Erbium-doped Photonic Crystal Fiber Laser

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Abstract We have demonstrated a low threshold all fiber laser based on a 9.68 m-long small core Erbium doped photonic crystal fiber (PCF) and also presented results from two separate device experiments. The threshold and maximum output power of the laser are 6.72 mW and 82.6 mW, respectively. Fiber loop mirrors is used as resonator mirrors. The overall system is all-fibered and with low threshold. The PCF we used as gain medium with 9.68 m long, 3.34 μm mode diameter, 0.143 numerical aperture, 1000 ppm doped concentration, 545 dB/km transmission attenuation coefficient to 1310 nm laser. A single-mode diode laser, centered at 980 nm, was used as pump source and the maximum power was 400 mW.

Keywords: fiber laser, Erbium-doped Photonic Crystal Fiber, fiber loop mirrors, all fiber system, low threshold

1. Introduction

Research into the field of photonic crystal fiber (PCF) has attracted a great deal of interest in recent years due to the novel and extended range of waveguide properties [1-4].These properties include: endlessly single-mode operation, anomalous dispersion down to visible wavelengths, and high or low nonlinearities—all of which can be achieved by appropriate design of the holes and rely upon the large occupied- space ratio between air and silica [5]. Rare earth-doped PCF was found many of these novel features. Currently, it became a hotspot, many study focused on rare earth-doped PCF [6-10]. It was applied in fiber laser and amplifier as active medium. Holes in rare earth-doped PCF make greater refractive index difference, it is good for transmission of single mode, reducing the threshold of stimulated radiation. And these holes in fiber are guaranteed doped particles can make good use of the pumping light, output power can be increased. Compared with EDFA, fiber laser has many advantages such as low threshold, high power. Erbium-doped fiber lasers which emit 1.55μm lightwave be widely used as source in optical fiber communication systems.

To obtain high-efficiency operation of a fiber laser, it is necessary to ensure a low laser threshold and high slope efficiency. Two strategies can be taken in terms of waveguide design: one is to minimize the effective mode area of the fiber, and the other is to maximize the intensity of the pump and signal beams in the vicinity of the doped section of the fiber [11]. To increase the intensity of pump beam, high output pump source was used. But the equipment of this structure is complex, prone

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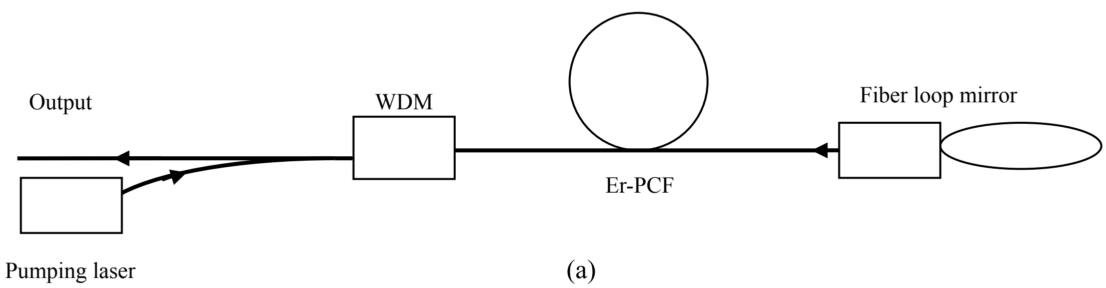
to be affected by outside environment and blocked miniaturization. All-fiber system is simple and can realize miniaturization. It will be more suitable for communication system.

In this letter, a simple and all fiber system of Erbium-doped fiber laser has been studied. Fiber loop mirror was adopted as a cavity mirror, Er+ doped PCF was applied as the active medium, the maximum output power of laser reached to be 82 mW.

2. Experimental setup

The experimental setup with continuous-wave output laser is shown in Fig.1. In Fig.1(a), a fiber pigtailed single-mode diode laser operating at a wavelength of 974 nm served as a pump source and was coupled into a 9.68 m-long Er+-doped PCF via an WDM. The laser cavity was defined by a fiber ring which was made by an optic coupler with 50:50 coupling ratio at 1550 nm and the 4% Fresnel reflection at the other end of the WDM. The maximum pump coupling efficiency was 87%. In order to improve the wavelength stability, a fiber grating with reflection wavelength centered at 1530.5 nm, 0.126 nm bandwidth and 90% reflectivity was insert into Fig.1(a). Then we get the system as illustrated in Fig.1(b). Here we call system of Fig.1(a) the first fiber laser, Fig.1(b) the second fiber laser. The fiber grating and fiber ring make of laser cavity. Er+-doped PCF made by FiberHome Technology in WuHan with 9.68 m long, 3.34μm mode field diameter, 0.143 numerical aperture, 1000 ppm doped concentration and 545 dB/km transmission attenuation coefficient to 1310 nm laser was used as gain medium, Fig.2 shows the cross section of the Er+-doped PCF.



