tunable slot, a fiber holder with a translation stage controlled by a stepper motor, and a uniform phase mask fixed on the holder. The photosensitive fiber with the phase mask can be translated along the fiber's axis. The ultraviolet (UV) light from a KrF excimer laser operating at 248 nm is focalized on the photosensitive fiber behind the uniform phase mask by a cylindrical lens. The energy of per pulse is 40 mJ and the repetition rate is 25 Hz. The tunable slot is used to limit the width of the UV light beam. The spontaneous radiation that emits from erbium-doped fiber amplifier (EDFA) pumped by 980-nm laser diode (LD) is used as the broad band source (BBS). The transmission spectrum is displayed on an optical spectrum analyzer (OSA).

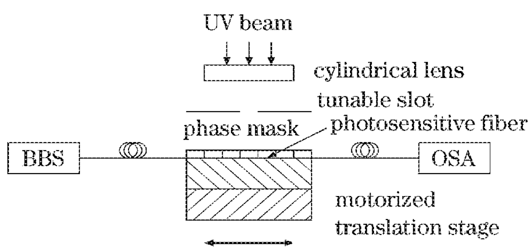

Fig. 1. Experimental setup.

We study the change regulation of the resonant wavelength and the transmissivity of the Bragg grating with the UV exposure. The length of the grating limited by the slot is 4 mm. The relationship between resonant wavelength of the grating and the UV exposure is shown in Fig. 2. Figure 3 shows the transmissivity of the grating versus the UV exposure. From Fig. 2, we can see that the resonant wavelength of the Bragg grating multi-decaying-exponentially increases with the exposure[5]. But the growth of the transmission peak of the Bragg grating is different. As shown in Fig. 3, the transmissivity of the Bragg grating grows quickly at first and then grows slowly. When the number of exposure gets 8000 pulses, the transmissivity gets its maximum value and then decreases. The phenomenon which

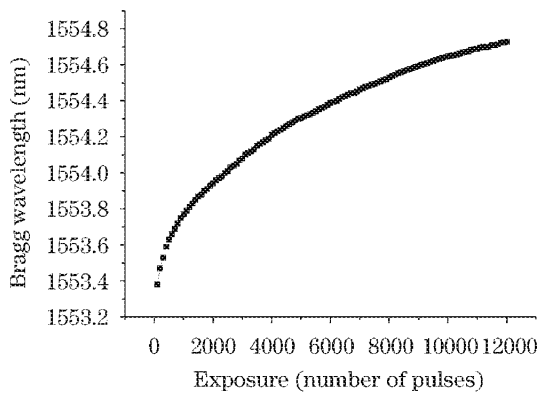

Fig. 2. Bragg wavelength shift versus UV exposure.

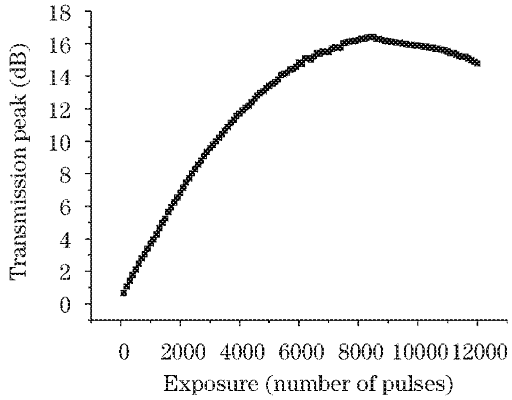

Fig. 3. Transmission peak versus UV exposure.

coincides with that obtained by J. Albert *et al.*[6] can be explained by the photosensitivity of the photosensitive fiber. At the beginning of the exposure, the index almost linearly increases and the modulation of the Bragg grating increases too, which induces the peak growth. When the exposure time is enough, the index increment gets its saturation and the modulation simultaneously decreases, which induces the peak reducing. According to these regulations, we may get two resonant peaks with the same transmissivity, but different resonant wavelengths in the Bragg grating by using two different exposures. The interval of the two resonant wavelengths is controlled by the two different exposures, and the two transmission peaks are determined by their lengths (i.e. the width of the tunable slot).

The dual-wavelength FBG obtained by our method is consisted of two sub-gratings. We set the width of the tunable slot 8 mm. With the first post-exposure of 18000 pulses, the transmission peak of the sub-grating firstly gets it maximum value and then decreases to a value of 20.25 dB, meanwhile its Bragg wavelength gets 1554.88 nm. Next we translate the fiber along its axis with the displacement of 8 mm, and then start the second exposure. We stop the exposure when the transmission peak increases to 20.25 dB. The pulses' number is 3000 and the Bragg wavelength of the second sub-grating is 1554.08 nm. Therefore, using this scheme, a 1.6-cm-long dual-wavelength FBG is obtained. The two transmissivities are approximately 20.25 dB and the separation of the two wavelengths is about 0.8 nm. Figure 4 shows the reflection and transmission spectra of the obtained dual-wavelength FBG.

