Narrow-Linewidth Laser and Photonic Microwave Generation using a Monolithic Integrated Amplified Feedback Laser with Delayed Optical Feedback

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Abstract A multifunctional narrow-linewidth laser and photonic microwave generation using a monolithic integrated amplified feedback laser under delayed optical feedback is demonstrated. The device can work in signal-mode and dual-mode states by varying the injection currents of laser sections. Photonic microwave is generated by mode-beating of the two laser modes. Through a dual-loop all-optical feedback, the linewidths of both the signal-mode optical signal and photonic microwave signal are reduced by more than three orders of magnitude. Single mode operation with 2.6 kHz linewidth and photonic microwave generation at 37.97 GHz with 1.6 kHz linewidth are experimentally realized.

Key words lasers; microwaves; distributed feedback lasers; injection-locked lasers, integrated optics devices

OCIS codes 140.3490; 140.3520; 130.3120

基于光反馈单片集成放大反馈激光器的窄线宽激光和微波信号产生

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摘要 提出了一种基于单片集成放大反馈激光器在光反馈的条件下产生窄线宽激光和窄线宽微波信号的方法。在不同的注入电流下,放大反馈激光器可以实现稳定的单模和双模激射。单模激射下,器件的激射波长为 1546.6 nm,边摸抑制比可达 54.2 dB,线宽为 9.59 MHz。双模激射下,模式间距为 0.3 nm,对应拍频频率为 37.6 GHz,拍频线宽为 4.2 MHz。通过引入一个双环光纤外腔,可以将放大反馈激光器输出的光信号反馈回激光器,提高整个复合腔的光子寿命,从而压缩光信号的线宽。在合适的反馈强度下,单模工作时光信号的线宽从 9.95 MHz减小到 2.6 kHz。双模工作时拍频信号的线宽从 4.2 MHz 减小到 1.6 kHz,均减小三个数量级以上。

关键词 激光器;微波;分布反馈激光器;注入锁定激光器;集成光学器件

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1 Introdution

Fast growing internet and mobile communication traffic result in booming demand for high speed, high bit rate fiber transmission system and wireless access networks[1]. High-order modulation formats and coherent detection are promising technologies to increase the spectral efficiency of optical transmission

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systems[2-3]. In such systems, the demand for narrow linewidth lasers becomes more stringent[4-5]. High quality narrow linewidth laser can also be useful in microwave generation applications, the simplest way of which is to heterodyne two narrow laser sources[6-7].

As a simple monolithic integrated device, amplified feedback laser (AFL) can function as a single mode laser or a dual-mode beating photonic microwave generator[8-9], depending on the currents injected into each laser sections[10]. However, the linewidth of both single mode and photonic microwave signal from the AFL are usually around a few MHz, which is under the requirements for many applications. In order to realize narrow linewidth operation, a dual-loop fiber ring cavity to increase the Q factor of laser cavity is introduced. Since the AFL can work in single mode state as well as dual mode state, a multifunctional device capable of generating both narrow-linewidth optical and photonic microwave signal is realized. As a narrow-linewidth laser, it can be used in coherent communication systems or sensor applications. As a narrow-linewidth photonic microwave generator containing two narrow-linewidth laser tones, it can find possible applications in radio over fiber (ROF) systems.

Using dual-loop delayed feedback scheme as shown in Fig. 1, the linewidth of both single-mode state and mode-beating state are reduced from MHz to kHz scale. Single mode operation with 2.6 kHz linewidth and photonic microwave generation at 37.97 GHz with 1.6 kHz linewidth are experimentally realized.

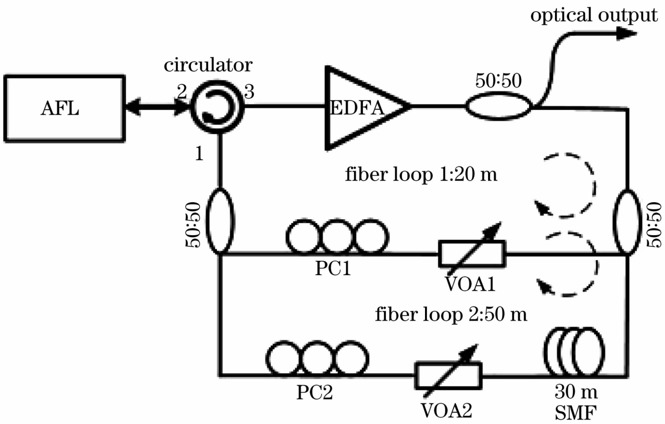

Fig. 1 Configuration of narrow linewidth laser and photonic microwave generation using AFL with optical feedback. EDFA: Erbium doped fiker amplifier; VOA: variable optical attenuator; PC: polarization controller; PD: photodetector; SMF: single mode fiber.

