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Stable single frequency and single polarization DFB fiber lasers operated at 1053 nm

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Abstract

Stable single-frequency and single-polarization distributed-feedback (DFB) fiber laser was realized by giving a pressure on the phase shift region of the fiber grating. The output wavelength of the DFB fiber laser is 1053 nm. When the pump power of 980 nm laser diode is 100 and 254 mW, the output power can reach 8.3 and 37.1 mW and the polarization extinction ratio was 26 and 20 dB, respectively. After chopped by Acousto-optic modulator (0.3 Hz), the pulse peak value variance is 4.65%(peak to peak) and 1.098% (RMS) for 31 min.
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Keywords: DFB fiber lasers; Single polarization; Single frequency

1. Introduction

Optical fiber distributed-feedback (DFB) lasers using ultraviolet light (UV)-written fiber Bragg grating on doped fibers feature single-frequency operation, thus are a promising technology for applications in optical fiber communications. Most fiber DFB lasers, however, actually operate in two orthogonal polarizations as a result of polarization independent in the fiber DFB lasers, which is not desirable for these applications [1].

Single polarization operation of the phase shifted DFB fiber lasers could be attributed to polarization dependence in either the grating reflectivity, background loss, medium gain, or the magnitude of the phase-shift experienced by the two polarizations. Yamashita and Hsu [2] reported single polarization operation of DFB fiber laser by use of injection locking techniques, but the setup was complicated and is difficult to realize. Storoy et al. [3] used the UV post-processing technique to fabricate phase shifted DFB fiber laser and by controlling the exposure time of the UV post-processing light to obtain single polarization operation. But we found that it is easy to mode hopping for the little difference of the gain threshold of the two polarization modes. Harutjunian et al. [4] reported that twisting the grating can also get single polarization operation, but it is difficult to handle and realize high stable operation for long time. Philipsen et al. [5] and Erdogan and Mizrahi [6] reported that stable single polarization DFB fiber lasers can be realized by using polarized UV illuminating the fiber during the fabrication of grating. But it is difficult to acquire polarized material for short wavelength of 193 nm, which was often used to illuminate and fabricate fiber grating. We have reported that stress-induced single polarization DFB fiber lasers, but the output was not stable and cannot be used as a high stable laser source [7].

Now, the paper reports that by giving a pressure on the phase shift region, the birefringent phase-shift can be strong enough to make the DFB fiber laser operate at single polarization. The output power can reach 8.3 and 37.1 mW when pumped by 100 and 254 mW of 980 nm laser diode, respectively. The polarization extinction ratio of the DFB fiber laser was 26 and 20 dB, respectively. After chopped by Acousto-optic modulator (0.3 Hz), the pulse peak value variance is 4.65% (peak to peak) and 1.098% (RMS) for 31 min. The laser has been operated for

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2 months, and can still keep stable single polarization and single longitudinal mode operation.

2. Experiment

The Yb^{3+}-doped fiber we used were fabricated by Wuhan Research Institute of Posts and Telecommunications of China. The fiber had a core diameter of 6.10 μm, a cutoff wavelength of 907 nm and an absorption of 68 dB/m at 975 nm which was provided by manufacturer.

A 10 cm Bragg grating was written in the 45 cm Yb^{3+}-doped fiber by a UV-excimer laser operated at 193 nm. The distributed phase-shift was induced by shielded method [8,9], of which the center is shielded to avoid the UV illumination. During the fabrication of the fiber grating, the output of the DFB fiber laser was monitored to acquire the utmost output power [9]. As soon as the output was high, the illumination was stopped. At this time, the output was always operated with two orthogonal polarization modes shown in Fig. 1, which can be seen from the interferometric rings of the laser that transimitted F-P interferometer and recorded by a set of monitor system.

After the fiber grating was annealed with 120 °C for more than 8 h, the fiber grating was pumped by a pigtailed semiconductor laser operated at 980 nm through a wavelength-division-multiplexed coupler (WDM). The output port of WDM and the other port of the Yb^{3+}-doped fiber grating were both fused with polarization independent isolators to prevent Fresnel reflection.

