Frequency and wavelength tunable optical microwave source based on a distributed Bragg reflector self-pulsation laser*

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Abstract: A frequency and wavelength tunable self-pulsation laser based on DBR laser devices is reported for the first time. This laser generates continuous tunable optical microwave in the range of 1.87–21.81 GHz with 3-dB linewidth about 10 MHz by tuning the injection currents on the front and back gain sections, and exhibits wavelength tuning range from 1536.28 to 1538.73 nm by tuning the injection currents on the grating section.

Key words: distributed Bragg reflector laser diode; self-pulsation laser; optical microwave sources; quantum-well intermixing

DOI: 10.1088/1674-4926/31/6/064007 **EEACC:** 2520

1. Introduction

Optical microwave sources are required for several applications in optical signal processing such as clock recovery, the control of add-drop multiplexers in optical time division multiplexed (OTDM) systems, and radio on fiber (RoF) systems; they are also key functional components for all-optical networks. Optical microwave sources have many advantages compared to electronic solutions, including high speed, low power consumption, low cost and high reliability. There are several solutions for optical microwave generation such as mode-locked lasers (MLLD)[1, 2], multi-section DFB self-pulsation lasers (SPL)[3, 4] and amplified feedback lasers (AFL)[5]. Moreover, separated DBR lasers with a Y branch can also be used as optical microwave sources, but their power consumption is much greater than that of monolithically integrated devices.

Tunability is another key requirement for many applications. For wavelength division multiplexed (WDM) optical communications, wavelength tunable optical microwave sources are desired, while for OTDM systems, frequency tunable optical microwave sources are required in order to satisfy the predetermined transmission line rates[6]. In the optical microwave sources mentioned above, DBR MLLDs have good wavelength tunability but their frequency tunability is only about 1 GHz[6]. DFB SPLs and AFLs have good frequency tunability but for a specific microwave frequency their wavelength tunability is limited by the DFB lasers[3−5].

In this paper, we demonstrate a kind of frequency and wavelength tunable self-pulsation laser based on a DBR laser for the first time, which generates continuous tunable optical microwaves in a range of 1.87–21.81 GHz with a 3-dB linewidth about 10 MHz and exhibits a wavelength tuning range from 1536.28 to 1538.73 nm. Compared to the DFB SPLs and AFLs, a quantum-well intermixing (QWI) step is added in the device fabrication process; however, wavelength tuning is induced in our device, which makes its application more flexible than any of the optical microwave source schemes mentioned above.

2. Device structure and fabrication

A schematic illustration of the DBR self-pulsation laser chip is shown in Fig. 1. The device is fabricated by two-stage metal organic vapor phase epitaxy and has a ridge waveguide structure with five separate sections. The front gain 1 section and back gain 2 section are both 300 μm long, the active layers of which are composed of the same MQW structure with eight 5.5 nm compressively strained quantum wells and nine 11.5 nm barriers and are sandwiched between two 120 nm 1.3Q waveguide layers. The length of the front and back phase sections are 160 μm and 120 μm, respectively, and the length of the grating section is 400 μm. In the phase and grating sections, QWI is carried out by P^+ implantation and the rapid thermal annealing (RTA) process and a blue shift of 90 nm is achieved relative to the gain sections. The separation between each section is 20 μm, which was implanted by protons and gives 40 kΩ electrical isolation. Both front and back output facets are left uncoated.

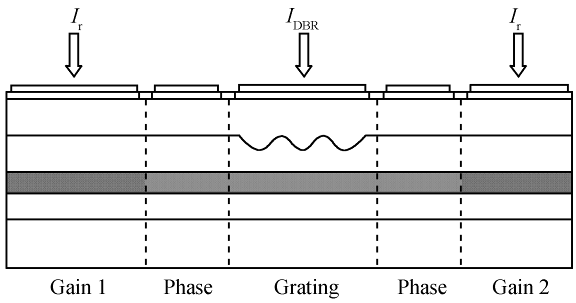

Fig. 1. Schematic diagram of the DBR self-pulsation laser.

