Highly polarized Yb-doped fiber laser based on a polarization-maintaining fiber Sagnac loop mirror and its power amplification

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ABSTRACT

A novel fiber laser configuration based on a polarization-maintaining fiber Sagnac loop mirror is proposed for generating linearly polarized light. The polarization-dependent reflectivity of the loop mirror provides the necessary polarization discrimination between the slow and fast axes. A robust linearly polarized all-fiber laser oscillator is demonstrated with a polarization extinction ratio better than 27 dB. After an integrated fiber amplifier, a 14.6 W narrow linewidth single-mode fiber laser at 1070 nm is obtained with an optical efficiency of 68% and a polarization extinction ratio of 22.4 dB.

Keywords: fiber laser; fiber loop mirror; polarization; fiber Bragg grating

1. INTRODUCTION

In recent years, fiber lasers have gained wide applications due to high efficiency, great compactness and superiority on thermal management. For many applications such as sensing, nonlinear frequency conversion, and laser beam combination, fiber lasers with diffraction-limited and single polarization output are necessary. Single polarization operation has been obtained by inserting a free space or in-fiber polarizer, such as polarization cube[1] and long-period fiber grating[2], into fiber laser cavities. Xia Liu et.al obtained a 10 W, 21 dB linearly-polarized output by polishing the end of the gain fiber with a Brewster-angle[3]. Coiling a highly birefringent large-mode-area fiber is an alternative route[4], while this method is not applicable to single mode fibers with a standard numerical aperture (NA). In order to obtain linearly-polarized laser operation, Shirakawa et al[5] used two FBGs made on polarization maintaining (PM) fiber to form a laser cavity and spliced one of the PM FBGs perpendicularly to the other. Fine temperature or tension adjustment was

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required to align the fast axis reflectivity peak of one FBG with the slow axis peak of the other one. This, however, increased the complexity of the laser. Single polarization fiber was also reported to be used for linearly-polarized laser generation in spite of its large propagation loss and low efficiency[6].

In this paper, we propose a novel method to obtain linear polarization operation by adopting a PM Sagnac mirror as both a high reflectivity mirror and a polarization selective device. The polarization-dependent reflectivity of the fiber loop mirror provides the necessary polarization discrimination between the slow and fast axes. With a fiber Bragg grating written in standard polarization-maintaining fiber as an output coupler, we obtain a master laser with a power of 1.05 W and a robust polarization distinction ratio (PER) of > 27 dB, which is higher than the typical values of 16-21 dB[3-5, 7-8] with other methods. After an integrated fiber amplifier forward-pumped by two 10 W laser diodes at 976 nm, we obtain 14.6 W, single mode fiber laser at 1070 nm with an optical efficiency of 68% and a PER of 22.4 dB. Additionally, the narrow-bandwidth of about 0.1 nm makes the laser suitable for applications such as frequency-doubling.