The Yb^{3+}-doped fiber grating was placed on an Al plate, which was temperature controlled. The temperature was set at 20 °C. The phase shift place was pressed by a piece of Al plate fasted by bolt. There was a piece of rubber on the undersurface of the Al plate to prevent breaking the fiber grating.

The output of the DFB fiber laser was monitored by F-P interferometer, CCD and a monitor. The pump power was set at 100 mW. Before pressing the phase shift region of the fiber grating, there were two sets of interferometric rings shown in Fig. 1, it could be verified by Glan Prism that the two modes were orthogonal polarization modes. Then the phase shift region was pressed by knobing screws which controlled the Al plate on the fiber grating. As soon as only a set of interferometric rings was emerged, the pressing was stopped.

The experimental setup is illustrated in Fig. 2.

The signal wavelength was measured to be 1053 nm by optical spectrum analyzer. The output optical spectrum of the fiber laser is shown in Fig. 3.

The output power is shown in Fig. 4 as a function of launched pump power. It can be seen from the figure that the output power was not increased totally linearly with the increase of the pump power.

The longitudinal modes was monitored by F–P interferometer, CCD and the monitor while the pump power was increased. It can be seen from the interferometric rings that when the pump power was 139 mW, the other polarization mode emerged and then disappeared when pumped by 174 mW. Though mode competition exists at this pump power region, it can output 8.3 and 37.1 mW when pumped by 100 and 254 mW, respectively, which can keep single polarization and single longitudinal mode output. The F–P interferometric rings are shown in Fig. 5. The polarization extinction ratio was 26 and 20 dB, respectively, which was tested by Glan prism and optical power meter.

The reason why the output power was not increased linearly with the increase of the pump power was not clear yet. But because the output power fell off so much, it probably due to an increase of the threshold for both polarization modes for some unknown reason. And it was found that, while the pump power was less than 100 mW,

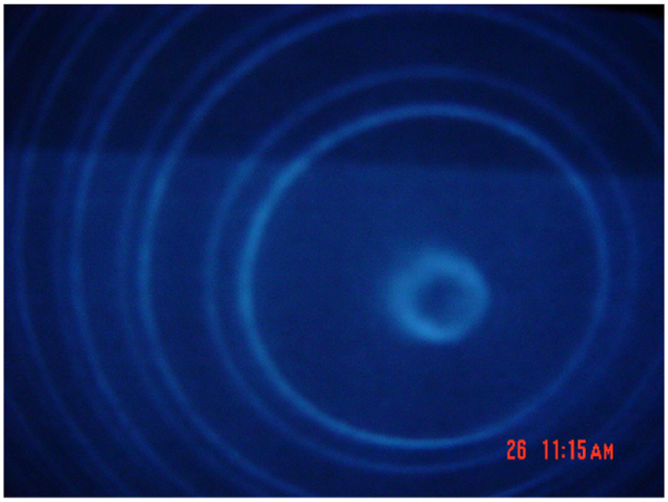

Fig. 1. The interferometric rings of the laser as soon as the fiber grating was fabricated, which transmitted F–P interferometer and recorded by a set of monitor system.

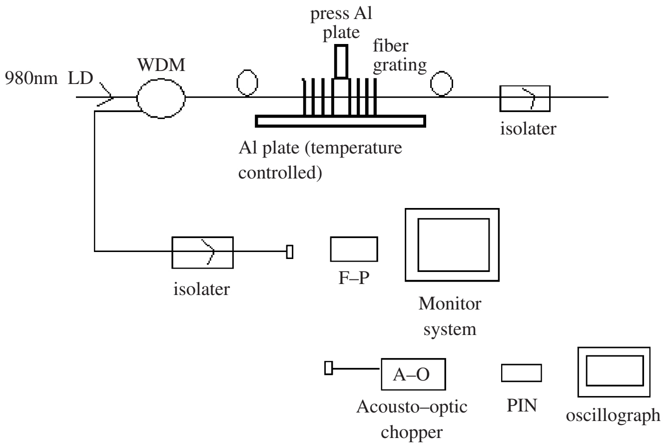

Fig. 2. Experimental setup (the pressure was applied on the grating phase-shift section): WDM, wavelength-division multiplexer; F–P, Fabry–Perot interferometer; 980 nm, the wavelength of laser diode which is used to pump the phase-shifted DFB fiber laser.

