6 kW monolithic high power fiber laser with single-end pumped configuration

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A single-end pumped monolithic fiber laser with 6 kW output has been demonstrated. To obtain a high power output by means of single-end pumping, a 900 μm double cladding fiber and a corresponding new designed signal/pump combiner are developed. In experiment, this monolithic fiber laser achieves 6.03 kW output with an M2 beam quality of 2.4, and a center wavelength of 1079.7 nm. This single-end pumped fiber laser manifests good thermal management ability, and is promising for higher power scaling.

(Received October 18, 2016; accepted June 7, 2017)

Keywords: Fiber laser, Single-end pump, Fiber device

1. Introduction

High power fiber lasers have been widely used in manufacture due to high average power, excellent beam quality and easy thermal management. With the emerge of double cladding fiber and high power laser diodes (LDs), high power fiber lasers have experienced a rapid development in last decades. The first kW-class fiber laser with nearly diffractive-limited beam quality was demonstrated in 2004 [1]. After that, the average output power of fiber lasers increased fast [2-6]. However, the elevation of pump brightness cannot meet the demand of power scaling of fiber lasers and gradually becomes one of the main limitations that impede the power upgrade of monolithic fiber lasers. According to the developed LD brightness, it is very difficult to inject enough pump power into single fiber with small claddings. To overcome such problem, IPG developed tandem pumping technology to pump active fiber with 1018nm fiber lasers. As the fiber laser pump source has at least ten orders of magnitude brightness higher than LDs, it is easy to provide 10kW class pump power injection into a single active fiber while no traditional LDs can. With its help, IPG developed 10kW single mode fiber laser [7].

In this paper, we report a single-end pumped monolithic fiber laser with 6 kW output. A 30/900μm active fiber is used as the power amplifier and a new designed signal/pump combiner with low pump and signal loss is developed to inject pump power into the active fiber. By enlarging the active fiber cladding, and matching it with related pump combiner, 10 kW class pump injection using LDs can be realized. A monolithic fiber laser with 6.03 kW output centered at 1079.7 nm in an all fiber configuration is realized. This method is promising for developing 10kW class monolithic fiber lasers with LDs pumping.

2. Experimental setup

The schematic experiment setup of 6 kW fiber laser is shown in Fig. 1. The monolithic fiber laser is based on a master oscillator power amplifier (MOPA) configuration. The oscillator stage is made up of a pair of fiber bragg gratings, 12m long Nufern 20/400 Yb-doped fiber (YDF, absorption coefficient is 1.2 dB/m at 976 nm) and a 7×1 multimode pump combiner which has 6 LDs centered at 976 nm connected to its pump fiber arms. Pumped by the LDs which totally has 300W output, the oscillator produces 200W signal centered at 1080 nm. The power amplifier stage is made up of a newly designed (6+1)×1 signal/pump combiner, homemade 30/900 YDF, a cladding power stripper (CPS) and an output quart block head (QBH).

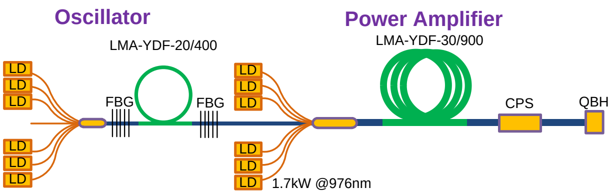

Fig. 1. Experimental setup

The configuration of the combiner is shown in Fig. 2. Different from side pump combiners [8~10], this one is based on end pump structure. One Nufern 30/400 passive signal fiber (NA=0.06) surrounded by 6 Nufern 300/330/360 multimode fiber (MMF) pump fibers is slightly tapered to form a fiber bundle with an outer diameter of 900 μm. The bundle is then spliced to a piece of homemade 30/900 passive double cladding fiber to form the combiner. In tapering process, only the pump fibers' diameter shrinks along the longitudinal direction, while the signal fiber's diameter keeps unchanged. Since the bundle and output signal fiber has the same core diameter and outer diameter, the combiner would have very low signal and pump loss, and can load much higher pump and signal power without the risk of burning up. It is measure that the combiner has a signal loss less than 0.15dB and a pump efficiency over 98%. Moreover, the pump fibers can have lager diameter by this way, and higher pump power can be injected into the amplifier stage. In experiment, 6 LDs with 300/330/360 fiber pigtails and output powers range from 1600W to 1700W are connected to the combiner, which possesses pump injection ability of 10kW.

