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RESEARCH ARTICLE

High efficient and narrow linewidth fiber laser based on fiber grating Fabry-Perot cavity

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Abstract A high Er^{3+}-doped narrow linewidth fiber laser based on fiber Bragg grating Fabry-Perot cavity was demonstrated. The spatial hole burning effect was restrained by a fiber Faraday rotator. Two short fiber Bragg grating Fabry-Perot cavities as narrow bandwidth filters discriminated and selected laser longitudinal modes efficiently. A stable single-frequency 1534.83 nm laser was acquired. Pumped by two 976 nm laser diodes and two-ended output, the fiber laser exhibited a 12 mW threshold. Total 39.5 mW output power and one end 22 mW output power were obtained at the maximum 145 mW pump power. Optical-optical efficiency was 27% and slope efficiency was 29.7%. The output power seemed to be saturated when pump power increased. The 3 dB linewidth of the laser was less than 7.5 kHz, measured by the delayed self-heterodyne method with 15 km monomode fiber. The high power narrow linewidth fiber laser can be used in high resolution fiber sensor systems.

Keywords laser technology, fiber laser, narrow linewidth, fiber grating Fabry-Perot cavity, high Er^{3+}-doped fiber

1 Introduction

Narrow linewidth fiber laser has important applications in optical sensors and high-resolution spectrum analysis. As a source for fiber sensors, a narrow linewidth fiber laser has particular characteristics of safety, remote control, small bulk and anti-electromagnetic disturbance. This laser type has potential application for defense due to its high sensitivity and the feasibility of multiplex transmission using wavelength division multiplexing (WDM) technology. There are several efficient methods in generating narrow linewidth fiber laser, including using one section of gain fiber as the saturable absorber acting as a very narrow filter [1–3], twisted-mode technique to restrain spatial hole burning effect in the laser material [4,5], and fiber Bragg grating (FBG). Short cavity single-frequency fiber lasers around 1550 nm using fiber Bragg reflectors were demonstrated first by Ball et al. in Er^{3+}-doped silicate fibers [6]. Both distributed feedback and distributed Bragg reflector lasers have already been demonstrated. Their potential advantages for mode-hop free, single frequency operation; high wavelength stability and accuracy; low noise; narrow linewidth; and a compact all-fiber design have attracted much interest since then [7,8]. The cavity configuration of narrow linewidth fiber laser includes linear and annular cavities. It is easier for the ring fiber laser to achieve narrow linewidth laser than line fiber laser. From the Er^{3+}-doped all fiber ring laser with inner fiber Bragg grating Fabry-Perot filter, a single frequency 1556.8 nm laser had been generated, and the maximum output power was 3.16 mW [9]. Er^{3+}-doped ring fiber laser with Bragg grating has achieved a 2 kHz linewidth laser [10]. From the saturable absorber ring fiber laser system, the lasing linewidth was less than 1 kHz [11]. Narrow linewidth ring fiber lasers have a disadvantage in their complicated structure, which leads to low efficiency and output power. The line fiber laser can generate a high-power laser. Using an Er^{3+}/Yb^{3+} co-doped phosphosilicate fiber with relatively high doping concentrations, distributed Bragg reflector (DBR) lasers showed output powers of up to 100 mW and a very narrow linewidth of less than 2 kHz [12,13]. A 200 mW, narrow linewidth 1064.2 nm Yb^{3+}-doped fiber laser has also been reported using the same short fiber grating F-P cavity [14]. This cavity should be sufficiently short so that mode spacing could be comparable to the grating bandwidth to overcome spatial hole burning. Using a short FBG Fabry-Perot etalon was a simple and efficient method for achieving single frequency lasers. The short cavity DBR fiber laser and distributed feedback (DFB) fiber laser have been studied in China. However, at present, optical-optical efficiency is very low, with maximal signal power of 11 mW and lasing linewidth of more than 1 MHz [15–18].

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In this paper, we present a narrow linewidth fiber laser using two fiber grating Fabry-Perot cavities as narrow bandwidth filters. Stable high single frequency output power with very narrow linewidth and high optical signal noise ratio are combined.

2 Experimental scheme and results

A schematic diagram of the fiber laser is shown in Fig. 1. The fiber laser is composed of two passive fiber Bragg grating Fabry-Perot (FBG F-P) cavities and an Er^{3+}-doped linear cavity. Optical gain is provided by a 3 m long Er^{3+}-doped fiber amplifier, which has peak absorption of 17 dB/m at 980 nm and 30 dB/m at 1530 nm. The fiber is pumped by a 976 nm laser diode. Two WDM couplers are used to launch pump power into the doped fiber. The effective pump power of LD1 and LD2 are 76 and 69 mW respectively. For a linear laser cavity, it is easy to produce the spatial hole burning effect in the gain material, which can arouse multilongitudinal mode oscillation and reduce laser coherence. This burning effect is produced by nonlinear wave mixing of the two counter-propagating waves in the laser gain material. To destroy the interference of the two waves, a fiber Faraday rotator with a rotator angle of 45° ensures that the polarization state of counter-propagating waves remain vertical to each other.

