Amplification of tunable ANDi Yb-doped mode-locked fiber laser

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Abstract: Ultrashort pulse source with high energy and tunable wavelength is highly demanded for a lot of applications. Amplified all-normal-dispersion(ANDi) mode-locked fiber laser with gain medium of Yb-doped fiber is a compact and excellent source that fulfills those requirements. In this paper, amplification of tunable ANDi Yb-doped mode-locked fiber lasers was experimentally investigated. The gain versus signal wavelength was analyzed. It was found that the maximum gain was obtained near 1 030 nm and the gain decreased as wavelength increased, due to the gain spectrum of Yb-doped fiber. The gain versus pump power was also investigated. Gain saturation and the effect of ASE noise on gain were observed. The spectral and temporal distortions of pulse seed induced by fiber amplification were discussed. The pulse was broadened slightlydue to dispersion. The spectrum was distorted by ASE noise and limited gain bandwidth. If the gain is large and the power of amplified signal is high, the spectrum will be broadened by the effect of self-phase modulation(SPM).

Key words: amplifier; ANDi; mode-locked

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波长可调节全正色散掺镱锁模光纤激光器的放大特性

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摘　要： 高功率，波长可调超短脉冲光源具有重大的应用价值。采用掺镱光纤放大的全正色散锁模光纤激光器能够满足以上优质光源的要求，并且结构紧凑。通过实验全面探索了波长可调节全正色散锁模光纤激光器的放大特性。分析了小信号增益系数随着信号光波长的变化。发现最大增益出现在波长为 1 030 nm 附近，并且增益随着信号光波长的增大而减小，这是由于掺镱光纤的增益谱特性决定的。也分析了增益系数随泵浦光功率的变化，观察增益饱和现象和放大自发辐射噪声。也讨论了种子脉冲在放大器中的时域与频域畸变。发现脉冲因为群速度色散而轻微展宽，频谱因为自相位调制也会发生轻微展宽。

关键词： 放大器；　全正色散；　锁模

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0 Introduction

Wavelength-tunable ultrashort-pulse sources with high-power have widespread applications in many fields, e.g. ultrafast optics, biology and medicine, and micromachining. Mode-locked fiber lasers are convenient and powerful sources of ultrashort pulses, due to its compactness, stability, etc. Recently, all-normal-dispersion (ANDi) Yb-doped mode-locked fiber laser attracted great interests, for their high-power output pulses and avery simple and stable designwithout dispersion-compensation components [1]. An intra-cavity filter is necessary to shape pulse and mode-lock in ANDi laser, and one can get a tunable ANDi laser by use of tunable filters. More recently, wavelength-tunable ANDi Yb-doped fiber lasers have been proposed by L. Kong [2], M. Schultz [3] and C. Ouyang[4], respectively.

In order to further improve the pulse energy, which is strongly desired for many applications, the amplification of the output pulses of ANDi fiber lasers is required. Compared with other amplifiers, rare earth-doped fiber amplifier attracts a lot of interests, for its high efficiency, low threshold, tunable, compact, and thermal performance advantages. Compared with other rare earth ions, Yb-doped fiber amplifiers offerhigh conversion efficiency and broad-gain bandwidth[5]. To achieve high power and less distortion output at different wavelength, it is necessary to investigate the gain characteristic of tunable ANDi laser.

In this paper, the amplification characteristic of tunable ANDi Yb-doped mode-locked fiber laserwith gain medium of Yb-doped fiberis investigated experimentally. The influences of signal wavelength and pump power on the gain are analyzed. The spectral and temporal distortions of pulse seed induced by amplification are discussed. The preliminary result of those amplification experiments shows that the greatest gain effect can be achievedonly at a certain wavelength and certain pump power.

