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High power composite cavity fiber laser oscillator at 1120 nm

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ABSTRACT

A high power composite cavity fiber laser oscillator at 1120 nm is demonstrated experimentally. Performances of the 1120 nm single fiber laser oscillator and the composite cavity are investigated and compared, and the parasitic oscillation created by the strong amplified spontaneous emission (ASE) can be suppressed effectively in the composite cavity scheme. 2.04-kW 1120-nm signal light with a good beam quality ($M^2 = 1.15$) is obtained, and the optical conversion efficiency of the composite cavity fiber laser oscillator is about 63% in the experiment. The compact architecture of composite cavity provides an effective scheme for power scaling of long wavelength lasers.

1. Introduction

High power fiber lasers and amplifiers with the large-mode-area (LMA) fiber have a great development in the latest decade [1–7], and they have been applied broadly in scientific and industrial areas. Although the Yb-doped fiber (YDF) laser can obtain a very broad wavelength range of 1030–1200 nm [8,9], the typical emission wavelength range of high power YDF laser is 1030–1100 nm, and power scaling of the fiber laser with longer wavelength is mainly limited due to the small emission cross section [10]. According to the successful applications of the fiber laser at 1120 nm as a pump sources of the Tm-doped fiber laser [11] and the 1178 nm Raman fiber laser [12], the high power 1120 nm fiber laser is attracted much attention in recent years [13–15]. In 2014, Zhang et al. obtained 1.28 kW power output at 1120 nm from an Yb-Raman fiber amplifier [14], and 1.5 kW 1120 nm laser with a high optical efficiency in an Yb-Raman combined nonlinear fiber amplifier was demonstrated [15]. These fiber amplifier schemes show the potential for power scaling of longer wavelength lasers.

In this paper, we present a high power composite cavity fiber laser oscillator scheme, and 2.04 kW signal power with wavelength of 1120 nm is obtained in the experiment. It is different with the Yb-Raman fiber amplifier architecture, the composite cavity consists of two fiber laser oscillators with different wavelengths of 1120 nm and 1060 nm, and the 1060 nm fiber laser oscillator is inserted into the 1120 nm laser cavity. In our experiments, the performances of the 1120 nm single fiber laser oscillator and the composite cavity fiber laser oscillator are investigated and compared, and the characteristics of the signal light are analyzed. The composite cavity scheme can effectively suppress the parasitic oscillation which is generated easily in the single fiber laser oscillator, and 2.04 kW 1120 nm laser with a good beam quality ($M^2 = 1.15$) is obtained. The composite cavity fiber laser oscillator worked steadily during the experiments, and the scheme can be employed for further power scaling of the lasers in range of 1100–1200 nm.

2. Experimental configuration

The composite cavity fiber laser oscillator schematic configuration is shown in Fig. 1. There are two fiber laser oscillators with different central wavelengths in the composite cavity, and the inner oscillator with wavelength of 1060 nm is inside the outer fiber laser oscillator. The 1060 nm laser oscillator consists of the FBGs and a piece of YDF with 15 m length. The high-reflection (HR) FBG and low-reflection (LR) FBG are made of 20/400 μm passive fiber with the central wavelength of 1060 nm. The reflectivity of HR FBG is about 99.5% and about 10% for the LR FBG. The spectral widths of the HR FBG and LR FBG are 3 nm and 1 nm respectively. The YDF is a LMA double-cladding fiber with 20 μm /0.06 NA core and 400 μm /0.46 NA inner-cladding. The nominal small-signal pump absorption of the YDF is 1.2 dB/m at 976 nm. The fiber laser cavity is pumped by six 180 W laser diodes (LDs) with central wavelength of 976 nm. The pump light is coupled into the gain fiber by a (6+1)×1 fiber coupler. The signal and output fibers of the fiber coupler are 20/400 μm passive fiber. The pump power coupling efficiency of the fiber coupler is about 98%, and the insertion loss is less than 0.2 dB. The unabsorbed pump light in the cladding of the fiber is stripped out by the cladding light stripper (CLS) in the end of the 1060 nm laser oscillator.

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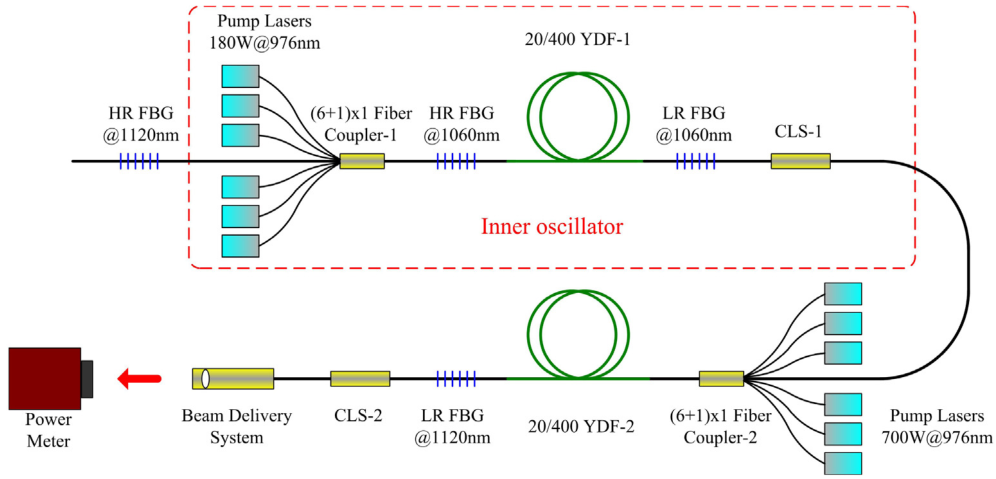

Fig. 1. Schematic configuration of the composite cavity fiber laser oscillator.

