Multiwavelength mode-locked SOA fiber laser operating at 16 ch × 10 GHz

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We present a multiwavelength mode-locked fiber ring laser incorporating two semiconductor optical amplifiers (SOAs) and a segment of dispersion-compensating fiber (DCF). One SOA is modulated by an injected external optical signal act as loss modulator and assistant gain medium. The other SOA is not modulated by injected signal and services in main gain medium. Two SOAs synchronously provide cavity gain for high repetition rate multiwavelength oscillation. A segment of commercial DCF is employed to introduce intracavity dispersion and functions as a self-tuned comb filter. Our laser source can generate 16 synchronized wavelength channels, and each channel is mode-locked at 10 GHz. 16 wavelengths from 1581.96 to 1597.52 nm are with a power deviation of about 4 dB and average width of mode-locked pulses is 39 ps. Oscillation wavelengths can be smoothly tuned and the output power are rather stable.

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Keywords: Multiwavelength, Mode-locked fiber laser, Semiconductor optical amplifier (SOA), Dispersion-compensating fiber (DCF)

1. Introduction

The rapid growth in bandwidth demand from optical fiber network systems has intensified research for high bit rate multiwavelength laser sources [1], and the need to extend the bandwidth of dense WDM systems has resulted in research of new transmission waveband, such as longer waveband (L-band, 1570 to 1610nm) within the low-attenuation window which can effectively double the potential bandwidth. Actively mode-locked fiber ring laser is an effective way to generate multiwavelength short optical pulses at high repetition rate. A lot of approaches have been developed for increase the product of channel number and repetition rate of multiwavelength laser sources [2-7]. On the one hand, ones may increase channel repetition rate by using high repetition frequency modulator, also may utilize rational harmonic mode locking technology to acquire channel repetition rate multiplication [3]. Moreover, In general, channel repetition rate is higher, mode-locked pulse obtained is shorter, which is very advantageous for high bit rate multiwavelength operation. On the other hand, in order to realize multiwavelength oscillation, various comb filters were incorporated to ring cavity, such as Fabry- Pérot (FP) filter [2, 3], Lyot filter [4], dispersion- compensating fiber (DCF) [5, 6], and so on.

In multiwavelength mode-locked fiber ring laser, cavity gain often is provided by Erbium-doped fiber amplifier (EDFA) [6, 7] or semiconductor optical amplifier (SOA) [2, 3, 5, 8]. The gain spectrum of EDFA is with a flat profile, which is especially important for multiwavelength operation. But, because gain of EDFA is also with a homogeneous character, special measures must be adopted to mitigate the mode competition in multiwavelength operation, which results in system complication and high cost. SOA has the property of primarily inhomogeneous broadening, and SOA-based multiwavelength fiber lasers exhibit stable operation without any assistant measures. In addition, to acquire high repetition rate, lithium niobate ($LiNbO_3$) modulator frequently is used in multiwavelength mode-locked source. But, $LiNbO_3$ modulator need be driven by radio frequency (RF) signal, however, it is very difficult to generate RF signal with high frequency. Moreover, $LiNbO_3$ modulator is with strong polarization dependence, which is disadvantage for stability of multiwavelength operation, and mode-locked pulse generated by active mode-locked source using $LiNO_3$ modulator is relatively broad too. Since gain of SOA can be modulated by an external injection optical signal, potentially ultrashort mode-locked pulses with high repetition rates can be readily obtained in SOA fiber ring laser [8].

In this paper, we present a multiwavelength mode-locked fiber ring laser incorporating two SOAs and a segment of DCF. In our setup, One SOA is modulated by an injected external optical signal and act as a twofold role, namely, loss modulator and assistant gain medium. The other SOA is not modulated by injected signal, services in main gain medium. Two SOAs synchronously provide cavity gain, which is necessary for high repetition rate multiwavelength oscillation. A segment of commercial DCF is employed to introduce intracavity dispersion and functions as a self-tuned comb filter [9]. Our laser source can synchronously generate 16 wavelength channels, and each channel is mode-locked at 10 GHz. Oscillation wavelengths can be smoothly tuned and the output power is rather stable.

2. Experimental setup

A schematic diagram of our experimental setup is depicted in Fig 1.

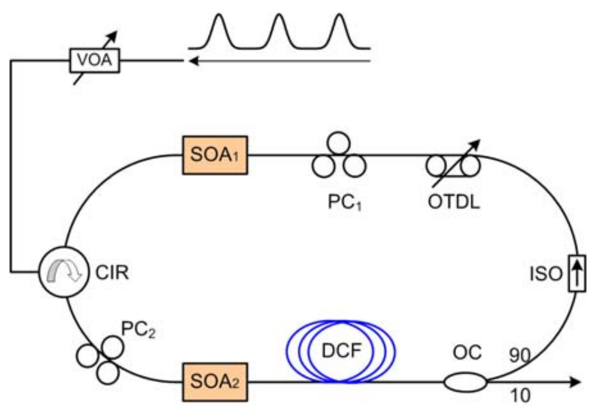


Fig. 1. Experimental setup. SOA: semiconductor optical amplifier; DCF: dispersion compensating fiber; CIR: circulator; ISO: isolator; TODL: tunable optical delay line; PC: polarization controller; OC: optical coupler; VOA: variable optical attenuator.