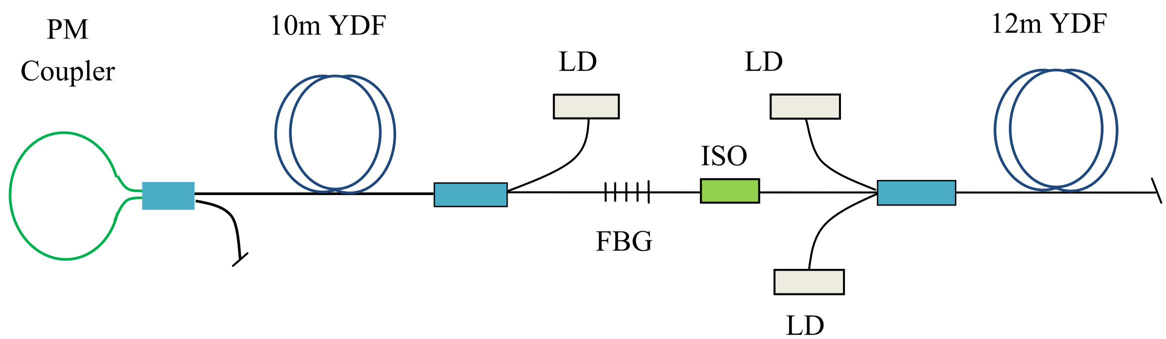

Fig 1 Schematic diagram of the linearly-polarized fiber amplifier

2. LASER SHEME

Our experimental setup is illustrated in Fig. 1. In the seed laser, the gain medium is a 10 m-long double-clad PM ytterbium-doped fiber (Nufern PM-YDF-5/130), which has a 5 μm diameter (NA 0.13) core, a 130 μm diameter (NA 0.46) pumping clad, and a nominal cladding absorption of 1.7 dB/m @975 nm. The pump source is a 10 W pigtailed laser diode (JDSU, 6398-L4i Series) with an NA of 0.22 and a nominal emitting wavelength of 976 nm. A fused pump combiner (Lightcomm PM (2+1)x1 combiner) is used to couple the pump light into the active fiber with a transmission loss of 7%. The laser cavity is formed with a PM Sagnac fiber loop mirror as a high reflector and a PM FBG as an output coupler. The FBG has a peak reflectivity of 11%. In the amplifier, a forward-pumping architecture is employed by using a 12 m-long ytterbium-doped fiber, a pump combiner and two laser diodes (all the same models as in the seed). The output fiber is 8° angle cleaved to minimize the back-reflection light into the amplifier.

The two output ports of a fused PM fiber coupler (Optizone PMFC1070nm2x2) are spliced together to make a fiber loop mirror. The reflectivity of a fiber loop mirror is given by[9]

$$R = 4\rho(1-\rho)T^2 \tag{1}$$

Where T refers to the single pass total transmission through the fiber coupler, and ρ stands for the coupling ratio to one of the two ports. The fiber coupler is fabricated for a 50/50 coupling ratio on slow axis. The coupling ratio and the transmissions at the fast and slow axes are measured. The total transmissions for the fast and slow axis of the fiber coupler are measured to be 2.1% and 91%, respectively. The coupling ratios are measured to be 53% and 50.4%, respectively. According to equation (1), the reflectivity on the fast and slow axis is about 0.044% and 82.8%, respectively, which provides a polarization discrimination between two axes.

The FBG was fabricated into the core of a panda PM fiber (Nufern PM980). A collimated KeF excimer laser beam was focused through a phase mask onto a horizontally positioned fiber. The typical energy density of the 248 nm pulses at the fiber was 0.05 J/mm^2 per pulse and the laser pulse rate was set to 30 Hz. The exposure time was changed according to the reflectivity needed. The FBG has a central wavelength of 1070 nm at slow axis and a -3 dB linewidth of 0.28 nm at room temperature. There is a Bragg wavelength for the fast axis as well about 0.26 nm away. However, the fiber loop mirror possesses a quite different reflectivity for light propagating on the fast and slow axis as shown in the previous paragraph. Therefore, laser action takes place only on the slow axis.