(a)

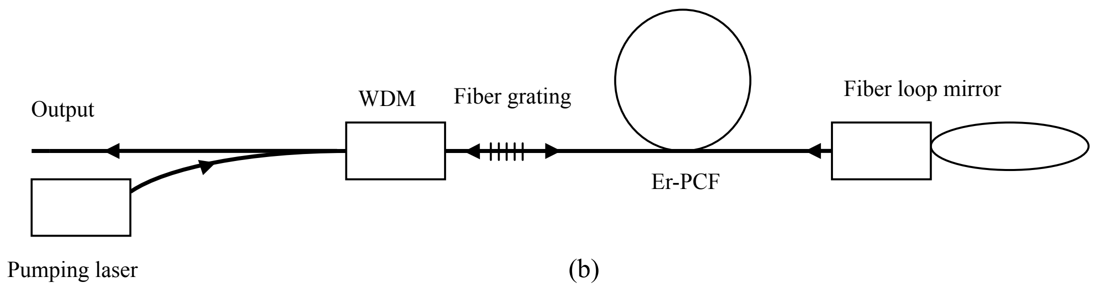


Fig.1 The experimental setup of two fiber lasers

(a) was structure of the first fiber laser (b) was structure of the second fiber laser

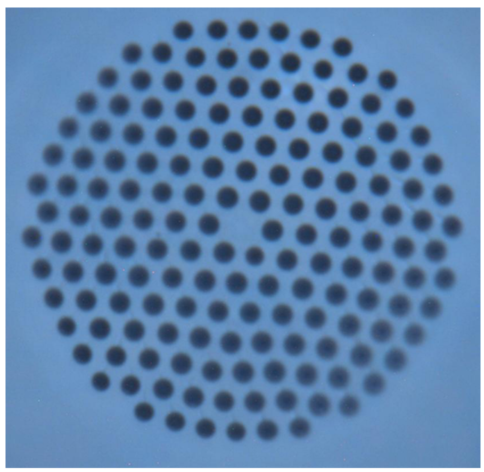


Fig.2 Optical microscope image of the Er+- doped PCF cross section

3. Experimental Results and Discussion

The absorption characteristics of the Er+ doped PCF were measured by a cut-back technique using a white light source. Fig. 3 shows the absorption spectra of Er+ doped PCF. We can see clearly in Fig 3. the absorption peaks of the Er+ doped PCF. 1550 nm wave band is the intrinsic absorption peak of Er+. It was interpreted that strong OH–absorption of the fiber due to the peak at 1390 nm of the spectrum [12].

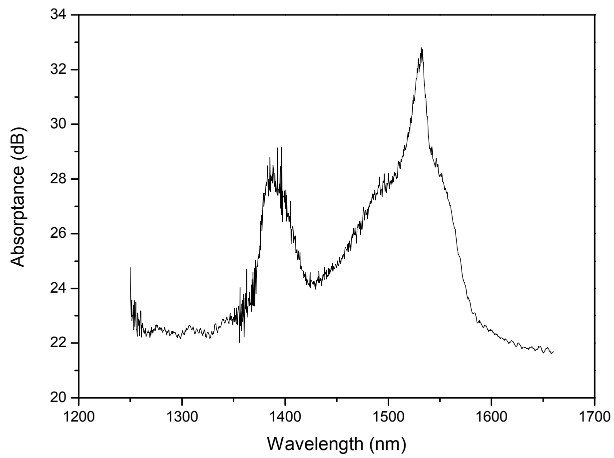
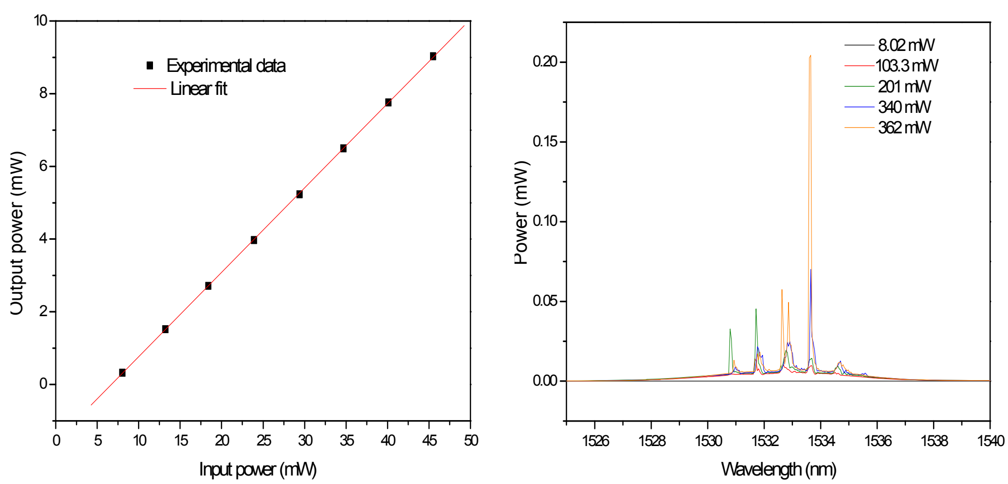


