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Influence of the fiber Bragg gratings with different reflective bandwidths in high power all-fiber laser oscillator

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ABSTRACT

The effects of large-mode-area (LMA) fiber Bragg gratings (FBGs) with different reflective bandwidths on bi-directionally pumped ytterbium-doped single-mode all-fiber laser oscillator have been investigated experimentally. The forward laser output power and the backward signal leakage were measured and analyzed. It was found that the laser output power and efficiency depended on the bandwidth of the high-reflection (HR) FBG used in the laser cavity. The broader bandwidth gives higher laser efficiency, especially at high power level.

1. Introduction

The research of high power fiber lasers and amplifiers has got great progresses in the last decade [1–11]. Especially, by using high quality LMA Yb-doped fibers (YDFs) and high-brightness high power pump diodes, the output power of YDF lasers has gone up to multi-kilowatt even more than 10 kW with near diffraction-limited beam quality [6]. Further more, the fiber lasers have got a big market share in scientific and industrial applications due to their outstanding characteristics such as high efficiency, high beam quality, and superior reliability etc.

With the application of the FBGs in all-fiber laser, the reliability and stability of the fiber lasers could be much improved. The performance of the all-fiber laser mainly depends on the parameters of the FBGs. The spectral width of the signal light would be broadened with the increasing of pump power due to nonlinear Kerr effect [12]. The line width of the signal light is related to the reflective bandwidth of the FBG [13].

In this paper, we have demonstrated a kilowatt-class all-fiber laser oscillator by using LMA FBGs with different parameters. The signal light and backward light of the all-fiber laser were measured for different reflective bandwidths of HR gratings such as 2 nm, 2.2 nm, 2.5 nm and 3 nm, respectively. The spectral broadening of the signal light was observed. With the increasing pump power, the signal power increased nonlinearly when it exceeded 1.1 kW by using the HR FBGs with reflective bandwidth less than 3 nm in our experiments, and the corresponding power of backward light increased rapidly. From the results of the experiments, it is easy to notice that the reflective bandwidth of the HR FBG is an important factor to affect the laser output power and efficiency of the all-fiber laser oscillator at high power level. In the final experiment, more than 1.54 kW output power with near diffraction-limited beam quality ($M^2=1.11$) was obtained from the all-fiber laser by using a HR FBG with broader reflective bandwidth, and the corresponding slope efficiency was about 82.3% with the injected pump power.

2. Experimental setup

The oscillator schematic configuration of all-fiber laser is shown in Fig. 1. The laser cavity consists of the FBGs and LMA gain fiber with 20 m length. The HR FBG and low-reflection (LR) FBG are made of 20/400 μm passive fiber with the central wavelength 1080 nm. The reflectivity of HR FBG is about 99.5% and about 10% of the LR FBG. The gain fiber is a LMA double-cladding YDF with 20 μm/0.06 NA core and 400 μm/0.46 NA inner-cladding, and it is coiled as a mode-filter to suppress high-order modes [14]. The fiber laser was pumped by twelve pump lasers (output power of 180 W) with central wavelength of 976 nm. The pump light was coupled into the gain fiber by $(6+1)\times 1$ fiber couplers of the fiber laser oscillator. The signal fiber and output fiber of the fiber

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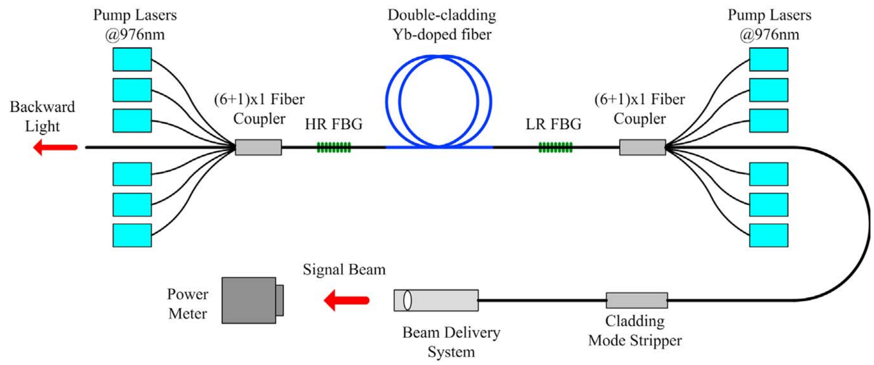

Fig. 1. Schematic configuration of the all-fiber laser oscillator.

coupler is 20/400 μm passive fiber. The pump power coupling efficiency is about 98%, and the insertion loss is less than 0.2 dB. The unabsorbed pump light in the cladding of the fiber was stripped out by the cladding mode stripper (CMS). The single-mode signal beam was measured from the beam delivery system of the all-fiber laser.

