High-efficiency fiber laser at 1018 nm using Yb-doped phosphosilicate fiber

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A high-efficiency fiber laser at 1018 nm using homemade Yb-doped phosphosilicate fiber is demonstrated. The fiber shows blueshifted emission spectrum compared to Yb-doped aluminosilicate fiber, and is considered favorable for the short wavelength Yb-doped fiber laser. With a 7 m gain fiber, up to 22.8 W output at 1018 nm is achieved with an optical efficiency of 53%. The amplified spontaneous emission at 1030 nm is suppressed to 50 dB below the 1018 nm laser. This work shows that highly-efficient fiber laser at 1018 nm can be obtained with Yb-doped phosphosilicate fiber. © 2012 Optical Society of America

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1. Introduction

Compared with solid state lasers and gas lasers, Yb-doped high-power fiber lasers attract more attention due to its excellent beam quality, convenient thermal management, and high optical efficiency. However, there are still several factors limiting further power scaling, such as low pump brightness, thermal load, and nonlinearities. Tandem pumping techniques, in which, one or several (diode pumped) fiber lasers pump another fiber laser or amplifier, is considered as an ideal scheme for high-power fiber lasers, mainly because of its high laser brightness and low thermal load [1–3]. Tandem pumped by a 1030 nm thin-disk laser, a single mode fiber amplifier with output power of 2.9 kW was reported [2]. A major breakthrough for nearly diffraction-limited fiber lasers was realized by IPG in 2009 [3]. Pumped by 45 fiber lasers, each with a 300 W output power at 1018 nm, a 10 kW single transverse mode Yb-doped fiber laser was demonstrated for the first time.

Although tandem pumping is promising for power scaling of fiber lasers, the development of high-efficiency fiber lasers at 1018 nm is challenging due to the usually low gain at short wavelength for standard Yb-doped silica fiber. The gain fiber has to be kept short to avoid the onset of parasitic lasing, which limits the pump absorption. With a 2.6 m Liekki Yb-doped fiber, a 7.5 W fiber laser at 1018 nm

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was reported recently [4]. However, the overall slope efficiency was only 16%, limited by amplified spontaneous emission (ASE). Output power of 77 W at 1018 nm was achieved with a MOPA scheme [5], where power conversion efficiency is 75% with a seed laser of 6 W.

In this paper, we present a high-efficiency fiber laser at 1018 nm with homemade Yb-doped phosphosilicate (PS) fiber, which has the advantages of blue-shifted emission spectrum [6] and photodarkening suppression [7,8] in comparison with the Yb-doped aluminosilicate (AS) fiber. This fiber is favorable for the Yb-doped fiber lasers operating at shorter wavelength. Up to 22.8 W output at 1018 nm has been achieved with an optical efficiency of 53% and an ASE suppression of 50 dB.

2. Experimental Configuration

The configuration of the fiber laser is shown in Fig. 1, which consists of two pump diodes, a power combiner, a pair of fiber Bragg gratings (FBGs), and a 7 m long double cladding Yb-doped PS fiber. The diameters of the core and inner cladding of the gain fiber are 15 and 130 μm, respectively. The estimated normal cladding absorption coefficient is about 1.4 dB/m at 975 nm. The numerical aperture (NA) of fiber core is 0.12. The FBGs are inscribed in Nufern LMA-GDF-15/130 fibers which have the same core and cladding diameters as the gain fiber, whose core NA is 0.08. The FBG with a high reflectivity of 98% at 1018 nm (HR FBG) is spliced to one end of the gain fiber, and the output coupler FBG (OC FBG) with a reflectivity of 24% is spliced to the other end of the gain fiber to form a cavity. The 15/130 fiber could support a few transverse modes. The above-mentioned reflectivities of the FBGs with a full width half maximum (FWHM) bandwidth of 0.16 nm are measured for the fundamental mode. The pump lasers are injected into HR FBG through a fiber combiner, whose input and output fibers have the same parameters as the pigtail fibers of pump LDs and FBG fiber. The unabsorbed pump is dumped at the splice point between the gain fiber and the OC FBG. The output fiber of the OC FBG and the input fiber of combiner are cleaved at an angle of 8° to suppress back reflection.

