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Ld-Clad-Pumped All-Fiber Tm^{3+}-Doped Silica Fiber Laser

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The CW 39.4 W all-fiber LD-clad-pumped Tm^{3+}-doped fiber laser output is reported with a slope efficiency of 34% in respect to the pump power. The all-fiber laser is made up by progressively splicing the pigtail fiber, matched FBG fiber and Tm-doped fiber. The reflective FBG and Tm-doped fiber end fresnel reflection build up the laser resonance cavity. Due to the multi-mode FBG as the reflective mirror, the output laser spectrum is multi-peaks at high power output, whereas the total spectrum width is less than 2nm at nearly 1.94 μm.

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High power lasers at the 1.9 μm region are very attractive for their applications in medicine and surgery,[1−4] and infrared-guided missile countermeasure.[5] Another important application is to pump Ho-doped crystal to generate a 2.1 μm laser with high peak power and high repetition frequency,[6] which can be used to pump $ZnGeP_2$ crystal OPO to generate 3–5 μm crucial mid-infrared countermeasure light sources.[7,8] Clad-pumped Tm-doped fiber lasers have many advantages to provide a high power laser at the wavelength approximate 1.9 μm region over solid state lasers, due to the high output power, good beam quality, compact fabric, wide tunable range, and high conversion efficiency.[9,10] With two dichroics to establish the cavity, the National Laboratory of Tunable Laser Technology of Harbin Institute of Technology obtained 8.4 W output power at approximately 2 μm with a slope efficiency of 57% from a 1.7-m-long Tm-doped LAM fiber, and the Shanghai Institute of Optics and Fine Mechanics of the Chinese Academy of Science realized 8 W output power from a Tm-doped silica glass fiber laser around 2.05 μm.[11,12] The Optical Fiber Technology Centre of the University of Sydney reported their 120 W output power with slope efficiency of 57% from a 4-m-long Tm-doped silica glass fiber pumped at both fiber ends by two 793 nm LDs.[13] The all-fiber laser scheme can provide narrow linewidth reflection and high reflectivity at special wavelength. The all-fiber laser schemes are more compact and stable, and are very suitable to couple with the LD output pump light. Pumped by the 1.5 μm Er:Yb co-doped fiber laser, IPG Photonics reports a cw 450 W output power at 1940 nm, with the diode conversion efficiencies of 20%.[14] Using the MOPA method, Nufern realized 70W laser output with a diode laser conversion efficiency of 50%.[15]

In this Letter, a high power LD-clad-pumped Tm-doped all-fiber laser is reported. Compared with the all-fiber programs of IPG and Nufern, this scheme is very simple and has relative high diode conversion efficiencies. The maximum output power of nearly 40 W is realized at 1.94 μm with the spectrum linewidth smaller than 2 nm. The output power and spectrum characteristics of the FBG couple scheme are also compared with those using the dichroic as the high reflective coupler.

The all-fiber laser experimental setup is shown in Fig. 1. The Tm-doped double-clad fiber is homemade by Fiber-home Technologies in China. The Tm-doped fiber core has a diameter of 25 μm (NA=0.13) with a Tm-doped concentration of about 2.2 wt.%. The hexagonal inner-clad diameter is 250 μm (NA=0.46), surrounded by a low refractive index polymer as the outer clad. The length of the used Tm-doped fiber is 3.2 m, and the main part of the fiber is cooled in a water box, except the two nearly ten centimeter fiber ends, which are in fiber clamps. The pump source is a 793 nm LD with a 200 μm output pigtail fiber (made by Dilas in Germany). In the all-fiber scheme, the nearly 10 mm FBG is inscribed in the passive H_2-loaded fiber core using a 248 nm excimer laser and a phase mask, and the fiber has a core diameter of 25 μm (NA=0.1) and a circular inner-clad diameter of 250 μm (NA=0.46). The fiber laser is made up by splicing the pigtail fiber, matched FBG fiber and Tm-doped fiber. The dichroic (793 nm HT < 97%, 1.9 μm HR > 99%) coupler experiment setup is shown in Fig. 2, the pump light is focused into the inner-clad of the Tm-doped fiber by a 1:1 multi-lens. The output fiber end 3.6% fresnel reflectivity acts as the output coupler. A silicon slice is used to isolate the unabsorbed pump light.

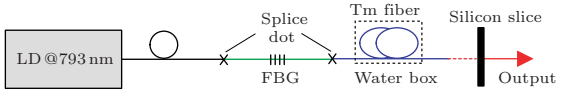

Fig. 1. The all-fiber laser experimental setup using the FBGs reflection coupler.

The output power characteristics are shown in

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Fig. 3. The all-fiber laser maximum output power is 39.4 W, with a threshold of 6.8 W and slope efficiency of 34% in respect to the LD output power. In the dichroic coupler scheme, the maximum output power is 9.8 W, limited by the coated polymer burning, as shown in Fig. 4. The slope efficiency and threshold is 40.4% and 4.4 W, respectively. Obviously, it has higher efficiency and lower threshold relative to the all-fiber scheme. This can be explained by the multi-mode FBG reflectivity being lower than that of the dichroic, and there is also laser output from the FBG fiber end.