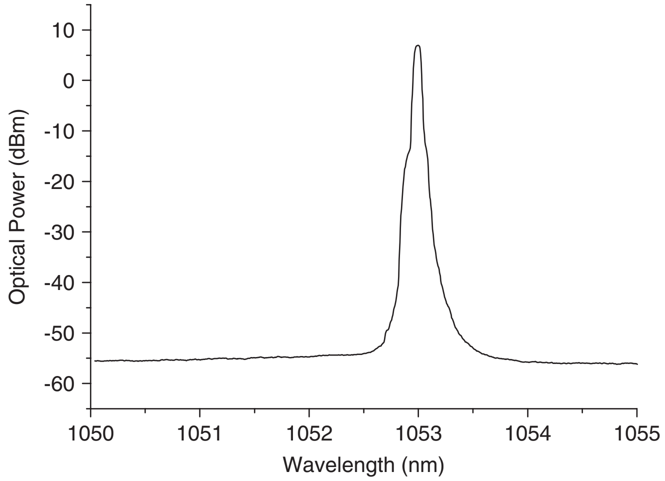

Fig. 3. The output optical spectrum of the Yb-doped DFB fiber laser.

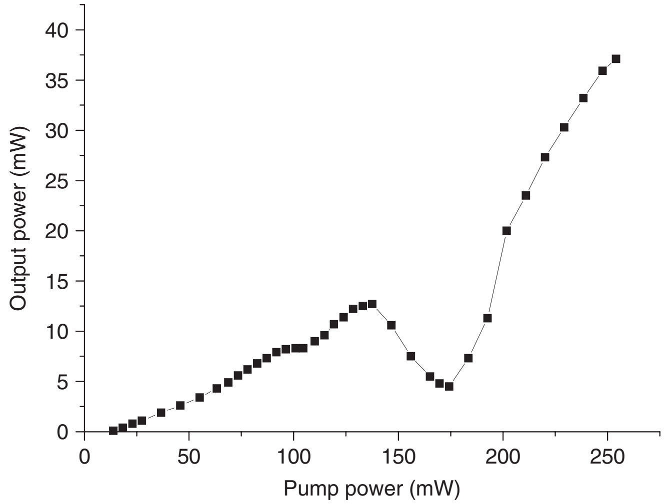

Fig. 4. The output power versus launched pump power.

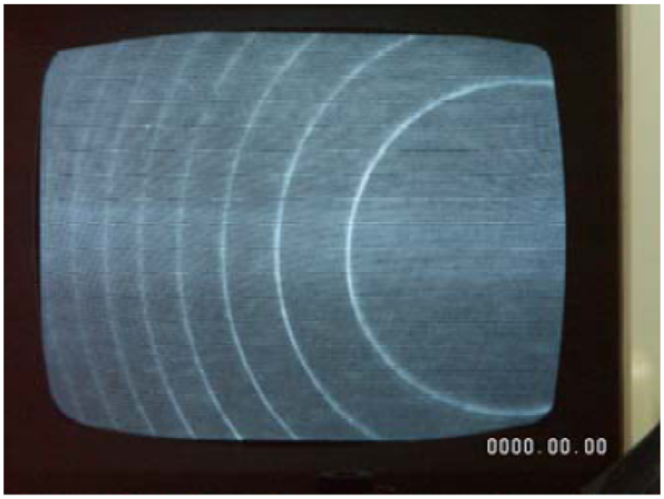

Fig. 5. The interferometric rings of the laser which transmitted F–P interferometer and recorded by a set of monitor system.

the higher the pump power, the higher the polarization extinction ratio; and then the polarization extinction ratio began to decrease with the increase of the pump power. While the pump power was greater than 139 mW, the polarization extinction ratio had no explicit relation with the pump power. When the pump power was greater than 200 mW, the polarization extinction ratio had a direct ratio with the increase of the pump power. The polarization extinction was 20 dB when the laser was pumped by 254 mW which was the maximum pump power of the laser diode.