As an application, we demonstrate a dual-wavelength EDF ring laser with the dual-wavelength fiber grating. Fiber lasers that oscillate simultaneously at multiple wavelength are important for applications in dense wavelength division multiplexed (DWDM) fiber communication systems, fiber sensors, and fiber-optics instrumentation[7−9]. The experimental configuration of the fiber ring laser is shown in Fig. 5. A 980-nm pump LD with a maximum power of 80 mW is coupled through a wavelength division multiplexer (WDM). The ring cavity is composed of a piece of EDF, a polarization-independent isolator (PI-ISO), a coupler (C) and the dual-wavelength FBG obtained in the experiment. Under the consideration of the relationship

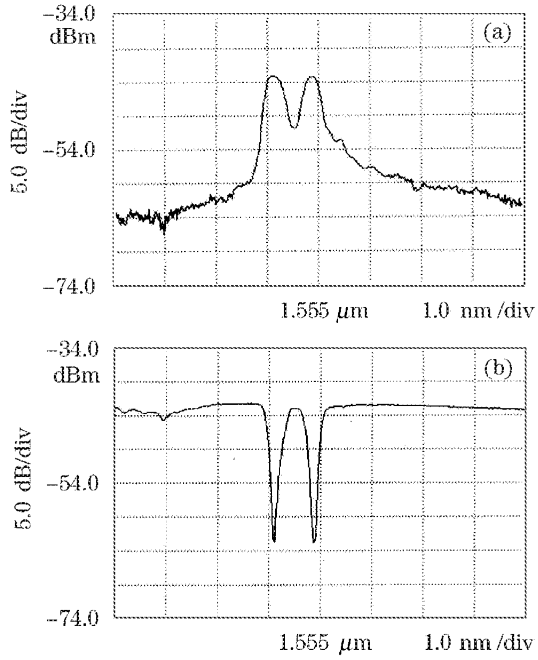

Fig. 4. (a) Reflection and (b) transmission spectra of the dual-wavelength FBG.

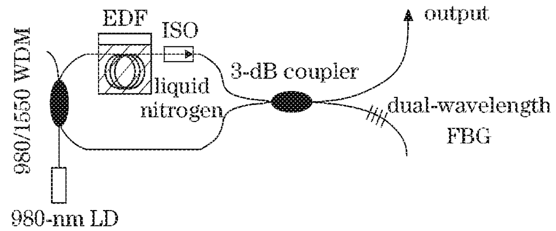

Fig. 5. Schematic diagram of the dual-wavelength fiber ring laser.

among the EDF's gain property, its ion-concentration, the pump power and the coupling-out ratio, we have optimized the EDF length of the cavity. It is well known that EDF at room temperature is a mainly homogenous broadened gain medium, whose homogeneous line width exceeds 10 nm. Therefore, it is difficult to achieve stable simultaneous multi-wavelength oscillation due to gain clamping in the EDF. In order to reduce the homogeneous broadening and achieve stable simultaneous multi-wavelength oscillation[10], the EDF is immersed in liquid nitrogen (at a temperature of 77 K). The laser that stably oscillates at two wavelengths 1554.08 and 1554.88 nm, with a spacing of 0.8 nm, is successfully obtained. The output spectrum is shown in Fig. 6. Each line width is < 0.1 nm. The output power are all > 3.1 mW. Figure 7 shows a group of spectrum curves in which each curve is scanned every 2 minutes. The result indicates that the laser has a good stability. The output laser is stable and narrow in line width because of the high reflectivity of the dual-wavelength fiber grating. In addition the structure of the dual-wavelength EDF ring laser is simple and can be realized easily.

In summary, we have demonstrated a novel method for fabricating dual-wavelength FBGs by using one phase mask. In the method, the double-exposure technique is applied. The separation of the two Bragg wavelengths

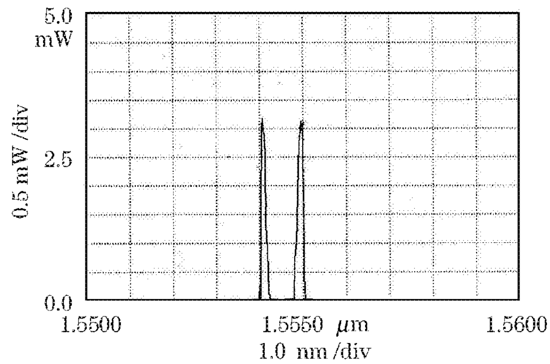

Fig. 6. Fiber laser output spectrum.

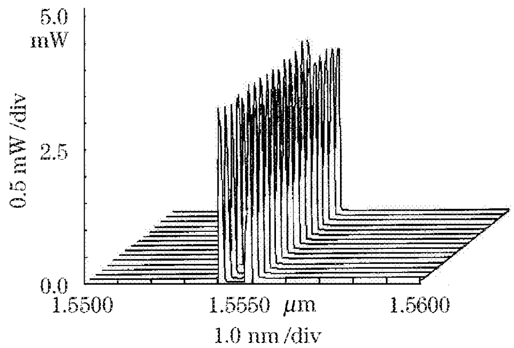

Fig. 7. Fiber laser output spectrum scanned every 2 minutes.

and the transmission peaks can be controlled. Using this technique, we get a 1.6-cm-long dual-wavelength Bragg grating whose interval of the two resonant wavelengths is 0.8 nm and all the transmissivities are 20.25 dB. Based on the dual-wavelength Bragg grating obtained in the experiment, we successfully demonstrate a stable dual-wavelength fiber ring laser with 0.8-nm interval. The double-exposure technique has many advantages such as simple operation, flexible control, and good repeatability, etc..

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