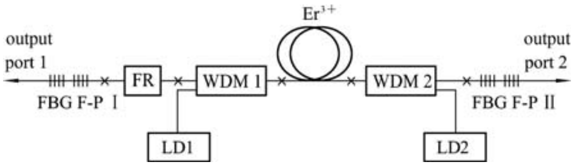

Fig. 1 Experimental setup of narrow linewidth fiber laser with two FBG F-P cavities

The structure of FBG F-P cavity is shown in Fig. 2. Two spectral narrow passive FBG F-P cavities are fusion spliced to the Er^{3+}-doped fiber amplifier. The reflectivity of each FBG in the cavity is 50%. The length of a cavity is 10 mm. The laser uses FBG F-P cavities as its frequency-selective components and reflector. If the Bragg center wavelength of each FBG in the cavity is the same, the FBG F-P cavity reflectivity spectrum will permit only several longitudinal modes to oscillate. The number of longitudinal modes in the Fiber grating F-P cavity is determined by the length of the F-P cavity and bandwidth of FBG. According to coupled mode theory, we can calculate the transmission and reflectivity spectrum of an FBG F-P cavity [19]. Only four longitudinal mode spectral lines are present in our FBG F-P cavity. The spacing of the longitudinal mode is more than 0.03 nm. If the lasing linewidth is less than 0.03 nm and no mode hopping is observed, we can judge that the fiber laser is a single frequency operation. Here we measure the reflectivity spectrum using amplified spontaneous emission (ASE) source. The 3 dB bandwidth of the FBG F-P etalon is about 0.17 nm. The depressions of the reflectivity spectrum correspond to the longitudinal mode spectral lines in the transmission spectrum. The reflectivity spectrum of the FBG F-P etalon is shown in Fig. 3.

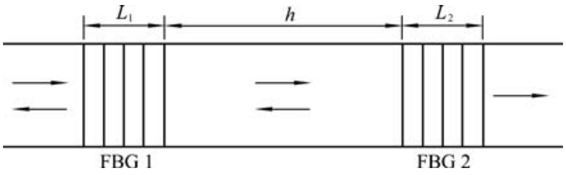

Fig. 2 Schematic diagram of FBG F-P cavity

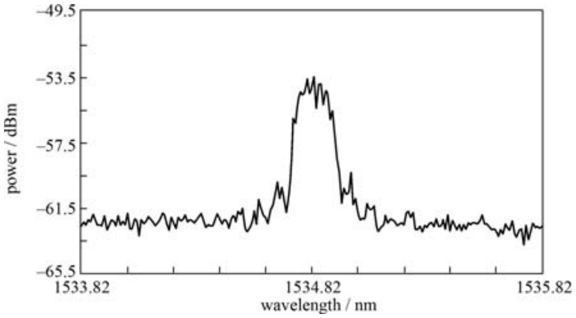

Fig. 3 Reflectivity spectrum of FBG F-P cavity

The lasing spectrum tends to become stable gradually when pump power is added. It began to be stable when pump power was 18 mW. 22 mW output power from output port 1 and 17.5 mW output power from output port 2 were generated, i.e., total output power of 39.5 mW was obtained upon the maximum 145 mW pump power. Optical-optical efficiency was 27%, and slope efficiency was 29.7%. Figure 4 shows the optical output power versus the pump power. The output power seemed to be saturated when pump power increased.