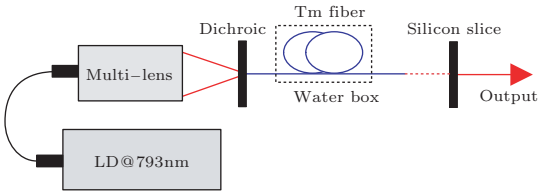

Fig. 2. The fiber laser experimental setup using the dichroic reflection coupler.

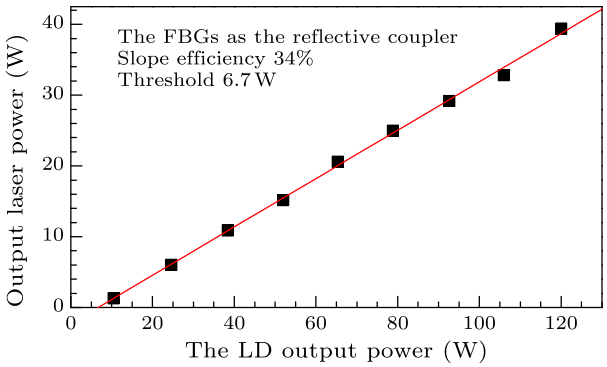

Fig. 3. Output laser power from the FBGs coupler laser scheme as a function of pump power.

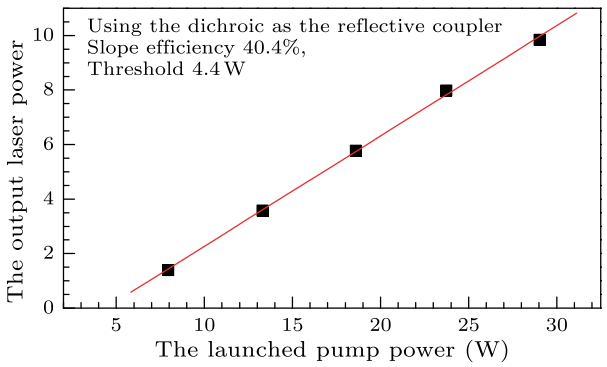

Fig. 4. Output laser power from the dichroic coupler laser scheme as a function of pump power.

The output laser spectrum is measured by the wavemeter (WA1500, made in Canada by EXFO). Figure 5 shows the output wavelength of the Tm-doped all-fiber laser when the output power is nearly 0.2 W. The output center wavelength is located at 1937.7 nm with the linewidth of 58.8 pm. When the output power reaches 20 W, the output laser spectrum begins to chop and change to be multi-peaks as shown in Fig. 6, and the total spectrum linewidth is less than 2 nm. In the dichroic coupler scheme, the output laser spectrum is very wide and strongly chopped, ranging from 1977 nm to 2000 nm at the output power of nearly 5 W, as shown in Fig. 7.

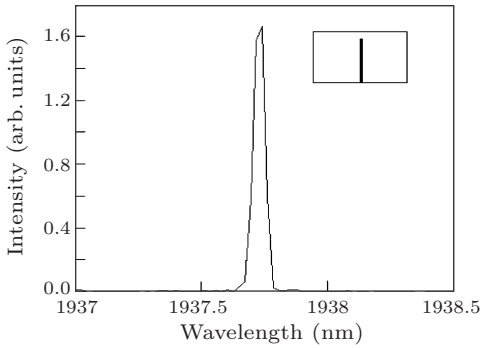

Fig. 5. The single-peak output laser spectrum from the FBGs coupler scheme at the output power of nearly 200 mW.

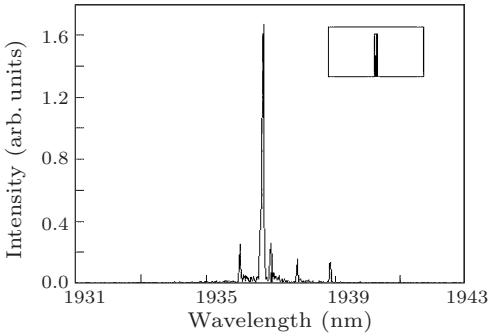

Fig. 6. The multi-peak output laser spectrum from the FBGs coupler scheme at the output power of nearly 20 W.

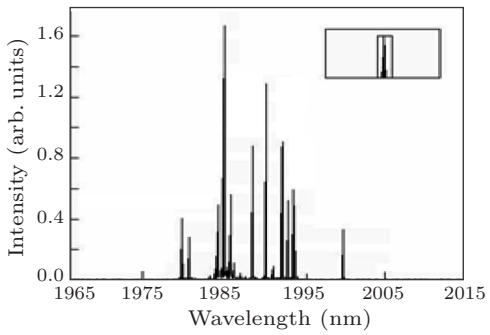

Fig. 7. The wide waveband output laser spectrum from the dichroic coupler scheme at the output power of nearly 5 W.

In summary, a cw 39.4 W all-fiber laser output at approximately 1.94 μm is realized from a 3.2-m-long Tm-doped silica glass fiber with a passive matched FBG. The maximum output power is only limited by the available pump source. The all-fiber scheme has a slope efficiency of 34.2%, lower than that of the dichroic coupler scheme. This can be explained due

to the fact that the dichroic has a higher reflectivity at 1.94 μm than the passive multimode FBG fiber, and the pump light has loss when passing through the splicing dots. In the case of high power operation, the output laser spectrum is chopping and becomes multi-peak, but the total spectrum linewidth is less than 2 nm, much narrower than the nearly 20 nm of the dichroic coupler scheme.

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