# A simple method to fabricate phase-shifted fiber grating

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We have successfully demonstrated a single-frequency distributed-feedback Yb-doped silica fiber laser. The laser cavity is 10 cm long and is formed by a simple method called the shielded method. The phase shift in the fiber Bragg grating is introduced by shielding a small region of the fiber during fabrication by ultraviolet (UV) light from a 193-nm excimer. Without complex pump configuration, the fiber laser gives a maximum output of more than 20 mW when pumped by laser diode at 978 nm with 100 mW. The laser shows a single frequency and single polarization operation.

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Phase-shifted distributed feedback (DFB) fiber grating laser has received great attention and careful research since it was first reported[1] because of its intrinsic fiber-compatible, simple, low noise, excellent mode selection, little output fluctuation, and very narrow linewidth[2]. Stable, spectrally narrow wavelength sources is a key requirement for wavelength division multiplexing optical communication system and for externally modulated high-data-rate system[3].

Usually, there are four methods to introduce phase-shift into a uniform fiber Bragg grating. The obviously direct way is to employ a phase-shifted phase-mask in which phase shift regions have been incorporated into the mask design[4]. But this method is inflexible because the phase shift in the phase mask is designed for a kind of unique fiber. When phase-shift is introduced into a different kind of fiber, the phase-shift is no longer as the same that designed to be. A second method is to post-process a uniform grating by exposing a grating region to ultraviolet (UV) laser radiation[5−7]. Because the refractive index and UV exposure distribution along the fiber are usually not uniform after exposing, the position of phase-shift can not be randomly chosen. The third one involves post-fabrication processing using localized heat treatment[8], however which can not introduce permanent phase-shift. And the last one, which has been extensively reported, is scanning beam technique employing a translating stage during etching[9−12], which needs complex and rigorous controlling system during fabrication. In this paper, we have employed a simple method to introduce a single permanent phase-shift into the uniform fiber grating named as shielded method. This method had been employed by fabricating semiconductor DFB laser[13]. By this method, no complex fabricating configuration is employed to introduce phase-shift and a 20-mW phase-shifted DFB fiber grating laser has been demonstrated without complex pump configuration.

The principle of the shielded method is depicted in Fig. 1.

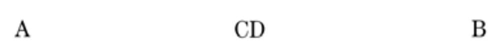


Fig. 1. Schematic diagram of shielded method (the uniform fiber grating AB with a small shielded region CD).

When etching uniform fiber grating, shield a small region from UV light. Then there is a refractive difference between the shielded region and the area which is exposed to UV light during fabrication. As a result, a discrete phase-shift is introduced into the fiber grating. As long as a proper length of shielded region is selected, the introduced phase-shift will approach $\pi$.

The introduced phase-shift employing the shielded method can be expressed as

$$\phi = \frac{2\pi(\Delta n)l}{\lambda_{\mathrm{B}}}, \quad (1)$$

where $l$ is the length of the shielded region and $\Delta n$ is the refractive index difference between the shielded region and the neighboring area which has received exposure from excimer and it is determined by[13]

$$\Delta n = n_{\mathrm{av}} - n_{\mathrm{s,eff}}, \quad (2)$$

where $n_{\mathrm{av}}$ is the average refractive index of the exposed region and $n_{\mathrm{s,eff}}$ is the refractive index of the shielded region.

Figure 2 is the transmission spectrum of the phase-shifted fiber Bragg grating. A narrow transmission window is created in the center of the fiber grating spectrum.

We have successfully demonstrated 20 mW output only using laser diode as the pump source. The threshold of the laser is 2 mW. When the pump power is increased to be 100 mW, the laser output power is 20 mW. Laser output fluctuation was monitored by a power meter. In one hour, the output power fluctuations is less than

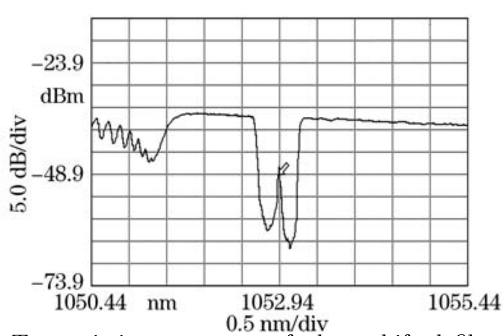


Fig. 2. Transmission spectrum of phase-shifted fiber Bragg grating.

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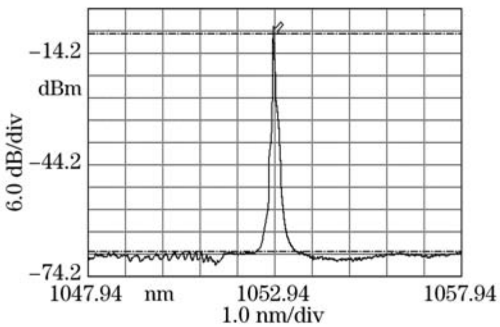


Fig. 3. Laser output spectrum when the pump power is 80 mW.

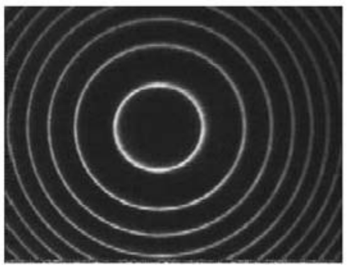

Fig. 4. Interference pattern from a FP interferometer which indicates the laser is single-frequency operation.

0.2 mW, which means that the fluctuation of the laser output power is less than 1%. The laser output spectrum corresponding to the 80-mW pump power is shown in Fig. 3.

In order to verify whether the laser output is single-frequency output or not, the output of the laser is fed into a Fabry-Perot (FP) interferometer. The mode pattern is shown in Fig. 4, which indicates that the laser is single-frequency operation. The degree of polarization of the laser is measured to be better than 20 dB.

In conclusion, we have proposed a simple method to fabricate the phase-shifted fiber Bragg grating. Employing this grating as a cavity, a phase-shifted distributed feedback fiber grating laser has been demonstrated. The threshold of the laser is 2 mW. When pumped by a laser diode at 978 nm delivering 100 mW, the laser gives an output of more than 20 mW.

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