3. Experimental Results and Analysis

The absorption and emission cross sections of the Yb-doped PS fiber are shown in Fig. 2, in which the spectral shape of the emission cross section is obtained from a fluorescence spectrum and the absorption cross section is calculated by the McCumber relation [9]. The emission fluorescence spectrum of this fiber was measured using AQ6370 optical spectrum analyzer from Yokagawa Corp. About 2 cm Yb-doped PS fiber was cladding pumped by 915 nm LD at the threshold. The fluorescence was collected at an angle of 90° with respect to the direction of pump laser. It is interesting to note that the important emission peak other than the 975 nm peak is at 1014 nm, which is about 16 nm blueshifted compared to that of the emission spectrum of Yb-doped AS fiber (1030 nm). Therefore, Yb-doped PS fiber is much more suitable for shorter wavelength operation.

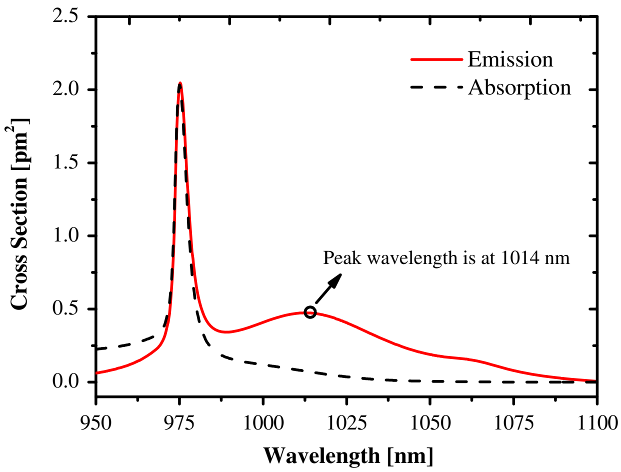

Fig. 2. (Color online) Absorption (dashed) and emission (solid) cross sections of the Yb-doped PS fiber.

The characteristics of the laser output with a 7 m gain fiber as a function of pump power is illustrated in Fig. 3. At pump power of 43 W, output power of 22.8 W at 1018 nm was achieved with a slope efficiency of 55.6%. Considering the laser leaking through the HR FBG, an even higher slope efficiency of 67% is obtained. Since the reflectivity of the HR FBG for LP01 mode is as high as 98% shown in Fig. 4, the high leakage through it indicates the excitation of higher order modes and/or cladding modes exist inside the laser. This might be caused by the unmatched NA of the gain fiber and that of the FBG fiber, and the splice eccentricity. The high leaked power through the HR FBG is also the major limiting factor for power scaling because the backward laser is harmful to laser diodes. Apparently, the next step

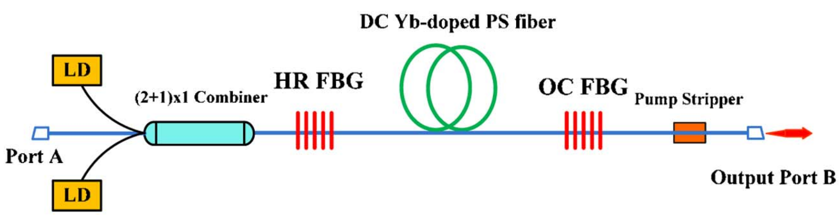

Fig. 1. (Color online) Experimental configuration.

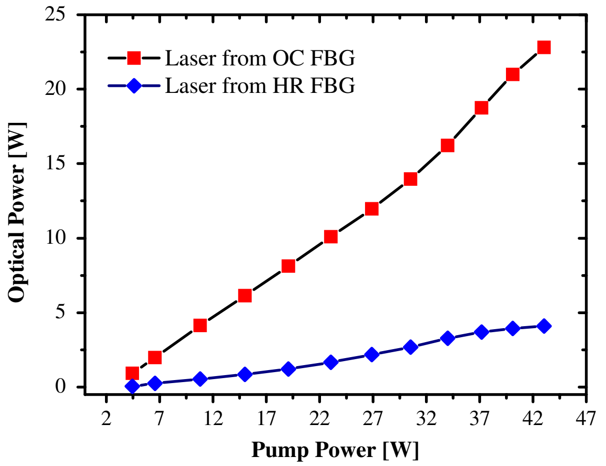

Fig. 3. (Color online) Measured laser output at 1018 nm versus pump power.