1 Experimental setups and results

Figure 1 demonstrates the experimental setup of the tunable ANDi laser with Yb-doped fiber amplifier. For the oscillator, two PBSs and a quartz birefringent plate serve as a tunable filter. The laser is mode-locked by nonlinear polarization rotation. Two quarter wave plates and one halfwave plate construct a polarization controller(PC). The PC with one PBS and some fiber achieves the effect of nonlinear polarization rotation. The output from PBS serving as signal is connected to an isolatorto ensure one-way transmission. We adopt the backward pumping scheme in the amplifier to avoid the influence of pumpon the amplifier output. The length of gain fiber in amplifier is 0.8 m.

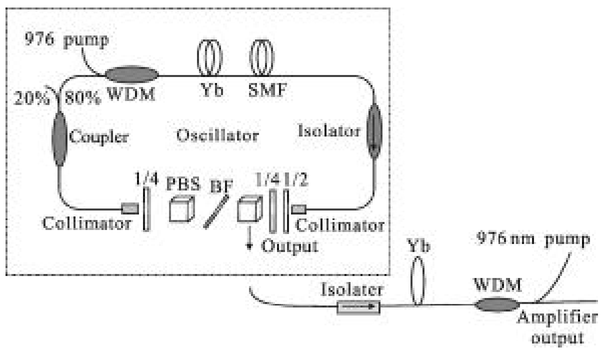


Fig.1 Experimental setup (WDM: wavelength division multiplexer, 1/2: half wave plate, 1/4: quarter wave plate, PBS: polarization beam splitter, BF: birefringent plate, SMF: single-mode fiber, Yb: Yb-doped fiber)

We had set up the cavity with total length of 9 m and gain fiber length of 1.16 m. The repetition rate was about 22 MHz, and the wavelength tunable range was 1 026-1 064 nm. The output power of the oscillator from PBS is about 3.5 mW. By tuning the filter, we can get mode-locked pulse at different wavelength. The spectra of different mode-locked wavelengths are given in Fig.2. In our ANDi laser, we can get any wavelength in the range easily by turning the birefringent plate in the cavity.

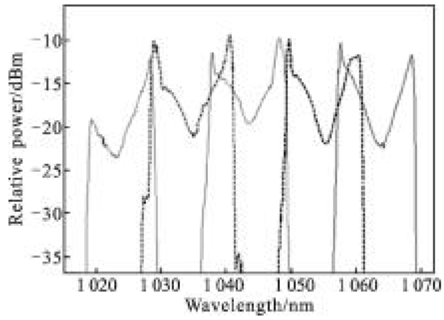
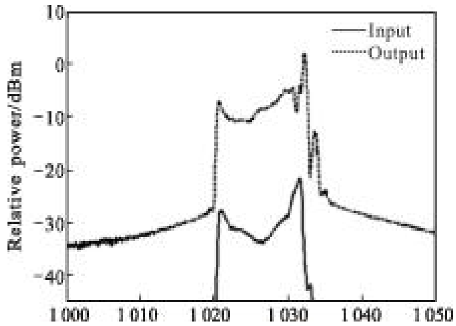
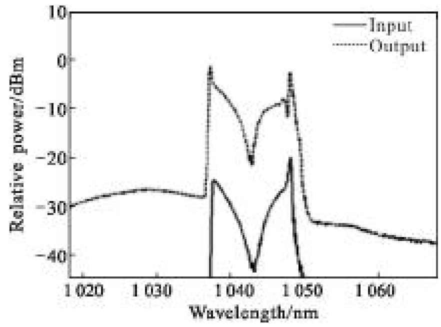


Fig.2 Typical spectrum of mode-locked pulses at different center wavelengths

We investigated the spectrum of the amplifier output at different wavelength. Fig.3 gives the typical spectraof two wavelengths. The solid and dottedlines