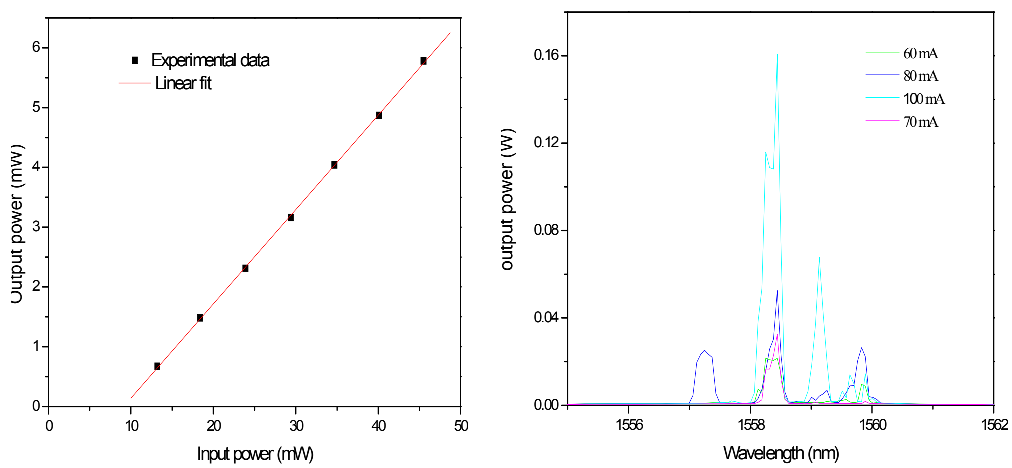
Fig. 3 Absorption spectrum of Er+ doped PCF with respect to 1310 nm broadband light source



(a) (b)

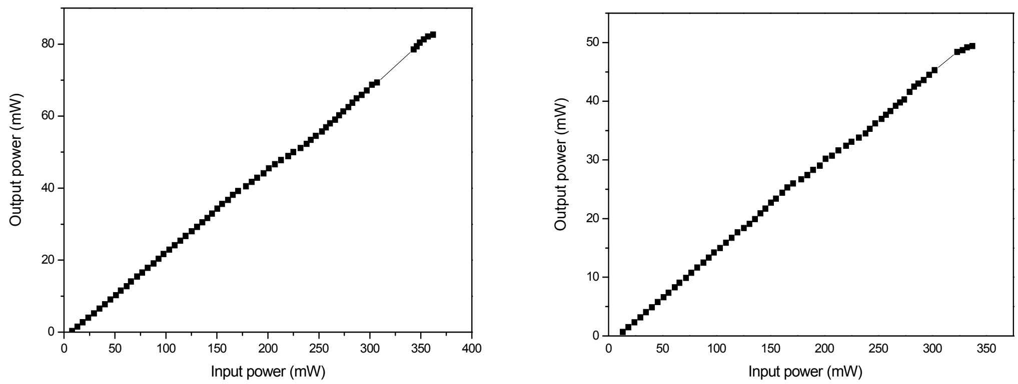
Fig. 4 Output characteristics of the first laser (a) was the relation of output power with input power near threshold (b) was output spectrums under different input power

The maximum pump coupling efficiency was 88%. Fig. 4 shows the laser output spectra and power obtained from the first system. A slope efficiency of 23% with respect to the absorbed pump power and a threshold of 6.72 mW were estimated. Accuracy of the spectrometer we used is 0.01. We can see in Fig. 4 output wavelength of the first system is unstable. The central wavelength is 1533.6 nm and the variation range of wavelength is±1 nm. The unstable wavelength could be due to the design of cavity. Fiber ring was used as cavity mirror with high reflectivity in a broad band lightwave in vicinity of 1550 nm. Fiber- the other mirror which was carefully cut have broad reflection bandwidth too. The cavity can not accurately select a mode of lightwave. Fiber grating which has high reflectivity at a special wavelength was inserted into the system to improve wavelength stability. A exact wavelength can be selected by using fiber grating. It was illustrated in Fig.5 the output wavelength of the second system is 1558.442 nm. By linear-fitting the experimental data we get the slope efficiency is 15.8% and threshold is 9.12 mW. The slope efficiency is lower than the first system's. It was considered insertion loss of fiber grating due to it.



