Dual-wavelength Er^{3+}-doped photonic crystal fiber laser based on superimposed fiber gratings

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Abstract: A new type of dual-wavelength photonic crystal fiber laser was proposed and demonstrated, based on superimposed fiber gratings. Linear cavity structure was used to induce the laser, Er^{3+}-doped Photonic Crystal Fiber was used as the gain medium, and two superimposed fiber gratings whose reflectivity were higher than 99% were used for wavelength selection. Based on gain equalization technologies, modal competition in the cavity was suppressed to realize dual-wavelength laser at room temperature. The 3 dB line-wide is less than 0.02 nm, 30 dB line-wide is less than 0.25 nm, and SMSR is 54.34 dB. The wavelength interval of dual-wavelength laser is 0.932 nm. The experimental result show that the wavelength and the laser energy of the dual-wavelength laser are stable.

Key words: fiber laser; dual-wavelength; Er^{3+}-doped PCF; superimposed fiber grating
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基于重叠光栅的双波长掺铒光子晶体光纤激光器

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摘 要: 提出了一种基于光纤重叠光栅的双波长光子晶体光纤激光器。激光器采用线形腔结构,掺铒光子晶体光纤为激光器的增益介质,反射率均高于99%的光纤重叠光栅用作激光器的波长选择器件。基于增益均衡技术,抑制谐振腔内的模式竞争,在室温下获得了稳定的双波长激光同时输出。实验结果表明:其 3 dB 线宽小于 0.02 nm,30 dB 线宽小于 0.25 nm,SMSR 为 54.34 dB,双波长激光的中心波长间隔为 0.932 nm。该双波长激光器输出的双波长激光具有较好的稳定性。

关键词: 光纤激光器; 双波长; 掺铒光子晶体光纤; 重叠光栅

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0 Introduction

Dual-wavelength fiber laser has extensive applications in the areas of laser medicine, microwave generation [1], optical fiber communications [2], millimeter-wave generation [3], optical sensing [4] and so on [5-6]. The homogeneous broadening and cross gain saturation effect of Er^{3+}-doped optical fiber will generate mode competition, and these will limit the potential applications of dual-wavelength and multi-wavelength fiber lasers[7]. Therefore, more and more researchers focus on the technologies of suppressing mode competition so as to improve the stability of the fiber laser, such as liquid nitrogen cooling technology [8], frequency shifter [9-10], special structure of optical fiber[11-13] and so on. In the paper, dual-wavelength Er^{3+}-doped PCF(Photonic Crystal Fiber)[14] laser based on a pair of SIFG(Superimposed Fiber Gratings) is proposed to avoid mode competition, the laser is based on gain equalization technology, and the experimental results demonstrates an improved stable laser output.

1 Experiment devices

The configuration of the proposed dual-wavelength Er^{3+}-doped PCF laser is shown schematically in Fig.1.

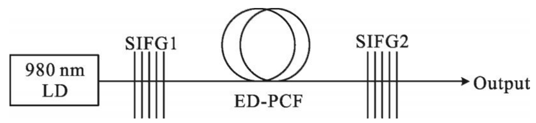

Fig.1 Experiment devices of the dual-wavelength Er^{3+}-doped PCF laser based on SIFGs

The two ends of the Er^{3+}-doped PCF are spliced with SIFG1 and SIFG2 respectively as linear cavity structure of the fiber laser. A 980 nm semiconductor LD(Laser Diode) is used as the pump light source with the maximum power of 750 mW, and an OSA(Optical Spectrum Analyzer) with resolution of 0.02 nm is used to monitor the laser output. A section of Er^{3+}-doped PCF are used as gain medium, two small weights are connected with the two ends of SIFG2 to balance the power of two wavelengths in the cavity.

The transmission spectrums of SIFG1 and SIFG2 are shown in Fig.2.