2 Experimental scheme

Figure 2 shows the schematic diagram of the AFL. It is designed to consist of a DFB section, a phase section and an amplifier section with lengths of 220, 240 and 320 μm, respectively. Each laser sections are independently driven by DC currents, as I_{DFB}, I_P and I_A. Detailed fabrication and performances of the AFL have presented in Ref. [4].

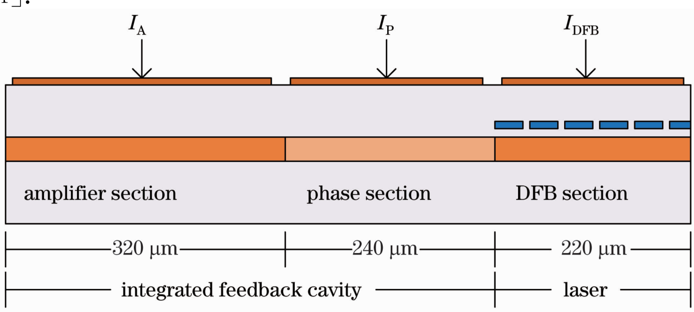

Fig. 2 Schematic view of the AFL.

The dual-loop feedback scheme is illustrated in Fig. 1. The fiber cavity consists of two parallel fiber-ring-cavity to obtain optical feedback. The different loop lengths are used to suppress the unwanted fiber cavity modes and realize single mode output. The total lengths of the two fiber loops are chosen to be 20 and 50 m, respectively. In each of the fiber loop, a VOA is used to control the optical strength, and a PC is used to adjust the polarization state of the optical signal. The linewidth of the signal mode optical signal is measured by delayed self-heterodyne method with a delayed fiber length of 60 km. Photonic microwave signal is detected by a PD and then measured by an RF spectrum analyzer.

3 Experimental results

When adjust the current injected into the AFL, single mode, dual mode and other states, including period oscillation and chaos state, can be obtained. Figure 3 shows the dynamic state mapping of the AFL in the plane of I_{DFB}, and I_A, where the phase current I_P is fixed at 0 mA.

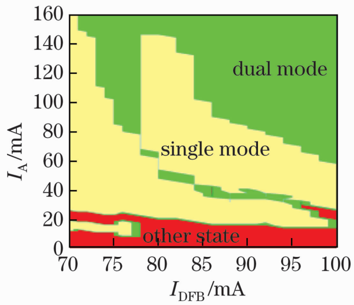

Fig. 3 Dynamic state mapping of the AFL in the plane of I_{DFB} and I_A, where I_P is fixed at 0 mA.

3.1 Linewidth reduction of single-mode laser

The single mode state of AFL is investigated. The optical spectrum is shown in Fig. 4(a), where the AFL is biased at (I_{DFB}, I_p, I_A) = (70, 0, 40) mA. The device lasing at 1546.6 nm with the side mode suppression (SMSR) of 54.2 dB. In free running state is shown in Fig. 4(b), the linewidth of the laser is 9.59 MHz, measured using delayed self-heterodyne method. When the feedback loops are employed, the laser linewidth is significantly reduced. As shown in Fig. 4(c), the resultant linewidth is 2.62 kHz, reduced more than 3000 times compared with free running state.

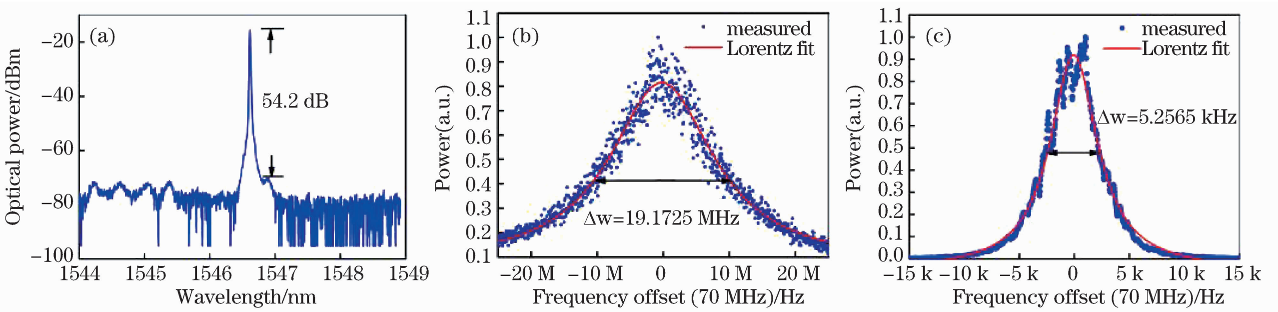

Fig. 4 (a) Optical spectrum of AFL under single mode state, when (I_{DFB}, I_P, I_A) = (70, 0, 40) mA. RF spectrum along with Lorentz fitting for single mode AFL under free running state (b); optical feedback state(c).