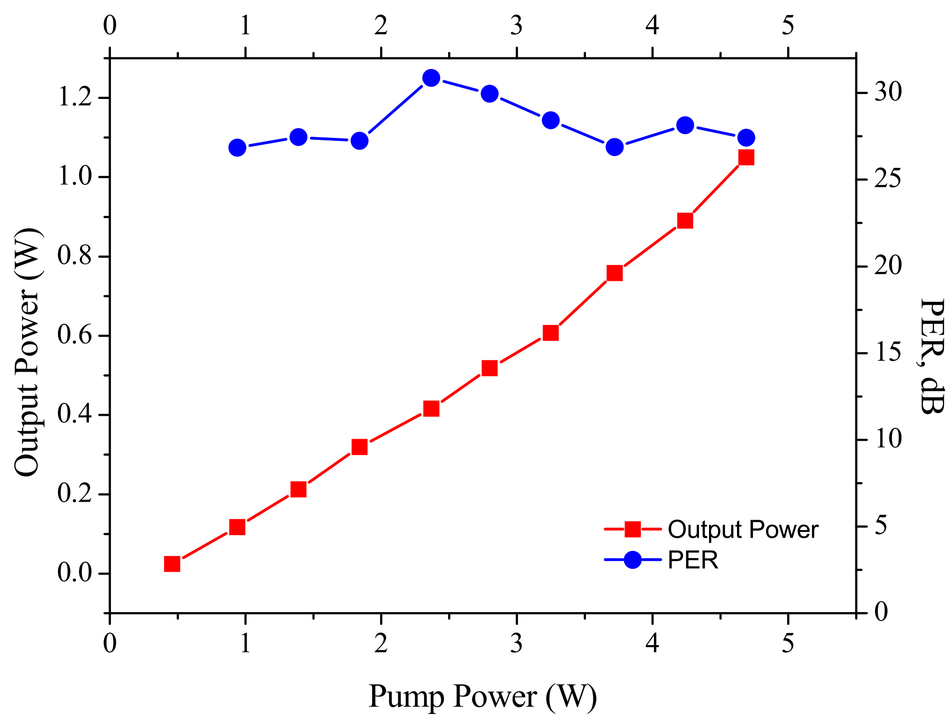

Fig 2 1070nm master laser power and polarization extinction ratio as a function of pump power

3. RESULTS

The laser operates in highly linearly polarized mode robustly, without the need of fine temperature or stress tuning of the FBGs as in other methods. Fig. 2 shows the seed laser power and PER as a function of the pump power. 1.05 W at

1070 nm is obtained with a 4.7 W pump power at 976 nm. To avoid damaging the Sagnac mirror (power limit specification is 1W for the micro-filter based fiber coupler) , the pump power is limited to 4.7 W, where the central wavelength of the laser diode is about 973nm, resulting in a relatively low optical efficiency. The power limit can be overcame by using a properly designed fused PM fiber coupler, which can stand much higher power[10]. The polarization extinction ratio of the seed is measured with a Glan-Prism. As depicted in Fig. 2, the maximum PER is 30.8 dB with the output power of 416mW, while PER of 27.4 dB is obtained at the maximum output power. Fig. 3 shows the spectrum of the seed at full output power, revealing a narrow linewidth of less than 0.09 nm.