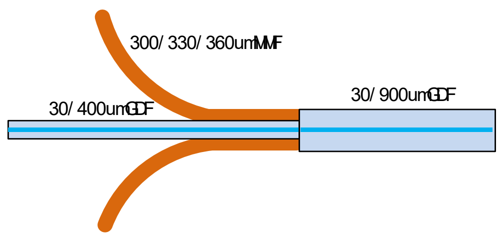

Fig. 2. The configuration of the combiner

The homemade 30/900 YDF has a 30 μm core and 900μm cladding with N.A. of 0.06 and 0.46 respectively. The absorption coefficient at 976nm is about 0.8dB/m. About 21 meters of this fiber is used. The CPS is water cooled and can strip maximum 1.2 kW cladding power safely. This is critical to the safety of the fiber laser, when LDs work at low drive current and too much unabsorbed pump power accumulates in the fiber cladding. The signal is output by the QBH, which is a quart block head spliced with a pieces of 30/900 passive double cladding fiber used for the combiner and cooled by water.

3. Results

In experiment, pump power output from the combiner is firstly measured. Since the area where combiner output fiber and the active fiber is spliced bears the seed signal and maximum pump power, it has the maximum heat load in the fiber system. During the experiment, to ensure the safe work of the fiber laser, the temperature of this area is monitored, and pump LDs is prepared to shut down while set critical temperature is reached. Also, the whole fiber laser including the oscillator and the power amplifier stage are placed on a water cooled aluminum plate. Especially, the active fibers are fixed into round tracks carved in the aluminum plate by heat-conductive silicone grease to reduce the heat accumulation in the fiber laser system while operating. Due to the thickness of the fiber cladding, the coiling diameter of the active fiber is about 0.8m, which is acceptable. The amplifier output power versus pump power is shown in Fig. 3. The fiber laser has a maximum output power of 6.03 kW while 9.95 kW pump power is injected, and an optic-to-optic efficiency of 61.25% is obtained. The output spectrum of the laser is shown in Fig. 4. The center wavelength measured is 1079.7 nm and 3dB bandwidth of the spectrum is 0.98 nm. At full power output operation, the maximum temperature of the combiner never exceeds 30 ^{o}C, which implies a good power load ability of the combiner.

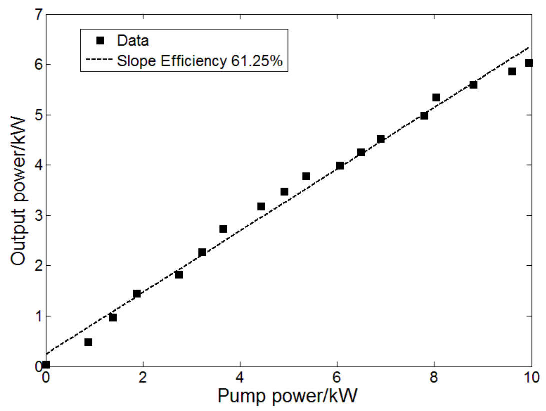

Fig. 3. Output power of the fiber laser vs. the total pump power

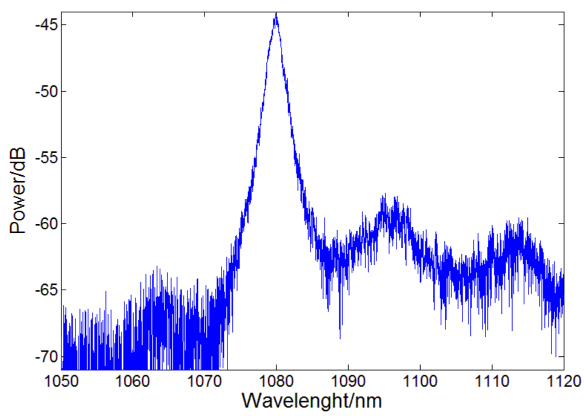

Fig. 4. Spectrum of the fiber laser at maximum output power

As beam quality of a fiber laser is concerned, we use 86/14 knife edge method to measure the M2 factor of the laser at the maximum output power point. Fig. 5 shows the M2 factor measured by the M2 analyzer. The measured M2x and M2y is 2.370 and 2.386 respectively. In experiment, the mode match between the oscillator and the power amplifier is not deliberately controlled. There is no mode match device between the oscillator stage and the power amplifier stage. The measured M2 of the system is about 2.12 while only the oscillator stage is operating. The beam quality continuously degrades with the increasing of the laser output power, no drastic degradation of the M2 is observed, which is the sign of the mode instability.

