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40nm Quasi-Continuous Wavelength Tuning of V-cavity Semiconductor Laser

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Abstract. Full band quasi-continuous wavelength tuning with ~36dB side mode suppression ratio of V-cavity semiconductor laser is reported. A simple and general tuning algorithm employing only two electrodes to control the frequency combs shifting synchronously is presented and demonstrated, respectively.

1. Introduction

Tunable lasers with large quasi-continuous tuning is important for biomedical and spectroscopy applications. So as to achieve good performance, many structures have been presented, such as sampled grating distributed Bragg reflector (SGDBR) laser, modulated grating Y-branch (MG-Y) laser, digital super-mode (DS) DBR laser and distributed feedback (DFB) laser array. However, all these grating-based structure require multiple epitaxial growth and complex tuning algorithm. Recently, a compact V-cavity tunable semiconductor laser was proposed [1]. Single-electrode controlled wavelength tuning of 16 and 26 consecutive channels with 100GHz spacing was demonstrated experimentally with an excellent side-mode-suppression-ratio (SMSR) of about 40 dB and 37dB, respectively [2]. Temperature induced gain spectrum shift is employed in combination with the Vernier tuning mechanism to extend the digitally wavelength tuning range to cover the full C-band [3]. The V-cavity tunable laser is an all-active device with no grating or ring resonators, and therefore it does not require any epitaxial regrowth. The fabrication process is similar to simple Fabry-Perot lasers and the device length is less than 0.5 mm.

In this paper, we proposed an easy current control algorithm which only need two electrodes to achieve quasi-continuous tuning in V-cavity tunable laser. At fixed temperature, 16nm quasi-continuous tuning range is obtained. By 49ºC temperature variation, the quasi-continuous tuning range can be extend to 40nm with ~36 dB SMSR, covering the full C-band.

2. Tuning algorithm

The V-cavity laser was designed and fabricated in InGaAsP/InP multiple quantum well structure. It comprises two F-P cavities with different optical path lengths, which form V-shaped branches with a reflective 2 ×2 half-wave coupler, as shown in Figure.1. The length of the short cavity (fixed gain cavity) is designed to be 466 μm to match its resonant wavelengths to the ITU grid of 100GHz spacing. The long cavity (channel selector cavity) is 5% longer so that the Vernier effect can be used to extend the tuning range. Three deep etched facets are used as the cavity mirrors [2]. The half-wave coupler consists of a non-imaging multimode interference (MMI) structure with an optimal coupling coefficient to ensure high side-mode-suppression-ratio (SMSR). Three electrodes separated by isolation gaps are fabricated on the top side and common electrode is deposited on back side. The digital wavelength tuning is accomplished through thermos-optic effect, thereby tuning the lasing wavelength to one of the resonant wavelengths of the short cavity by aligning it to one of the resonant wavelengths of the long cavity [3].

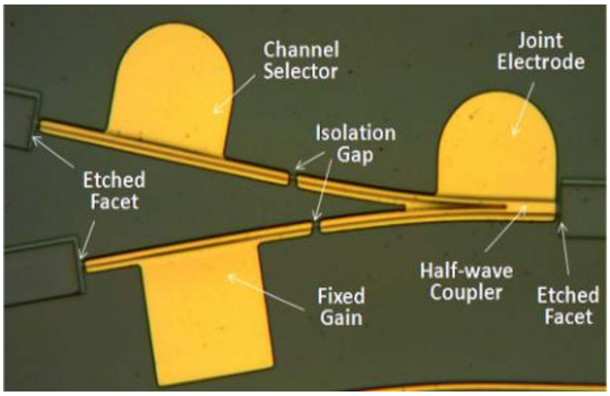

Figure 1. Optical microscope image of V-cavity laser.

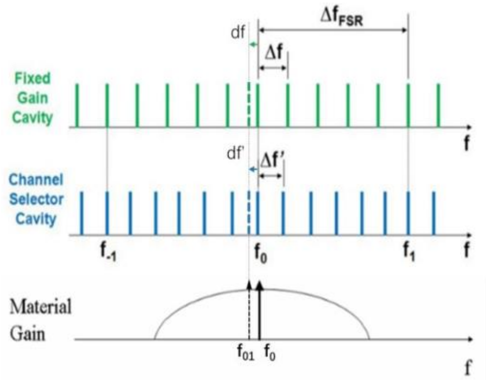

Figure 2. Schematic diagram of the synchronous frequency combs shift.

As shown in Figure.2, in order to achieve quasi-continuous tuning in V-cavity laser, the resonant frequency combs of the two cavities should be tuned synchronously with the same tuning speed (df=df') to avoid mode hop [4]. We only need to tune the wavelength combs of two cavities synchronously by one channel spacing (i.e.100 GHz) before jumping to the setting currents for the next channel where the next resonant peak of long cavity coincides with the next resonant peak of short cavity. Splicing multiple fine tuning sections of 100GHz spacing, we are able to obtain a large quasi-continuous tuning range.