The outer fiber laser cavity consists of a pair of FBGs with central wavelength of 1120 nm, a piece of gain fiber, a fiber coupler and the inner 1060 nm laser oscillator as shown in Fig. 1. The length of the YDF is 20 m, and it has the same parameters with the gain fiber (YDF-1) of the inner oscillator. The $(6+1)\times 1$ fiber coupler is also the same as the coupler in the 1060 nm laser oscillator. The pump LDs of the 1120 nm laser cavity are six 700 W semiconductor lasers with wavelength of 976 nm. The 1060 nm laser generated from the inner oscillator and the 976 nm pump light are coupled into the gain fiber (YDF-2) by the $(6+1)\times 1$ fiber coupler. The FBGs located in the two ends of the outer cavity are with the same parameters as the FBGs in the 1060 nm laser cavity, but the central wavelength is 1120 nm. The same CLS is followed the LR FBG of the composite cavity, and the signal beam is measured from the beam delivery system of the composite cavity fiber laser oscillator.

In order to improve the beam quality of the signal light, the gain fibers (YDF-1 and YDF-2) of the composite cavity fiber laser are coiled with the same radius of 6 cm as a mode-filter to suppress the high-order modes [16]. In the experiments, the LDs and the fiber laser system are cooled by a water chiller, and the temperature is set as 25 °C.

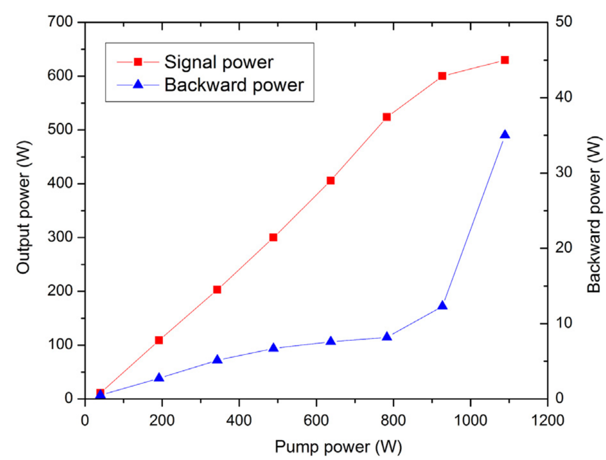

Fig. 2. Output power and backward power versus pump power of the single fiber laser oscillator.

3. Experimental results and discussions

3.1. Performance of the 1120 nm single fiber laser oscillator

In the first experiment, the performance of the single fiber laser oscillator at 1120 nm is investigated. The single fiber laser oscillator configuration is without the inner oscillator (180 W LDs, fiber coupler, 1060 nm FBGs, YDF-1 and CLS-1) as shown in Fig. 1. Turned on the LDs, the signal light was obtained at the end of the fiber laser cavity, and the output power was measured by a power meter. The signal power increased linearly with pump power increasing as shown in Fig. 2, but the slope efficiency of the fiber laser was reduced when the signal power exceeded 600 W in the experiment. At the same time, the backward power of the fiber laser was measured from the end of HR FBG. When the output power reached 600 W and the slope efficiency began to decrease, the backward power increased rapidly from 12 W to 35 W, and the corresponding output power of the fiber laser was about 630 W. The more power of the backward light was leaked from the fiber laser oscillator, the less output power was obtained with the same pump power injection of the laser cavity.

The spectra of signal light with different output powers are compared by an optical spectrum analyzer (OSA) as shown in Fig. 3. There is only one peak with central wavelength of 1120 nm when the output power of the single fiber laser oscillator is about 109 W. With the output power increasing, the parasitic oscillation of the 1120 nm fiber laser oscillator is appeared, and the corresponding light with wavelength of 1060 nm is detected when the output power is about 630 W. The unwanted 1060 nm light, which has a large emission cross-section of the Yb ions, can be created during the mode competition in the YDF laser oscillator. Both the 1120 nm and 1060 nm lasers are amplified with the 976 nm pump power increasing, and an amount of the 1060 nm light can be leaked from the fiber laser oscillator in the backward direction. Therefore, the backward power increased quickly and the corresponding output power increased slowly as the experimental results at a relative high power level.

3.2. Performance of the composite cavity fiber laser oscillator

In order to suppress the parasitic oscillation in the YDF laser cavity and obtain high output power with wavelength of 1120 nm, a composite cavity fiber laser oscillator (shown in Fig. 1) is investigated experimentally. In the composite cavity, the 1060 nm light can be generated with the corresponding 976 nm pump power injection of the inner oscillator at the beginning, and propagates in the core of the fiber. Then the 1120 nm laser is obtained from the outer fiber laser oscillator via the Yb^{3+} transfer (the signal laser is generated directly via the Yb ions by absorbing the pump laser) in the gain fiber (YDF-2) with the injection of the 1060 nm light. Although the YDF has a relative low absorption coefficient at 1060 nm, the core-pumping mode can compensate and increase the absorption. With the generation of 1120 nm signal laser,