Narrow linewidth Yb-doped double-cladding fiber laser utilizing fiber Bragg gratings inscribed by femtosecond pulses

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Abstract. A narrow-linewidth high power laser in all fiber format at 1064 nm is demonstrated. The resonant cavity is composed of two distributed Bragg reflector (DBR) fiber gratings, which were inscribed into the core of the double-cladding fiber by use of 800 nm femtosecond laser pulses and a phase mask. The spectrum of the laser exhibited a narrow linewidth of 21 pm at the output power of 0.8 W. The wavelength and power of the laser featured long term stability.

1. Introduction

Rare-earth-doped fiber lasers have become an important tool in many industries with applications ranging from material processing to telecommunications [1]. High slope efficiencies, power scalability, broad wavelength tunability, and diffraction-limited beam qualities at high power are the prominent advantages of the fiber laser [2]. Narrow linewidth fiber laser, as an important branch of fiber laser, has excellent time coherence and low phase noise thus obtain widely application and great prospect in many fields such as sensor, high precision spectral analysis and large capacity optical fiber communication [3]. The construction of all-fiber narrow linewidth fiber laser utilizing fiber gratings makes the structure of fiber laser more compact and the output of laser coupling into fiber more convenient and efficient. It greatly expanded the application of the narrow linewidth fiber laser, as a new generation light source of WDM optical communication, thus promoted the optical fiber communication to the development of more channels and larger capacity. In addition, narrow linewidth fiber laser is widely used in optical fiber sensing because of its small size, low weight, and high sensitivity.

The resonant cavity structures of the narrow linewidth laser using FBG are divided into two categories: distributed feedback (DFB) and distributed Bragg reflector (DBR). The former one can only achieve the laser output at several mW due to its short cavity length [4]. Therefore, it cannot achieve higher power of narrow line width laser output. However, using 800nm femtosecond laser pulses and phase mask technique to produce fiber Bragg gratings (FBGs) directly in the core of the common double-cladding fiber could achieve extremely narrow linewidth and excellent thermal stability. Hence, the structure of DBR, two FBGs as resonator mirrors, could help to achieve high power, narrow linewidth laser output.
2. The laser setup
Here we present a high-power (0.8 W) narrow linewidth (21 pm) fiber laser operating at 1064 nm. The laser cavity is established by two spectrally narrow passive-double-cladding fiber Bragg gratings (FBGs) that are fusion spliced to a 1.5 m long Yb-doped double-cladding fiber. The active fiber was an Yb-doped silica fiber with a 10 μm core diameter and a 125 μm hexagonally shaped inner cladding. The passive double-cladding fiber’s structure is the same. Figure 1 shows the schematic of the laser.

Two FBGs, the input coupler and the output coupler, were inscribed into the core of the passive fiber in order to create the frequency selective feedback for the cavity. To fabricate the FBGs, the outer polymer cladding of the passive fiber was stripped away, and the femtosecond laser beam was focused using a cylindrical lens before passing through a phase mask into the core of the passive fiber. The pulses had 50 fs pulse duration at 800 nm, 1kHz repetition rate and 800 nJ pulse energy. The induced FBG was 6 mm long and had the grating period of about 1.1 μm, corresponding to the 2nd order resonant reflection at about 1064 nm. Figure 2 shows the reflection spectrum of the FBG.

3. Results and discussion
The laser is excited by a 915 nm LD pump laser with a maximum output power of 5W. Figure 3. shows the optical output power at 1064nm versus the launched power. More than 0.8W output power has been obtained for the maximum launched power of about 1.8w. The slope efficiency was 48.8% with a threshold of about 0.2 W launched power.

Figure 4 shows the typical output laser spectrum. The center wavelength of the laser was 1069.55nm with a bandwidth of about 21.9 pm for an output power of 0.8W, which is significantly narrow at these power levels [2]. The optical signal to noise ratio was measured to be about 40 dB. It can be observed that there is a greater amount of ASE, which is almost the same with the previous results [3]. This is due to the ASE being double passed through the cavity after reflecting off the high reflector.
The stability of the center wavelength and laser spectrum was investigated at full power over a 3 h period. Figure 5 shows the stability of the center wavelength when the FBGs use water-cooling and no cooling. It can be seen that the stability of the center wavelength can be greatly improved by using water-cooling for FBGs.

Figure 6 shows the center wavelength variation with the launched power. The center wavelength shift toward longer wavelength as the launched power was increased because of the thermo-optical effect in the grating.

So we researched the thermo-optical effect of FBG and validated it through the experiment. Figure 7 shows the resonant wavelength of the FBG as the function of the temperature. The peak wavelength shift toward longer wavelength as the temperature was increased. This result is in line with our previous experiment.

Figure 8 and figure 9 show the laser spectrum variation over 3 h period with and without water-cooling. So we find that FBGs cooling make the performance of the fiber laser more stable and reliable.
Figure 7. The peak wavelength of the FBG reflection spectrum variation versus the temperature.

Figure 8. The laser spectrum variation with water-cooling.

Figure 9. The laser spectrum variation without water-cooling.

4. Summary
In summary, we have presented a high power laser with more than 0.8W output, narrow linewidth of 21pm Yb-doped double-cladding fiber laser that utilizes two FBGs inscribed directly into the double-cladding fiber core using femtosecond laser pulses. The laser works at 1064nm, which exhibits extremely good stability by temperature control of the FBGs. The output power of the laser doesn’t have any saturation at present power level. So we predict further power scaling to higher power by using a more powerful pump laser.

5. Acknowledge
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