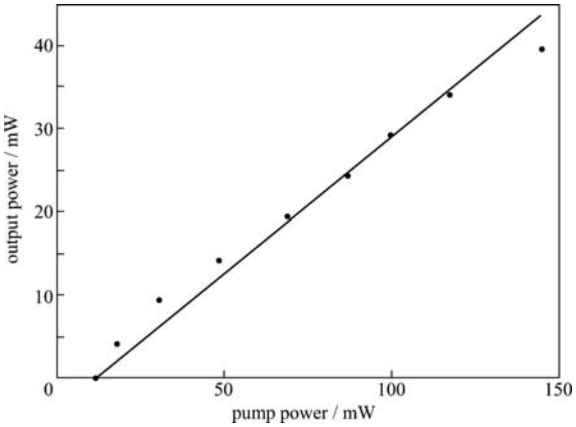

Fig. 4 Output power vs. pump power

Figure 5 shows the emission spectrum of fiber laser measured by an Ando 6319 Optical Spectrum Analyzer (OSA). The span range is 5 nm and the resolution of the OSA is limited to 0.01 nm. We can achieve data from the OSA that the wavelength of fiber laser is 1534.83 nm, and the 3 dB bandwidth is less than 0.01 nm. Because the linewidth is far less than 0.03 nm and no mode hopping is observed at least 1 hour, we can judge that the fiber laser is a single frequency operation. The optical signal to noise ratio (OSNR) is determined by the amplified spontaneous emission and is larger than 50 dB. The lasing spectrum from two output ports is the same, and no mode hopping is observed.

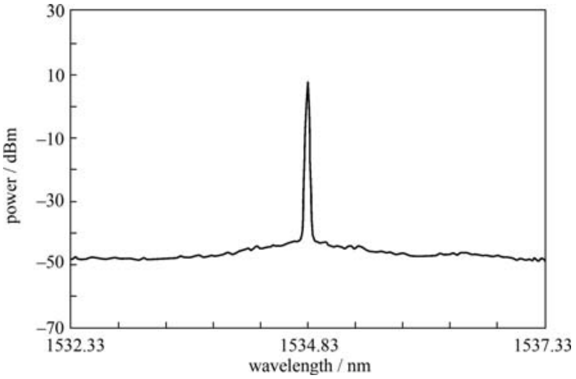

Fig. 5 Output narrow linewidth spectrum of fiber laser

3 Delayed self-heterodyne experimental result

The delayed self-heterodyne/homodyne measurement technique is an established method for measuring the kilohertz level linewidth of lasers [20]. Because the self-homodyne technique is not allowed in the use of a standard RF spectrum analyzer, and the modified self-homodyne is more complicated for using phase modulator and local oscillator, the linewidth of the fiber laser is measured using the delayed self-heterodyne method. Figure 6 shows the experimental setup for delayed self-heterodyne measurement.

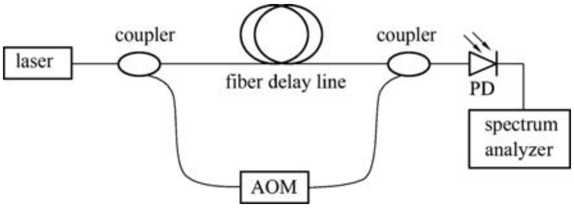

Fig. 6 Experimental setup for delayed self-heterodyne

The laser beam is split into two beams by a 3 dB coupler. One beam is delayed by a 15 km mono mode fiber, while the other beam passes through an acousto-optic modulator (AOM) with a carrier frequency of 70 MHz. After that, the two beams are combined at another 3 dB coupler. Finally, the beam passes through an optical detector with a bandwidth of 155 MHz and analyzed by an RF spectrum analyzer (Advantest R3267, frequency ranges: 100Hz to 8 GHz). Figure 7 shows the resulting line shape of the heterodyne signal. From the heterodyne signal, we take 3 dB down from the maximum value to estimate its bandwidth, which is about 5 kHz. However, the resolution of the delayed self-heterodyne method is limited to 7.5 kHz by using only a 15 km single mode [21]. These data suggest a linewidth of less than 7.5 kHz.

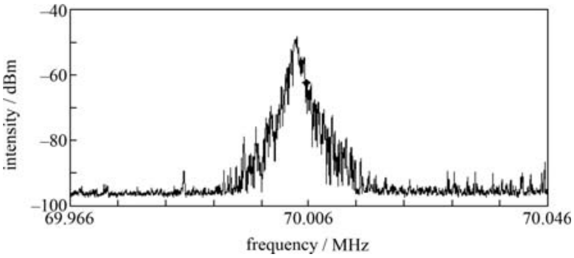

Fig. 7 Heterodyne signal measured at measurement 15 km delay fiber

4 Conclusions

In this paper, we present a narrow linewidth fiber laser using two fiber grating Fabry-Perot cavities as narrow bandwidth filters and fiber Faraday rotator to restrain the spatial hole burning effect. A stable single frequency 1534.83 nm laser was acquired. The fiber laser exhibited a 12 mW threshold. Total 39.5 mW output power was obtained upon the maximum 145 mW pump power. Optical-optical efficiency was 27% and slope efficiency was 29.7%. The 3 dB linewidth of laser was less than 7.5 kHz, measured by the delayed self-heterodyne method with a 15 km monomode fiber.

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