* Project supported by the National High Technology Research and Development Program of China (Nos. 2006AA01Z256, 2007AA03Z419, 2007AA03Z417), the State Key Development Program for Basic Research of China (Nos. 2006CB604901, 2006CB604902), and the National Natural Science Foundation of China (Nos. 90401025, 60736036, 60706009, 60777021).

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Received 26 November 2009, revised manuscript received 11 January 2010

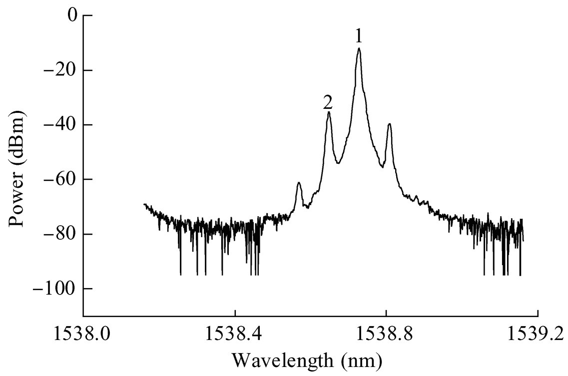

Fig. 2. Typical optical spectrum of the device. $I_{\rm f}$, $I_{\rm r}$ and $I_{\rm DBR}$ are 108.3 mA, 106 mA and 9 mA respectively.

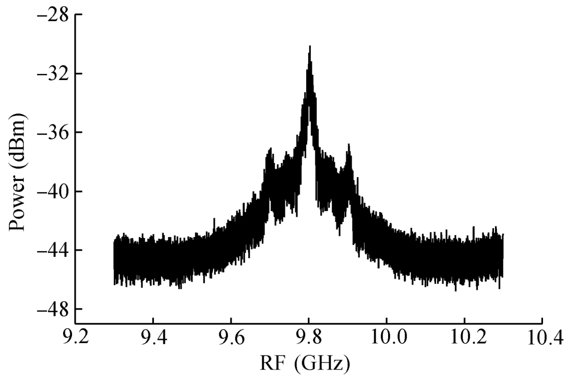

Fig. 3. Typical RF spectrum of the device. $I_{\rm f}$, $I_{\rm r}$ and $I_{\rm DBR}$ are 108.3 mA, 106 mA and 9 mA respectively and the 3-dB linewidth is about 10 MHz. Measured by RB = 300 kHz, VB = 10 kHz.

The front gain 1 section and the grating section form the front DBR laser, while the back gain 2 section and the grating section form the rear DBR laser. When operated individually, the threshold currents of the front and rear DBR lasers are measured to be 30 mA and 35 mA, respectively. At a current of 100 mA injected into gain 1 section singly, the optical power of the front DBR laser is 8 mW. The self-pulsation characteristics of the device are investigated when both the front and rear DBR lasers are driven above their threshold currents, the DBR section is also injected by independent DC current sources, and the temperature of the device holder is kept at 25 ℃. The light from the facet of section gain 1 was coupled into a tapered single mode fiber and tested by an optical spectrum analyzer or a radio frequency (RF) spectrum analyzer through a high-speed photodiode up to 22 GHz.

3. Device performance

Figures 2 and 3 show the typical optical spectra and the RF spectrum, which are obtained when the gain 1 section, gain 2 section and grating section are at 108.3 mA, 106 mA and 9 mA current injection respectively. Peak 1 in Fig. 2 is 1538.727 nm, which belongs to the front DBR laser, and peak 2 is 1538.647 nm, belonging to the rear DBR laser. The wavelength detuning ($\Delta\lambda$) between peaks 1 and 2 is 0.08 nm, and according to the relationship between frequency domain and wavelength domain, $f = c\Delta\lambda/\lambda^2$, where c is the velocity of light and λ is the wavelength of the lasing mode, the beat frequency of these two modes in theory is about 10 GHz, which fits well with the experimental result in Fig. 3.