The laser cavity are formed by two SOAs, a segment of DCF, a circulator (CIR), an isolator (ISO), a tunable optical delay line (TODL), two polarization controllers (PCs) and a 10/90 optical coupler (OC). A 10-GHz external pulse train at 1549 nm is injected into the cavity via a variable optical attenuator (VOA) and a CIR. SOA_1 is modulated by injected external optical signal, acts as loss modulator and assistant gain medium. The CIR and ISO allow the light to propagate unidirectionally and ensure only the SOA_1 being modulated. SOA_2 purely services in gain medium. The SOA_1 can provide the small signal gain of about 24dB at 1588 nm driven by a 250-mA current source. Whenas, the SOA_2 can provide the small signal gain of about 25 dB at 1588 nm driven by a 250-mA current source. SOA_1 and SOA_2 respectively have polarization sensitivity of 0.5 dB. The two SOAs with inhomogeneous broaden property simultaneously provide cavity gain, which is very necessary for multiwavelength operation. The two PCs are used inside the cavity to optimize operation. The DCF supplies different effective cavity lengths for different wavelengths. The total dispersion of the DCF is about 87 ps/nm, and it services in a self-tuned comb filter. TODL is with maximum delay time of 300 ps and is utilized to adjust the cavity length for obtaining more wavelength oscillation and wavelength tunable. The fundamental frequency of the fiber ring laser is 0.277 MHz at the wavelength 1588.28 nm, and the corresponding optical length of the ring cavity is calculated to be 1.083 km. A minority of the light is extracted out by using a 10:90 output coupler, and is monitored by an optical spectrum analyzer (OSA, Anritsu MS9710C), and a communications signal analyzer (CSA, Tektronix 8000B).

3. Results and discussion

Bias current of the two SOAs were 250 mA. In general, a broader pulse trains are injected into ring cavity to modulate spontaneous emission field in SOA by cross gain modulation (XGM), which are able to result in a narrower mode-locked pulse train generation. To investigate external optical power influence on mode-locking behaviour, we gradually increased external optical power from 0 mA. The dynamics of the harmonic mode-locking are shown in Fig. 2.

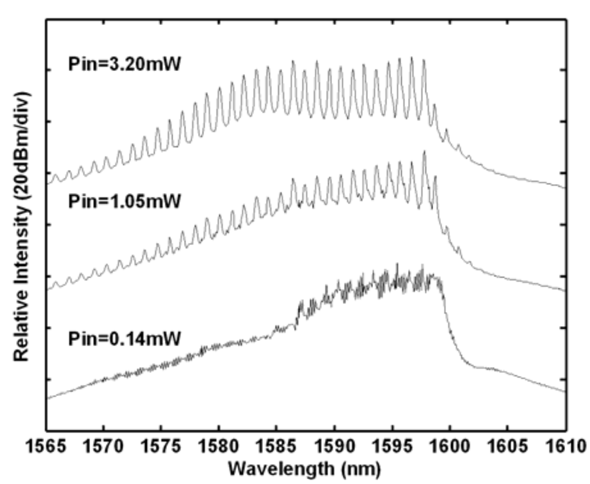
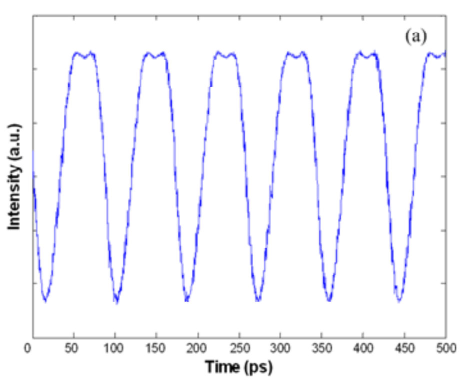
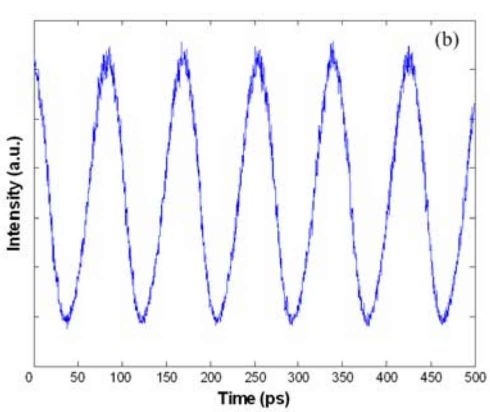


Fig. 2. Dynamics of the harmonic mode-locking.