(a) (b)

Fig.5 Output characteristics of the second laser (a) was the relation of output power with input power near threshold (b) was output spectrums under different input power



(a) (b)

Fig.6 Lasers' output power against pump power

(a) was output of the first fiber (b) was output of the second fiber

4. Conclusion

In conclusion, we have demonstrated a low threshold all fiber laser based on a 9.68 m-long small-core PCF and presented results from two separate device experiments. Firstly, we report a simple all fiber laser with 23% slope efficiency, 6.72 mW threshold and 82.6 mW maximum average power by fusion splicing to standard single-mode fiber components. Secondly, a fiber grating served as a cavity mirror was used. We get the best result in home of all fiber Er+ doped PCF laser, the threshold is 9.12 mW and slope efficiency is15.8% by linear fitting the experimental data.

Reference

1. Nicholson J W, Bise R, Alonzo J, Stockert T, Trevor D J, Dimarcello F, Monberg E, Fini J M, Westbrook P S, Feder K. Visible Continuum Generation Using a Femtosecond Erbium-Doped Fiber Laser and a Hybrid HNLF-PCF Nonlinear Fiber. Optical Fiber communication/National Fiber Optic Engineers Conference, 2008, 11(24 -28):1– 3

2. Eom J B, Moon S, Paek U C, Lee B H, Yang GH. Fabrication and transmission characteristics of couplers using photonic crystal fibers. Optical Fiber Communication Conference, 2002, 3(17-22): 465– 466

3. Hansen T P, Broeng J, Jakobse C, Vienne G, Simonsen H R, Nielsen M D, Skovgaard P M W,. Folkenberg J R and Bjarklev A. Air-guiding photonic bandgap fibers: Spectral properties, macrobending loss, and practical handling. J. Lightwave. Technology, 2004, 1(22): 11–15

4. Knight J C, Birks T A, Russell P S J, Atkin D M. All-silica single-mode optical fiber with photonic crystal cladding. Optic Letter,1996, 11(21): 1547–1549

5. Sellami Ali1, Khalid A. S. Al-Khateeb, Belloui Bouzid. A Novel Erbium-Doped Fiber Laser Source (EDFL). Photonic

Technology Letter, 2005, 1(17)

6. Yu Jianjun, Jeppesen P, Palsdottir B, Knudsen S N. Reducing pulsewidth broadening in L-band EDFAs by use of a new L-band EDF. Photonics Technology Letters, 2001, 7 (13): 654 – 656

7. Mizrahi V, DiGiovann D J i, Atkins R M, Grubb S G, Park Y K and Delavaux J M P. Stable single-mode erbium fibergrating laser for digital communication. Lightwave Technology, 1993, 11: 2021–2025

8. Bellemare A, Karasek M, Riviere C, Babin F, G. He, V. Roy, G.W. Schinn. A broadly tunable erbium-doped fiber ring laser: Experimentation and modeling. Topics Quantum Electron., 2001, 1 (7): 22–29

9. K. Furusawa, A. Malinowski, J. H. V. Price, T. M. Monro, J. K. Sahu, J. Nilsson, D. J. Richardson. Cladding pumped Ytterbium-dopedfiber laser with holey inner and outer cladding. Optics Express, 2001, 9: 714–720

10. C. J. S. de Matos, S. V. Popov, J. R. Taylor. Temporal and noise characteristics of continuous-wave-pumped continuum generation in holey fibers around 1300 nm. Applied Physics Letters, 2004, 85: 2706

11. P. C. Becker, N. A. Olsson, J. R. Simpson. Erbium-Doped FiberAmplifiers, Fundamentals and Technology. San Diego: Academic, 1997.

12. Yongqin Yu, Shuangchen Ruan, Chenlin Du, Jihong Zhao, Jianchun Zeng. Spectral broadening using a polarization-maintaining photonic crystal fiber by an optical parametric amplifier. In: Proceedings of SPIE, 2006, 6(25)