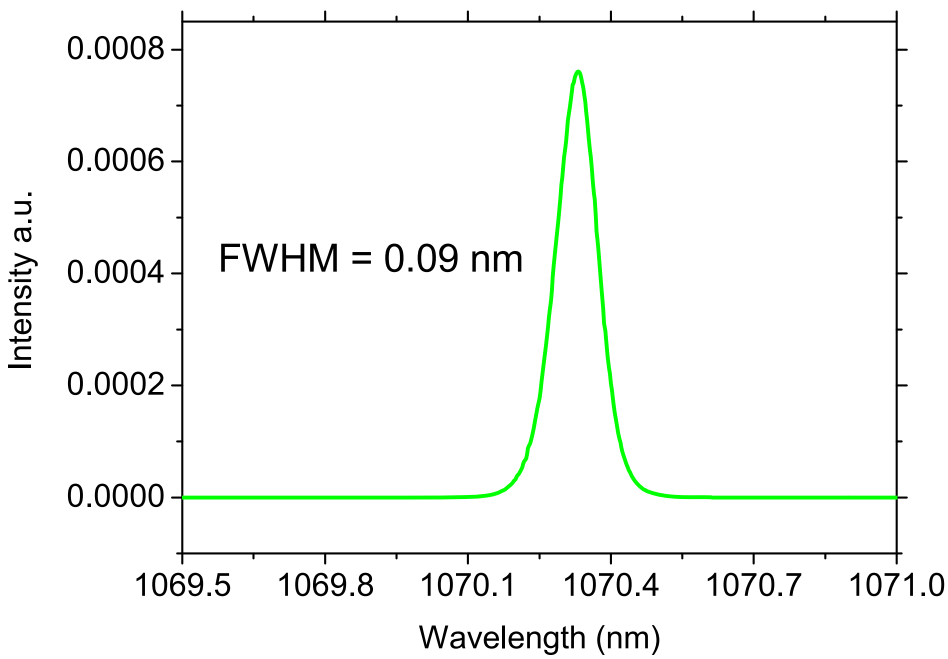

Fig 3 output spectrum of the seed laser

The output power and the PER of the amplifier at different pump powers are shown in Fig. 4. Up to 14.6 W of the linearly-polarized output laser is obtained with an optical efficiency of 68%. The PER of the amplifier is lower compared with the seed laser, which is mainly due to the polarization cross-talks introduced at the pump combiner and the fiber splices. A PER of 22.4 dB is achieved at the highest output power. The spectrum of the amplifier output is showed in Fig. 5, no sign of parasitic lasing or significant level of ASE is seen and the signal-to-noise ratio is more than 50 dB. The linewidth is 0.1 nm, without significant broadening compared with that of the seed laser.