(a) Center wavelength of 1 026 nm



(b) Center wavelength of 1 043 nm

Fig.3 Spectra of input and output of the amplifier

represent the spectra of input and output of the amplifier, respectively. We can see ASE noise which decreases the signal-to-noise ratio of the output pulse clearly in the output spectrum. Compared Fig.3(a) to Fig.3(b), the gain of the broadband signal spectrum is uneven in both wavelength. For the case of center wavelength at 1 026 nm, the gain in longer wavelength part is larger. Meanwhile, for the case at 1 043 nm, the shorter wavelength part is amplified larger than the longer wavelength part. We can conclude that the part of signal which is near the peak of Yb-doped fiber's gain spectrum will get higher gain, due to the broad spectrum of ANDi laser and uneven gain spectrum of Yb-doped fiber. We can also find that the spectrum is broadened slightly. The higher the gain is, the wider the spectrum is broadened. Thus the broadening may be induced by self-phase modulation in the gain fiber.

The gain versus signal central wavelength is given in Fig.4. The length of Yb-doped fiber is 80 cm, and the pump power is about 400 mW. It is found that the maximum gain is obtained near 1 030 nm and the gain decreases as wavelength increases. This phenomenon is consistent with the trend of the ASE of Yb-doped fiber since the peak of ASE spectrum is near 1 030 nm.

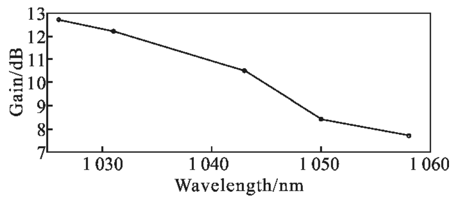


Fig.4 Small-signal gain versus the central wavelength of signal

Figure 5 presentsthe gain versus pump power at signal wavelengths of 1 031 and 1 050 nm. It shows that, the output power of amplifier increases linearly with the increase of the pump power at the beginning. But the increase of output power slows down when the pump power increase higher. In the end the output power would remain stable and does not change with pump power for the case of 1 031 nm. That is the signal gain reached saturation point. For the amplification at 1 050 nm, the output power even decreases with the increase of pump power. It may be because that, when the wavelength of signal pulse is away from the gain peak of Yb-doped fiber, the large pump power will transfer to strong ASE noise instead to the signal.

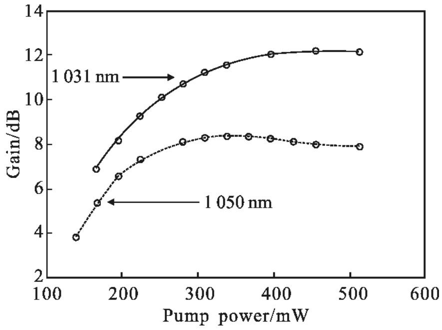


Fig.5 Amplifier gain versus pump power

The change of pulse width due to fiber amplification at signal wavelength of 1 026 nm is showed in Fig.6. The pulse is broadened slightly for group-velocity dispersion accumulating in the gain fiber. But the spectral and temporal distortions of pulse seed induced by amplification are not serious, anditcan suppose that the shape of the output pulse is almost the same as the input one.

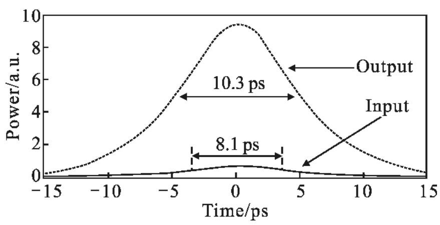


Fig.6 Autocorelation traces and durations of input and output pulse

2 Conclusion

We have investigated the amplification of tunable ANDi Yb-doped mode-locked fiber laser. It is found that the signal near 1 030 nm would get the largest gain, and the gain would decrease with the increase of wavelength. The uneven gain spectrum of Yb-doped fiber will lead to the distortion of signal spectrum. The spectral and temporal of pulse seed are both broaden for nonlinear phase shift and linear dispersion accumulating in the fiber amplifier. The signal gain will reach saturation point when the pump power is large enough.

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