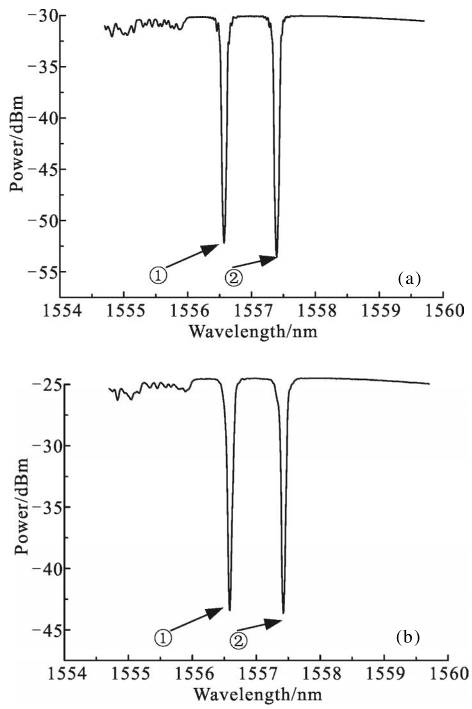

Fig.2 Transmission spectrum of SIFG1 and SIFG2

From Fig.2(a), the peak reflectivity of SIFG1 are 99.37% and 99.55% respectively, the peak wavelength are 1 556.572 nm and 1 557.396 nm respectively, 3 dB bandwidth are both 0.1 nm, the wavelength interval between two gratings is 0.824 nm, meeting nanometer (nm) or subnanometer (sub-nm) as channel spacing unit requirements in the communication. From Fig.2(b), the peak reflectivity of SIFG1 are 98.42% and 98.22% respectively, the peak wavelength are 1 556.590 nm and 1 557.420 nm respectively, 3 dB bandwidth are both 0.1 nm, the wavelength interval between two gratings is 0.830 nm, meet nanometer (nm) or (sub-nm) as channel spacing unit requirements in the communication.

2 Experimental principle

The principle of system is: 980 nm LD pump into the resonator which is composited by SIFG1 and SIFG2 through SIFG1, erbium ions which are in the Er^{3+}-doped fiber have the effect of amplification, by adjusting the loss and threshold gain at λ_1 and λ_2 in the cavity, to reach[15]:

$$g_{\lambda_i} \times L = G_{th}(\lambda_i) = \delta_{\lambda_i},\ i=1,2 \qquad (1)$$

In the formula, g_{λ_i} is gain factor at λ_i, L is Er^{3+}–doped fiber length, $G_{th}(\lambda_i)$ is one-way threshold gains at λ_i, δ_{λ_i} is one-way loss in cavity at λ_i.

3 Experimental results and discussion

Dual-wavelength PCF laser optical connection are shown in Fig.3. SIFG is a novel fiber laser wavelength selection component with high speed and accuracy. In the experiment, the resonance wavelengths of SIFG1 are 1 556.480 nm and 1 557.308 nm, and the reflectivity are 99.5% and 99.7% corresponding to the wavelength of 1 556.480 nm and 1 557.308 nm, respectively. The resonance wavelengths of SIFG2 are 1 556.520 nm and 1 557.352 nm, and the reflectivity are 99.3% and 99.3% corresponding to the wavelength of 1 556.520 nm and 1 557.352 nm, respectively. The length of Er^{3+}–doped PCF is 5 m.

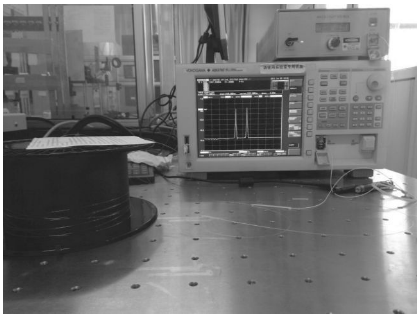

Fig.3 Dual-wavelength PCF laser optical connection

When the pump laser power is 27 mW, and the weight were adjusted to an appropriate state, simultaneous dual-wavelength lasing oscillations are obtained, and the output power spectra is shown in Fig.4. The center wavelengths are 1 556.50 nm and 1 557.324 nm, respectively. The peak powers of the fiber laser are −44.64 dBm and −45.90 dBm at two wavelengths respectively. 3 dB line-width both are 0.025 nm. The output laser power increase gradually with the increase of the pump power, while laser line becomes smoother and the peak wavelength and line width of the laser are very stable.

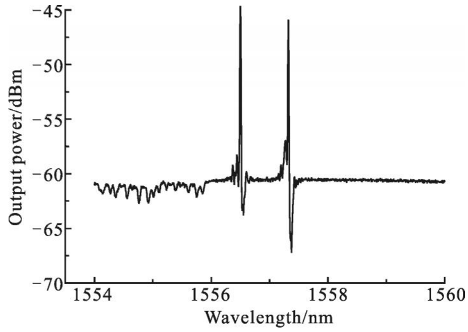

Fig.4 Output spectra of the dual-wavelength PCF laser versus threshold power

The stability of the laser system is verified by scanning the output laser 10 times at the step of 3 minutes with the pump power of 700 mW at room temperature (25℃), as shown in Fig.5. The 3 dB line-width of dual-wavelength laser is less than 0.025 nm, 30 dB line-width is less than 0.15 nm, SMSR (side mode suppression ratio) is 45 dB and the stability of output spectrum waveform is good.