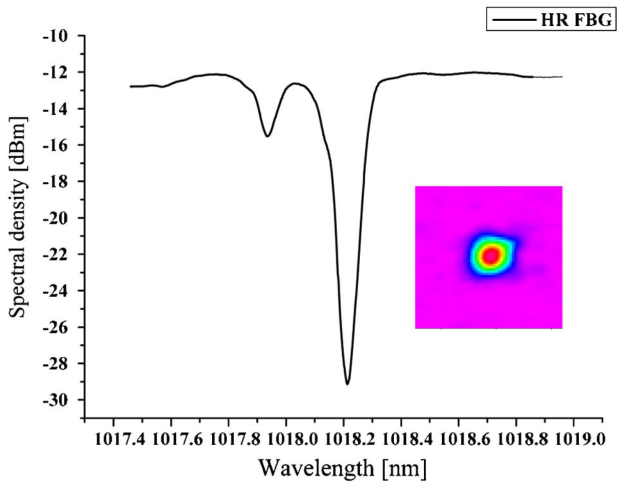

Fig. 4. (Color online) Spectrum of HR FBG.

is to improve the FBGs quality in a better matching passive fiber or inscribing FBGs in the gain fiber directly. An optimization of the OC FBG reflectivity and gain fiber length is also necessary to further improve the laser performances.

The reflectivity spectrum of HR FBG, centered at 1018.21 nm, is shown in Fig. 4. About 17 dB of reflectivity for single mode laser at 1018 nm is measured. The inset is a beam profile of fiber laser output at maximum power. The M^2 factor is measured to be 1.72 with a LQM-HP, PRIMES.

The laser emission spectra at the maximum pump power of 43 W are shown in Fig. 5. Clearly, the ASE at around 1030 nm is 50 dB below the 1018 nm laser emission, indicating excellent ASE suppression with this Yb-doped PS fiber. The detailed spectral characteristics from HR FBG and OC FBG ends are shown in Figs. 5(b) and 5(c), which shows that the center peak wavelengths are the same within the FWHM width. Comparing the laser spectra with the FBG spectrum shown in Fig. 4, one can see that the center wavelength of FBG is redshifted at high power due to the increase of temperature.

4. Conclusions

We demonstrated a high-efficiency all-fiber laser oscillator at 1018 nm using a homemade double-cladding Yb-doped PS fiber. Up to 22.8 W output is achieved with a 7 m gain fiber at a pump power of 43 W. An optical efficiency of 53% is realized at the maximum pump. The ASE is suppressed to 50 dB below the laser emission. To the best of our knowledge, this is the first report that Yb-doped PS fiber is used for short wavelength laser at 1018 nm. The performance can be further improved by optimizing the parameters of the laser cavity. It is expected that the Yb-doped PS fiber can be employed for high-power fiber laser at 1018 nm.

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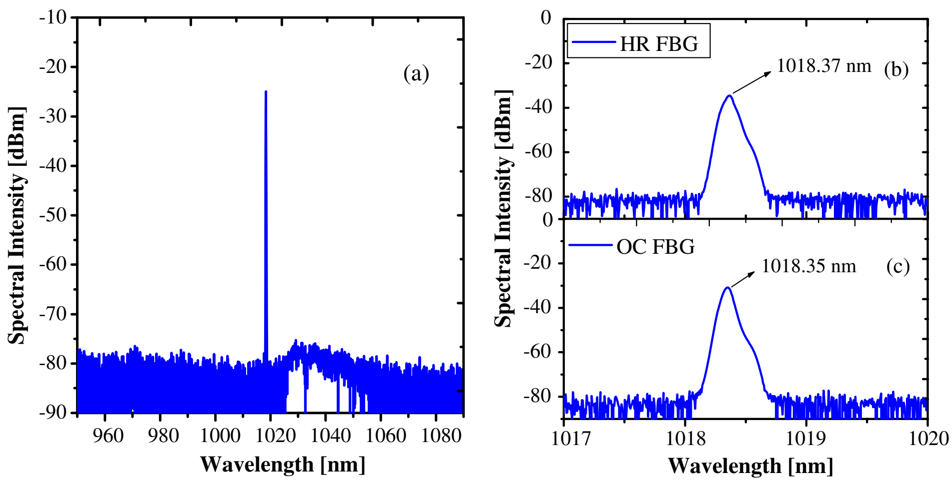

Fig. 5. (Color online) Output spectra at the maximum pump power. (a) Broad spectral range measured from OC FBG end. (b), (c) Detailed spectra at 1018 nm from HR FBG and OC FBG end, respectively.

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