In the all-fiber laser system, the splice spots of the fiber components were aligned precisely in the fusion splicing process, and the fusing-loss was optimized less than 0.15 dB for reducing the signal power loss and suppressing high-order modes generating in the fiber laser [15]. During the all experiments, the all-fiber laser and the pump lasers were cooled by a water chiller.

3. Experimental results and discussions

In the first experiment, the HR FBG with bandwidth of 2 nm and LR FBG with bandwidth of 1 nm were used in the all-fiber laser oscillator. The signal power increased linearly up to 1.14 kW with the increasing pump power, and the corresponding slope efficiency of the fiber laser was about 78.2% as shown in Fig. 2. Continued increasing the pump power, the maximum signal power was measured as 1.3 kW, but the slope efficiency of the fiber laser was reduced obviously when the signal power exceeded 1.14 kW. The backward power was measured from the signal fiber of the fiber coupler by a power meter, and it increased quickly with the increasing pump power as shown in Fig. 2, especially when the slope efficiency of the fiber laser was reduced. The maximum power of the backward light was tested as 50 W in the experiment.

The spectrums of signal light were analyzed with different powers by an optical spectrum analyzer (OSA) as shown in Fig. 3. The spectral bandwidth of the signal light in the fiber laser was broadened with the increasing power due to the nonlinear Kerr effect of the YDF lasers. During the experiment, there was no stimulated Raman scattering (SRS) effect. The spectrums of the backward light of the all-fiber laser were also measured with different signal powers, and the spectral width was broadened and exceeded the reflective bandwidth of the HR FBG with the increasing power as shown in Fig. 4. The major power of the backward light was tested with the wavelengths exceeded the reflective bandwidth of the HR FBG, and it increased with the broadening of the signal spectral bandwidth in the experiment. From the results, the backward power depended on the reflectivity and reflective bandwidth of the HR FBG, and the signal power would be reduced with the increasing backward power in the same pump power correspondingly.

In the second experiment, different reflective bandwidths of the HR FBGs were compared in the same all-fiber laser scheme. The reflective spectrums of the HR FBGs were measured by the

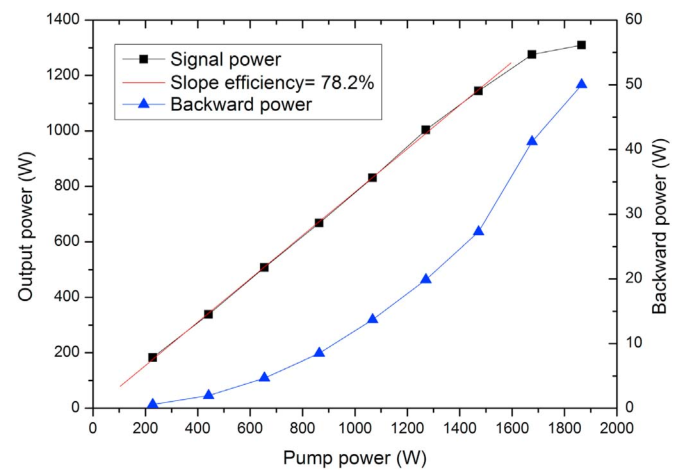

Fig. 2. Output power and backward power versus pump power of the all-fiber laser.

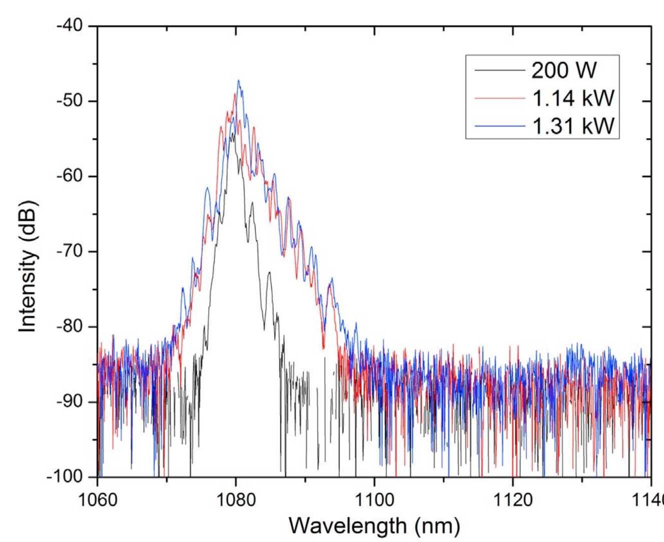

Fig. 3. Spectrums of signal light compared with different powers.

OSA respectively, and the corresponding spectral bandwidths were about 2 nm, 2.2 nm, 2.5 nm and 3 nm as shown in Fig. 5. The characteristics of the signal spectrums were observed and analyzed with different reflective bandwidths as 0.04 nm, 0.5 nm and 1.5 nm of the LR FBGs in Ref. [11], and the original signal spectral bandwidths of the fiber laser depended on the reflective bandwidths of the LR FBGs. Narrow spectrum of the signal light should be generated by using relative narrow bandwidth of the LR FBG,