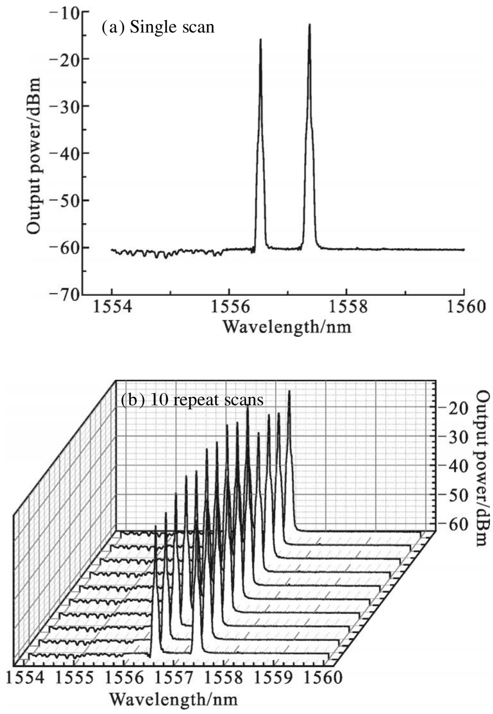

Fig.5 Continuous scanning spectra of dual-wavelength laser at about 700 mW pumped

In order to better observe output stability further, the peak change and central wavelength change curves are shown in Fig.6 and Fig.7.

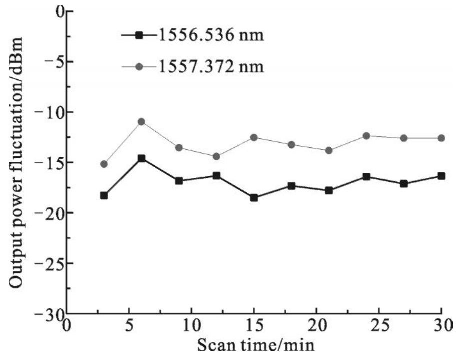

Fig.6 Peak power fluctuation curve of continuous output laser at about 700 mW pumped

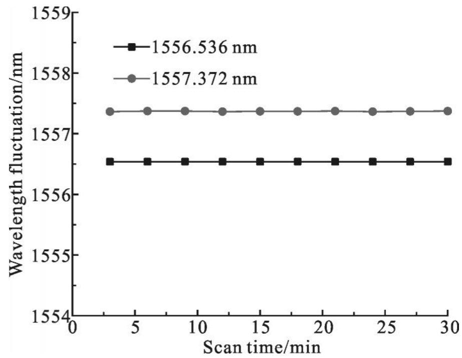

Fig.7 Center wavelength fluctuation curve of continuous output laser at about 700 mW pumped

It can be seen from Fig.6 and Fig.7, the maximum wavelength changes are 0.04 nm and 0.08 nm at the wavelength of 1 556.536 nm and 1 557.372 nm respectively, the peak power changes are 3.91 dBm and 4.2 dBm at the wavelength of 1 556.536 nm and 1 557.372 nm respectively. The stability of output power and center wavelength is very good at room temperature.

The key point of this experiment is the welding of Er^{3+}-doped PCF and single-mode fiber bragg grating. Due to the special structure of PCF, KL-170A type welding machine is used, pre-weld current, pre-weld time, weld current, weld time, propel speed and welding propulsion are adjusted manually to guarantee perfect welding. Connection loss of SIFG1 and Er^{3+}-doped PCF, SIFG2 and Er^{3+}-doped PCF are 0.02 dB and 0.03 dB respectively.

4 Conclusion

A kind of linear cavity dual-wavelength PCF laser based on superimposed fiber gratings is proposed, a pair of superimposed fiber gratings composite linear cavity which are used as wavelength selective devices, Er^{3+}-doped PCF used as gain medium. Experimental results showed that, through fine regulate the weight on two ends of SIFG2, makes gain and loss equal at two wavelengths in resonance cavity, inhibit mode competition, get stable dual-wavelength laser output at 1 556.536 nm and 1 557.372 nm at room temperature, the line-wide is less than 0.02 nm, 30 dB line-wide is less than 0.25 nm, and SMSR is 54.34 dB, the maximum wavelength fluctuation value is 0.08 nm, the maximum peak power fluctuation value is 4.2 dBm, the wavelength interval of dual-wavelength laser is 0.932 nm.

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