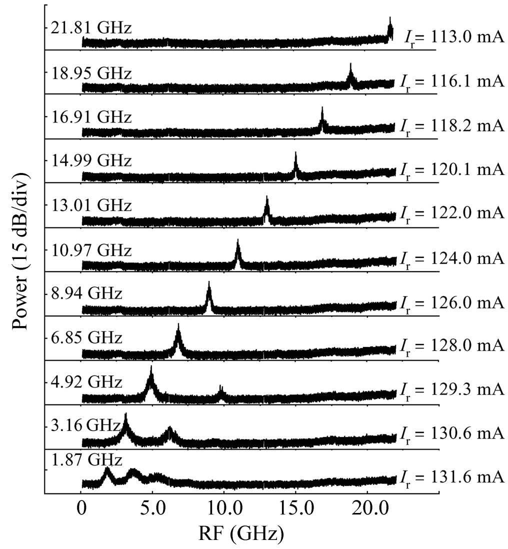

Fig. 4. RF spectra of the device. $I_{\rm f}$ and $I_{\rm DBR}$ are fixed at 108.3 mA, 9 mA with $I_{\rm r}$ varied as denoted. Measured by RB = 3 MHz, VB = 300 kHz.

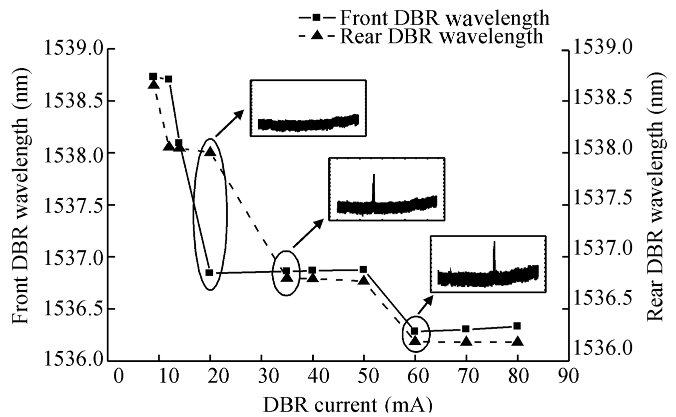

Fig. 5. Wavelength tuned by the increase of $I_{\rm DBR}$.

When the injected currents on gain 1 section ($I_{\rm f}$) and grating section ($I_{\rm DBR}$) are fixed and the injected current on gain 2 section ($I_{\rm r}$) is increased, redshift happens to the rear DBR laser, $\Delta\lambda$ will decrease and the self-pulsation frequency will decrease. Figure 4 shows that the self-pulsation frequency increases from 1.87 to 21.81 GHz when $I_{\rm r}$ decreases from 131.6 to 113 mA while $I_{\rm f}$ and $I_{\rm DBR}$ are fixed at 108.3 mA and 9 mA respectively. When $I_{\rm r}$ is larger than 131.6 mA, the self-pulsations will disappear, and when $I_{\rm r}$ is smaller than 113 mA, the detection limit of our electrical spectrum analyzer is reached. When $I_{\rm r}$ and $I_{\rm DBR}$ are fixed and $I_{\rm r}$ is increased, redshift happens to the front DBR laser, $\Delta\lambda$ will increase and the self-pulsation frequency will increase.

When $I_{\rm DBR}$ increases from 9 to 80 mA, the emitting wavelength tunes from 1538.73 to 1536.28 nm and the mode hops 3 times, as shown in Fig. 5. Self-pulsation appears at all wavelength ranges but not at all gating injection currents. We can see that self-pulsation only happens when the wavelengths of the front and rear DBR lasers are at the same mode, and if only one hops because of the increasing I_{DBR}, self-pulsation will disappear. Although the change of the wavelength will cause the shift of the self-pulsation frequency, all frequencies in the microwave tuning range of the device can be obtained by tuning I_r or I_f.

4. Conclusion

In conclusion, wavelength tunable self-pulsation lasers based on DBR laser devices have been fabricated. A microwave tuning range of 1.87–21.81 GHz self-pulsation frequency with a 3-dB linewidth about 10 MHz with a wavelength tuning range of 1536.28–1538.73 nm is achieved.

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