Efficient linearly polarized ytterbium-doped fiber laser at 1120 nm

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We report a 20 W linearly polarized, spectrally clean Yb-doped fiber laser at 1120 nm with an optical conversion efficiency of 54%. An excellent polarization extinction ratio of more than 23 dB is obtained using fiber Bragg gratings (FBGs) polarization selection technique at all power levels. The results reveal that a Yb-doped fiber laser at 1120 nm could be a promising replacement compared to Raman fiber lasers.

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1. Introduction

Fiber laser sources at 1120 nm have attracted much attention, thanks to a variety of applications such as the pump of a 1178 nm Raman fiber laser [1,2] and a Tm-doped fiber laser [3]. Over the past few years, Raman fiber lasers at 1120 nm have shown dramatic progress in power scaling with excellent beam quality. With a cladding pump scheme, a 100 W Raman fiber laser operating at 1120 nm was reported by Codemard *et al.* [4]. Feng *et al.* [5] reported a single-mode continuous wave Raman fiber laser at 1120 nm with an output power of more than 150 W, which is the highest-power Raman fiber laser known. Apart from Raman fiber lasers, Yb-doped fiber lasers also have the ability to provide amplification over a very broad wavelength range from 1.1 μm to 1.2 μm [6,7]. By heating the Yb-doped fiber, Kalita *et al.* [8] illustrated an all-fiber, narrow-linewidth fiber laser at 1179 nm with an output power of 12 W. Linearly polarized Yb-doped fiber laser with 3.35 W output laser at 1150 nm was reported by Sinha *et al.* [9]. Pumped by 1070 nm fiber laser and heated to 70 °C, output power of 3.2 W at 1160 nm was realized by Kurkov *et al.* [10] using ytterbium fiber. A maximum output of 167 W with Yb-doped photonic bandgap fiber at 1178 nm was achieved by Olausson *et al.* [11], which efficiently suppresses amplified spontaneous emission at the conventional ytterbium gain wavelengths. Indeed, Yb-doped fiber amplifier at 1120 nm with a slope efficiency of 46% was shown by Liem *et al.* [12], which seeded with a 1.5 W Raman fiber laser at 1120 nm and generated output lasers up to 25 W with a launched pump power of 53 W.

In this paper, an all-fiber, single-polarization Yb-doped fiber laser at 1120 nm is demonstrated. The maximum output power of 20 W is obtained at pump power of 37 W with an optical efficiency

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of 54%. An excellent polarization extinction ratio (PER) of more than 23 dB at all output power level is achieved thanks to the fiber Bragg gratings (FBGs) polarization selection technique in our system [13]. To the best of our knowledge, this is the first report of a highly efficient, linearly polarized Yb-doped fiber laser at 1120 nm using the FBGs polarization selection technique. Compared to Raman fiber lasers at 1120 nm pumped by 1070 nm Yb-doped fiber laser, 1120 nm Yb-doped fiber laser directly pumped by 975 nm laser diodes (LDs) shows a higher overall efficiency.

2. Experimental Setup and Results

The experimental configuration is shown in Fig. 1. An Yb-doped, panda-type double-clad fiber, with a core and inner cladding diameter of 5 μm and 130 μm, respectively, is employed as the gain medium in the system. The fiber length of 12 m has been selected to optimize pump absorption, which has nominal clad pump absorption of 1.7 dB at 975 nm. One end of the Yb-doped fiber is spliced with a 99% high reflectivity (HR) FBG, while an optical circulator (OC) FBG with a reflectivity of 9.5% is perpendicularly spliced to the other end of the gain fiber, to make the fast axis of HR FBG point to the slow axis of OC FBG, as shown in Fig. 2. With the FBGs polarization selection technique, we can easily obtain linearly polarized laser with an excellent polarization degree. The output fiber of a $(2+1)\times 1$ combiner, whose signal and output fibers match with the gain fiber, is spliced with an HR FBG. Total pump power from two LDs at 975 nm is launched into a Yb-doped fiber through this combiner. The rear HR FBG is spliced with the gain fiber. The other end of the gain fiber is spliced to the OC FBG. A piece of passive polarization maintaining (PM), single-clad fiber is spliced to the other end of the OC FBG. The splice point between the passive fiber and the OC FBG is likely to get damaged due to residual pump power, which requires operations of pump dump and cooling on a piece of copper. The end faces of a signal fiber of combiner and the PM passive output fiber are cleaved to an angle of 8 deg to prevent backreflection (Fig. 1).

Output power at 1120 nm as a function of pump power is shown in Fig. 3. With the total 37 W coupled pump power, up to 20 W laser output has been achieved with an optical efficiency of 54%. Considering the pump power not absorbed completely, we can

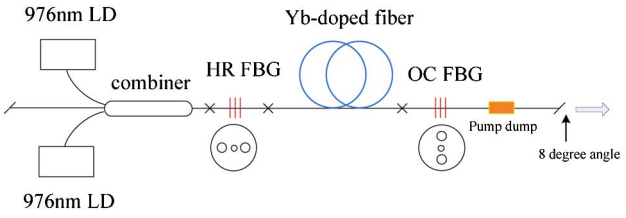

Fig. 1. (Color online) Experimental setup of the high-power, linearly polarized fiber laser at 1120 nm.