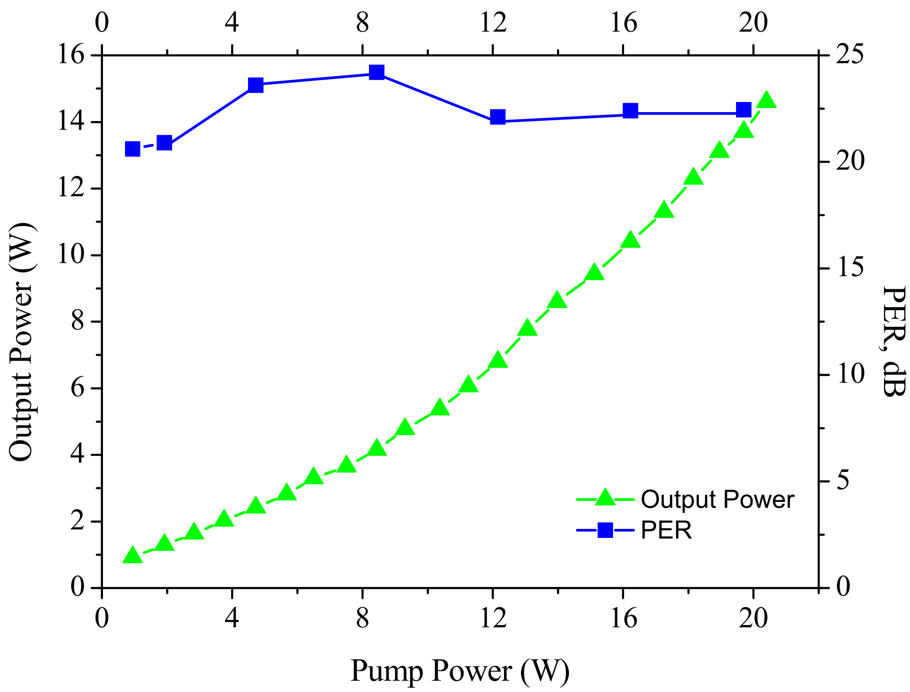

Fig 4 Output power and PER of the amplifier at different pump powers

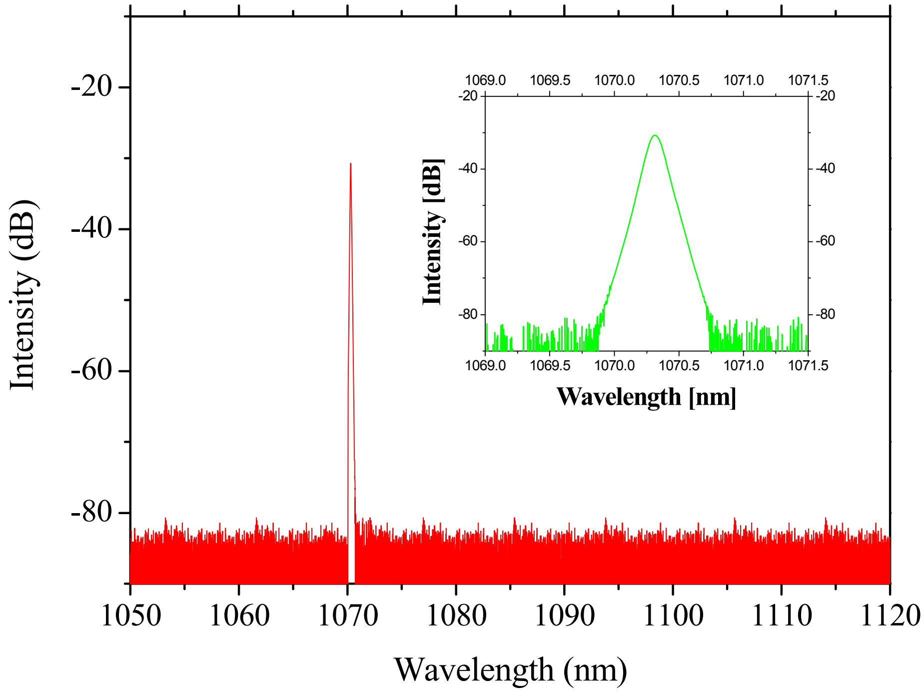

Fig 5 Spectrum of the amplifier at the maximum output power in a wide wavelength range from 1050nm to 1120nm. Inset, spectrum of the amplifier in a narrow wavelength range from 1069nm to 1071nm

We also conduct an experiment to find how the power of the seed laser influences the output power of the amplifier. The power of the amplifier output as a function of the seed power with a pump power of 18 W is shown in Fig. 6, from which we can conclude that 400 mW is enough to saturate the amplifier. When further decreasing the seed laser power, ASE becomes a problem. The minimum seed power for suppression of ASE is found to be 300mW when the pump power is above 10 W.

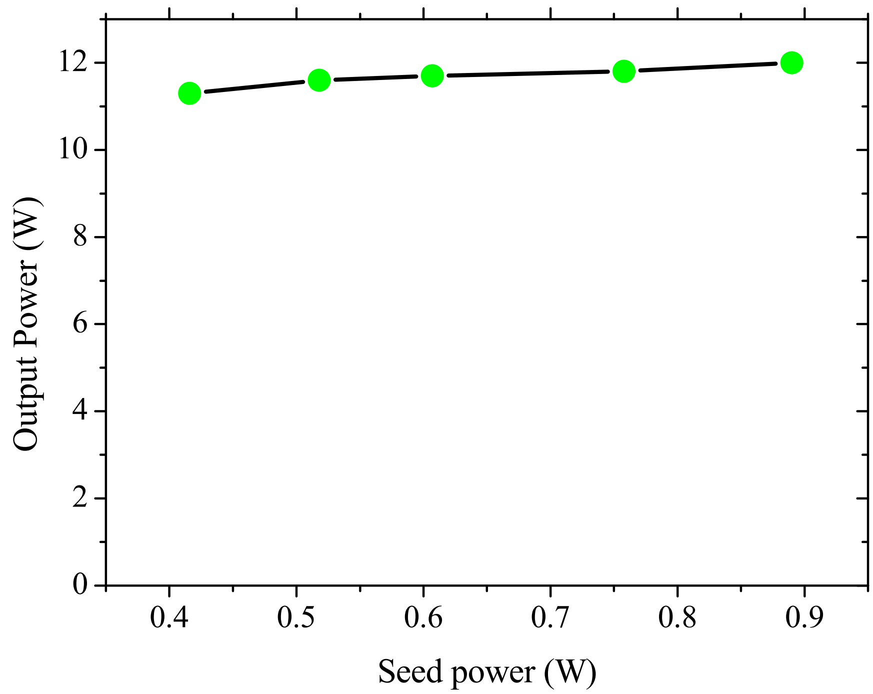

Fig 6 Amplifier output power as a function of the seed power

4. CONCLUSION

In conclusion, we propose and demonstrate a novel method to achieve a fiber laser with a PER of > 27 dB by employing a PM fiber Sagnac mirror and a PM FBG. The linear polarization operation is very robust, without requiring fine temperature or stress tuning as in other methods. With a forward-pumped amplifier, we obtained a 14.6 W single mode fiber laser at 1070 nm with a PER of 22.4 dB, a linewidth of 0.1nm, and an optical efficiency of 68%. The laser power can be scaled up by using a high-power fiber coupler and adding more pumping laser diodes. Up to hundred watts is feasible which could be used as a pump source for the 1120nm generation[11].

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