Then the laser was chopped by Acousto-optic chopper. The pulse was detected by a fiber pigtailed PIN, of which the bandwidth is 2.5 GHz. The pulse width was 200 ns. In order to write down the peak value without missing a data, the repetition rate was set at 0.3 Hz. The stability was measured for many times as shown in Table 1.

Then the repetition rate was set at 1 Hz. The amplitude envelope was recorded 128 times, which was shown in Fig. 6. From Fig. 6, peak to peak jitter was about 5.5%, which was a little high because the pulse has some time jitter.

Now, the laser has been operated for 2 months, and can still keep stable single polarization and single longitudinal operation.

The stress level we have applied to induce the fiber DFB laser run at single frequency and single polarization mode was estimated. The birefringence, which is induced by the transverse force, is given by [7,10]

$$B_{\mathrm{f}} = (4Cf)/(\pi r), \tag{1}$$

where $C = n^3(p_{12} - p_{11})(1 + \nu_{\mathrm{p}})/(2E)$ is the relative optoelastic constant, f is the force per unit length (N/mm), and r is the fiber radius, n is the average fiber refractive index, E and ν_{p} are the modulus of elasticity and Poisson's ratio for the fiber, respectively, and p_{11} and p_{12} are the photoelastic coefficients of silica. The typical values of C for fused silica are $p_{12} = 0.27$, $p_{11} = 0.12$, $\nu_{\mathrm{p}} = 0.17$, $E = 7.6 \times 10^4\,\mathrm{N/mm^2}$, and $n = 1.47$, which yields $C = 3.6 \times 10^{-6}\,\mathrm{mm^2/N}$. Substituting the values to (1), we get the birefringence

Table 1
The pulse stability of the laser chopped by Acousto-optics chopper with the 0.3 Hz repetition

Test times (times)	Output power (mW)	Duration (min)	Stability (peak to peak) (%)	Stability (RMS) (%)
1	37.1	31	4.65	1.098
2	37.1	21	4.54	0.866
3	37.1	9	5.54	0.853
4	37.1	7	3.4	0.885
5	8.3	9	4.27	0.76
6	8.3	9	4.64	0.78
7	8.3	20	5.5	0.82
8	8.3	7	4.08	0.82
9	8.3	11	4.95	0.94

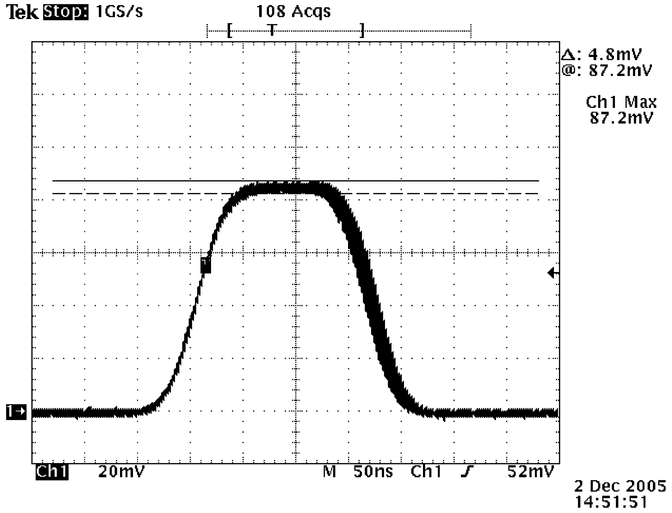

Fig. 6. The amplitude envelope of the fiber DFB laser which was chopped by Acousto-optic chopper (times: 128; repetition: 1 Hz).

$B_f = 1.5 \times 10^{-3}\,f\,\mathrm{mm/N}$ through the same analysis of the paper [7], the press should be greater than $6.7 \times 10^{-3}\,\mathrm{N/mm}$.

3. Conclusion

In conclusion, we have demonstrated that the birefringent phase-shift attributed to the press of the phase-shift region can be strong enough to make the fiber DFB laser output single polarization and single longitudinal mode. The output was stable. The output power was 8.3 and 37.1 mW when pumped by 100 and 254 mW, respectively. The polarization extinction ratio was 26 and 20 dB, respectively. The power variance is 4.65% (peak to peak) and 1.098% (RMS) for 31 min.

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