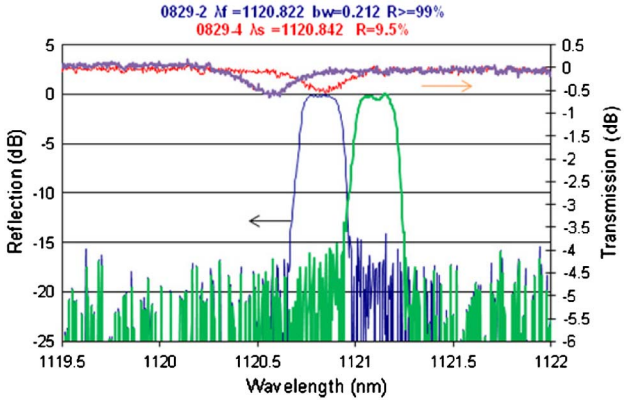

Fig. 2. (Color online) Spectral characteristics of optical circulator FBG (upper curves) and high reflectivity FBG (lower curves).

obtain a much higher optical efficiency. The laser threshold is as low as 2 W (Fig. 3), which is also an advantage compared to the reported 1120 nm Raman fiber lasers.

Measured with a high-quality Glan polarizer, the PER of laser output at different laser powers is illustrated in Fig. 4. Thanks to the FBGs polarization selection technique, excellent PER is obtained at all power levels. The measured PER is more than 23 dB and typically 25 dB at the maximum output power of 20 W. No significant power dependence has been observed. A highly linearly polarized laser is required for many applications, such as laser guide star [14], which requires a PER of more than 17 dB. The results demonstrate that the linearly polarized 1120 nm Yb fiber laser is suitable for pumping Raman fiber laser at 1178 nm, which can be frequency doubled to 589 nm for laser guide star application.

An AQ6370 optical spectrum analyzer from the Yokagawa Corp. was used to measure the spectral characteristics of the laser output. The optical spectrum at the maximum output power is shown in Fig. 5. As seen in this figure, the signal–noise ratio (SNR) is more than 50 dB, which means the amplified spontaneous emission (ASE) is low at all levels in

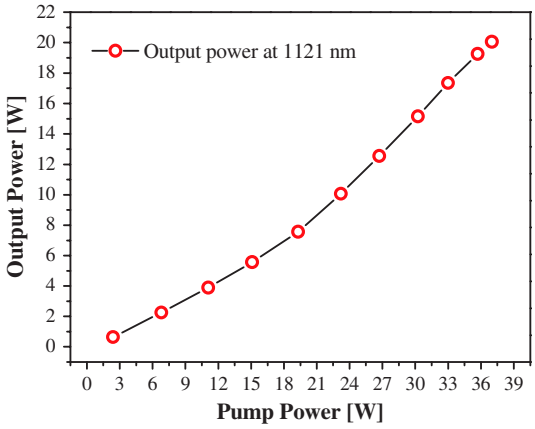

Fig. 3. (Color online) Laser output power at 1120 nm vs. pump power.

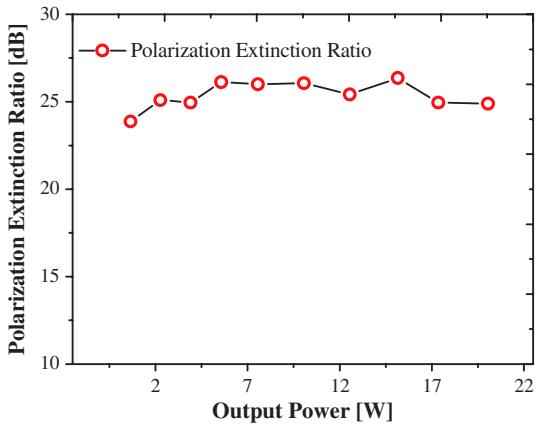

Fig. 4. (Color online) Polarization extinction ratio as a function of output power.

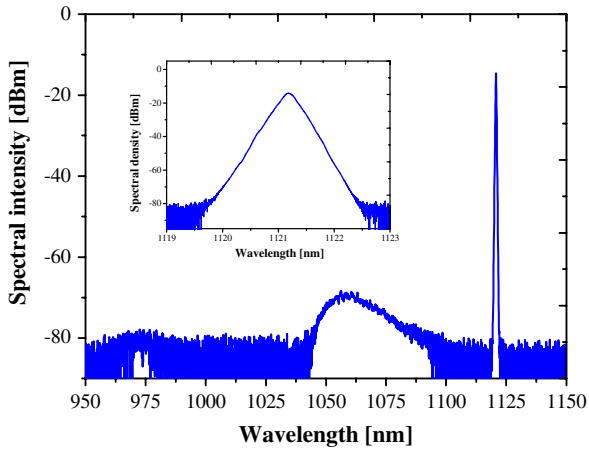

Fig. 5. (Color online) Optical spectrum at the maximum output power. Inset, detailed spectrum at 1120 nm.

the experimental condition. As one of the most important issue for long wavelength emitting with Yb-doped fiber, unwanted emission from ASE may result in considerable deterioration of the system performance. The inset in Fig. 5 shows a close-up view of the laser spectrum, which shows a single peak at 1121 nm compared with that of two reflective peaks of PM FBGs. This also indicates the excellent PER of the laser. The laser linewidth broadens with respect to increasing output power, as is typical for fiber lasers. A FWHM bandwidth of 0.22 nm is measured with a resolution of 0.02 nm at the maximum output.

3. Conclusion

We have demonstrated a highly efficient linearly polarized fiber laser at 1120 nm. The achieved 20 W output power is limited by the available pump power and the low tolerance of combiner for high laser power. The PER of the laser output is measured to be more than 23 dB, and does not degrade with increasing output power. Optical efficiency is as high as 54%, and no power roll off was observed in the experiment. As is widely known, ASE is one of the important issues for long wavelength emission of Yb-doped fiber. Therefore, technique schemes such as Raman fiber laser and photonic crystal fiber have been designed to prevent the occurrence of ASE. However, this paper has shown that ASE can be suppressed for a 1120 nm laser with proper laser design. To the best of our knowledge, this is the first report of a linearly polarized laser with Yb-doped fiber using the FBGs polarization selection technique at 1120 nm.

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