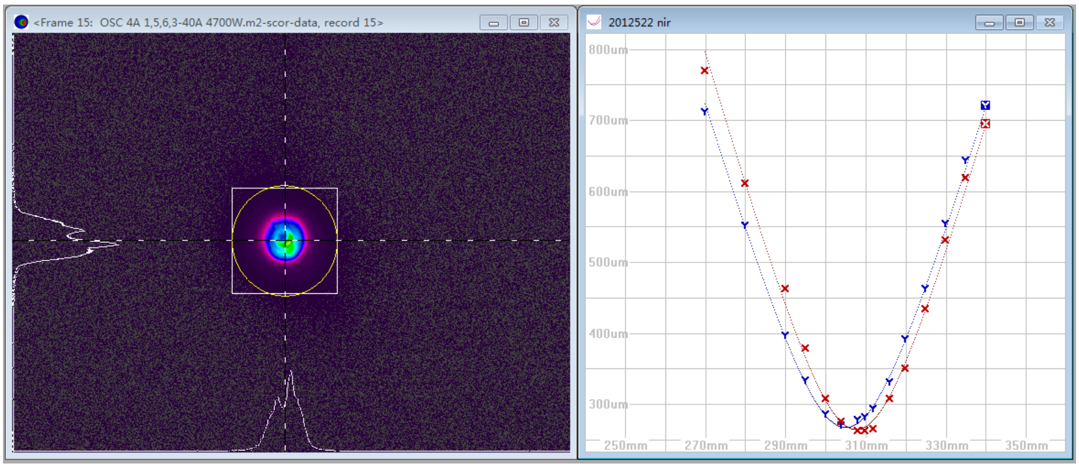

Fig. 5. Measured M2 factor of the fiber laser at the maximum output

4. Discussion

In experiment, the overall amplification efficiency is only 61.25%, which is lower than ordinary ones. The reason lies in the homemade 900 active fiber, which has a relative high signal loss caused by the lack of elimination of water in the fiber fabrication process. It arises from the fiber preform fabrication which is based on MCVD method, but no Cl_2 gas is used to take away the water formed in the chemical reaction process due to environment influence consideration. Moreover, in the fiber fabrication process, Phosphorus is used to suppress the photon darkening effect and less Ytterbium could be doped, which cause the active fiber has a relative low absorption coefficient at 976 nm. Thus, relatively long fiber must be used, and increases the difficulty to control the nonlinear effect in the fiber. Stimulated Raman scattering (SRS) and four-wave mixing (FWM) peak near 1115 nm and 1095 nm are observed in Fig. 4. High power 1080 nm signal generates SRS noise at 1115 nm and then the signal together with the SRS noise generates FWM noise at 1095 nm. To improve the system, it is necessary to reduce the background loss and increase the absorption coefficient of the active fiber by improving the doping technic.

Also, the main purpose of the experiment is to verify the bump injection ability of the whole system design, it is lack of consideration of the way to enhance the beam quality of the laser system. However, it is necessary to add mode match and other technics such as using a core-index modified power amplification fiber to improve the beam quality in the future.

5. Conclusion

In this paper, we demonstrate a single-end pumped monolithic fiber laser with 6 kW output. To obtain 10 kW class pump power injection, a new designed signal/pump combiner with low pump and signal loss is developed. By pumping a homemade 30/900 active fiber using this combiner, 6.03 kW output centered at 1079.7 nm in an all fiber configuration is realized. By improving the active fiber and increasing the seed injection power, such configuration is promising for 10kW class output.

Acknowledgements

Special thanks to Aoxiang Lin, Ali You, Huan Zhan, Li Ni, Xiaolong Wang, Cong Gao, Yuying Wang, Kun Peng, and Zhaonian Jia for their help with fabricating and providing the 30/900 YDF.

The research is funded by the program for the National Science Foundation of China (NSFC) (11404305, 11474257).

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