When the power of the external pulse was very small, the multiwavelength operation on continuous waves (CWs) was achieved. With increasing of the injected power, the multiwavelength CW operation was suppressed and the multiwavelength mode-locked pulse trains were achieved. Sixteen wavelengths began to be synchronously mode-locked when the injected power was increased to 1.5 mW. When the injected power was continuously increased to 3.2 mW, 16-wavelength oscillation had already been rather sturdy, whose range was from 1581.96 to 1597.52 nm and are with a power deviation of about 4 dB. Wavelength spacing was about 1.04 nm, which agreed well with the theoretical value 1.10 nm, as the modulation frequency was 10 GHz and the total dispersion is 90 ps/nm (including 3 ps/nm dispersion contributions from the remaining part in addition to DCF in ring cavity). With the injected power continuously increasing, gain of the SOA_1 was rapidly saturated and mode-locked pulses no long happened to obvious change. Fig. 3 shows the waveforms of injected external optical signal and 10GHz multiwavelength mode-locked pulses. Fig. 3(a) depicts the waveform of injected external optical signal, which is with a pulse width of about 55 ps. Fig. 3(b) depicts the waveforms of 10GHz multiwavelength mode-locked pulses, average width of mode-locked pulse estimated by the digital sampling oscilloscope is 39 ps, and the output average power was about 5.4 dBm.



(a)



(b)

Fig. 3. Waveforms of injected external optical signal and multiwavelength mode-locked pulses.

Fig. 4 shows the repeatedly scanned spectra of the multi-wavelength mode-locked fiber laser output. A total of ten measurements were made at five minutes' interval. The output power was rather stable and the temporal power fluctuation was less than 0.6 dB, which owe to polarization insensitive devices being employed in ring cavity.

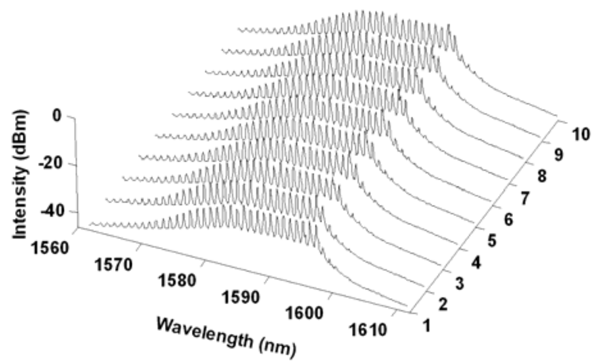


Fig. 4. Repeatedly scanned output spectra of the multiwavelength mode-locked fiber laser.

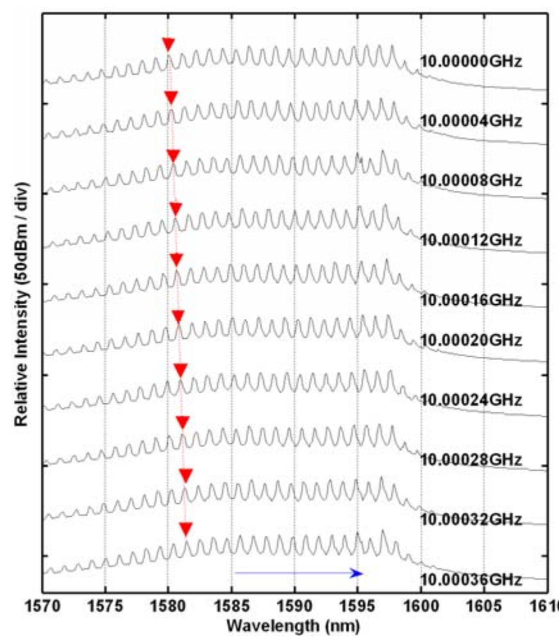


Fig. 5. Spectra shift of the 16-wavelength by varying the modulation frequency.

Fig. 5 shows the spectra shift of the 16-wavelength when the modulation frequency was tuned from 10.00000 to 10.00036 GHz at frequency spacing of 0.00004 GHz. The 16 wavelength profiles simultaneously shifted in the same direction with fixed wavelength spacing, which is able to be explained as that when the external modulation frequency or the length of the TODL is changed, the wavelength components satisfying the harmonic mode-locking condition are changed consequently. By this means, oscillation wavelengths can be smoothly tuned to appointed wavelengths.

4. Conclusions

A 10 GHz multiwavelength mode-locked SOA fiber laser operating at 16 channels have been presented and shown. Because SOA is modulated by external optical signal acts as loss modulator, multiwavelength short pulse train with higher repetition rate can be readily obtained. By further optimizing system parameters such as ring cavity dispersion, a more channel and shorter mode-locked pulse train can be acquired. Presented method can still be used to other scopes, including optical sensing, optical instrumentation, and so on.

Acknowledgements

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