3.2 Linewidth reduction of photonic microwave signal

In dual-mode state, the optical spectrum is shown in Fig. 5(a). Beating of the two main modes at the PD generates a microwave signal at 37.6 GHz as shown in Fig. 5(b). The 3-dB linewidth of free running state is 4.2 MHz. After dual-loop feedback, the resultant power spectrum is shown in Fig. 5(c). A microwave signal at 37.97 GHz with the 3-dB linewidth of 1.6 kHz is realized through feedback, which is reduced more than 2500 times compared with original free running state.

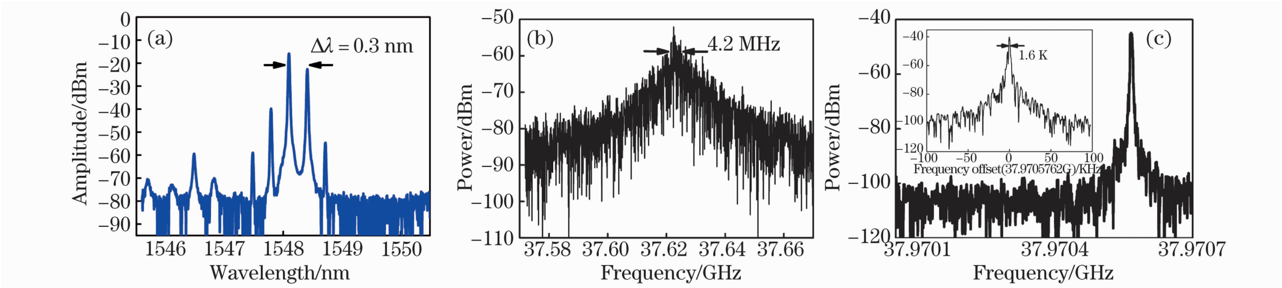

Fig. 5 (a) Optical spectrum of AFL under dual-mode station, when (I_{DFB}, I_P, I_A)=(95.5, 0, 160) mA. (b) RF spectrum of free running dual-mode AFL. (Span: 50 MHz; RBW: 100 kHz) (c) RF spectrum of dual-mode AFL under optical feedback. Insert: zoom in RF spectrum of AFL with 200 kHz span and 1 kHz RBW.

To examine the stability of the output microwave signal, the frequency and power versus time are measured at a time interval of 1000 s, with 10 s sampling rate. As the results illustrated in Fig. 6, the microwave signal is relatively stable in 1000 s time interval. The [root mean square (RMS)] frequency and power hopping can be calculated using:

$$\sigma(\tau)=\sqrt{\frac{\sum_{i=1}^{N}(\nu_{i+1}(t)-\nu_i(t))^2}{N}},\tag{1}$$

where ν_i is microwave frequency or power at each sampling point, and N is the number of samples. The calculated relative frequency instability is 2.67×10^{-3}, and the power hopping is 0.19 dB.

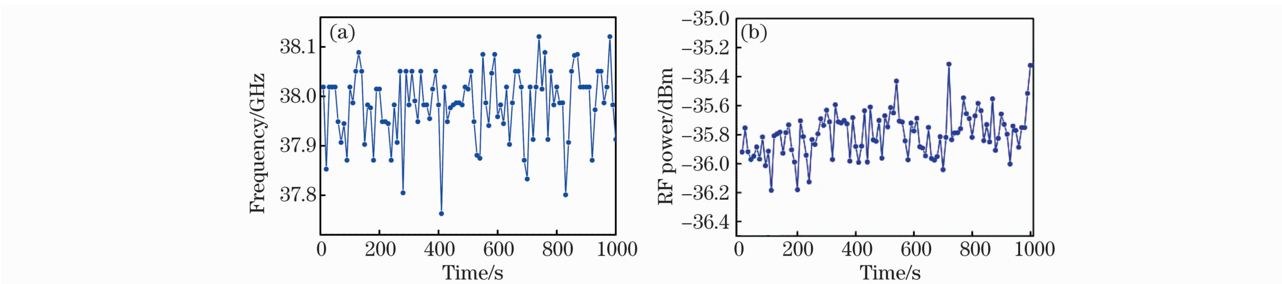

Fig. 6 Microwave stability measurement. (a) Frequency fluctuation versus time; (b) power fluctuation versus time.

4 Conclusion

In conclusion, a narrow linewidth laser source and photonic microwave generator using a monolithically integrated AFL with optical feedback are proposed and demonstrated. By employing a dual-loop fiber-ring external cavity, single mode operation with 2.6 kHz linewidth and photonic microwave at 37.97 GHz with 1.6 kHz linewidth is experimentally realized. The measured frequency instability and power hopping are 2.67×10^{-3} and 0.19 dB at 1000 s time interval, respectively. These results show the potential application of AFL in the development of compact and low-cost narrow linewidth source as well as photonic microwave generator.

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