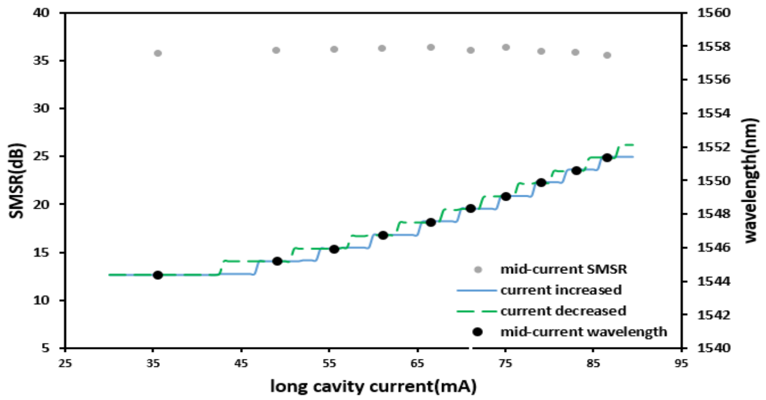

Figure 3. Choosing the working points of each channels

Figure.3 show the wavelength as a function of increased current and decreased current in long cavity respectively, with the short cavity current fixed. Digital tuning with 100GHz spacing is visible. The effects of hysteresis are also obviously visible. To avoid mode hop and ensure high SMSR during the quasi-continuous tuning, we choose the mid-currents of the overlapping regions of current increased and current decreased single electrode tuning channels as the setting currents. These currents are supposed to obtain the highest SMSR in each of channels. In this example, all mid-currents implemented ~35 dB SMSR. Changing the biased current of short cavity, we can obtain more setting currents with great SMSR by above-mentioned method.

By using the setting currents, we can construct the synchronous saw-tooth current functions for two tuning electrodes. Quasi-continuous tuning with good SMSR is able to implement by the current function. Current linear interpolation can be used to obtain smaller wavelength interval in quasi-continuous tuning.

The two electrodes tuning algorithm is also suitable for other V-cavity lasers theoretically, such as V-cavity laser with quantum well intermixed [5] and V-cavity laser with integrated thin-film heaters [6] .These V-cavity lasers are supposed to gain great promotion in power flatness and tuning speed.

3. Experimental results and discussions

We use the V-cavity laser in a XMD package with a thermal-electric cooler (TEC) for temperature control. The temperature is fixed at 35ºC, the coupler electrode is biased at 15 mA. Two synchronous saw-tooth waves are injected to short cavity and long cavity respectively. As shown in Figure.4, short cavity current varies from 35 mA to about 82 mA for each fine tuning sections, long cavity current increases about 50 mA for each fine tuning sections and the lowest current of fine tuning section slightly increases about 5 mA. In a word, tuning two currents synchronously for 40~50 mA will induce a continuous tuning with 100GHz.

Since the temperature coefficient of the gain spectrum shift to longer wavelength is about 0.5nm/K and the thermal-optic coefficient of the laser is about 0.1nm/K [3], the gain spectrum shift is 5 times faster than frequency combs shift when current increase, so that the mode at the short wavelength end of gain spectrum would hop to the next free spectral range (FSR) during the current fine increasing process. In order to achieve the continuous tuning for a free spectral range (~16nm), we set the short cavity current to vary from about 80 mA to about 120mA. The gain window would be aligned to next FSR. Long cavity injected current still follows the above-mentioned rule. Tuning range would be extended to cover 16nm with ~36 dB SMSR. The overlapped emission spectra of 16nm tuning with 0.06nm spacing is shown in Figure.5. The wavelength tuning range is limited by current range. Because of performance degradation at high current injection, we set the current less than 150 mA for each electrodes. According to our experiment, 16 nm is almost the largest range at a fixed temperature.

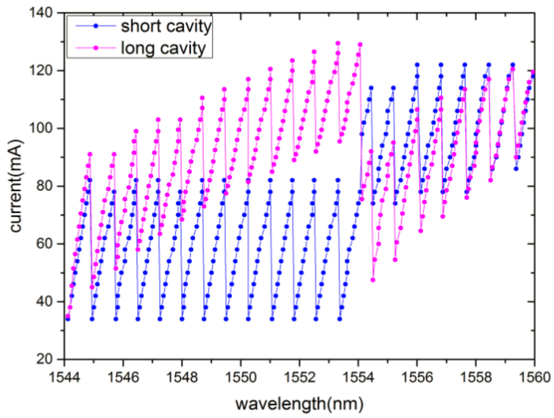

Figure 4. Measured quasi-continuous tuning curve.

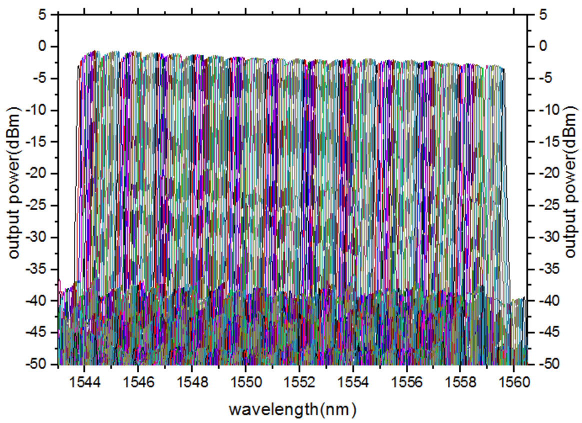

Figure 5. Overlapped laser spectra.

Because of 0.5 nm/K gain spectrum shift, the temperature varies 30ºC can extend tuning range for about 15nm. We set three temperature steps at 16ºC, 35ºC and 65ºC, and obtained quasi-continuous tuning range of 10.1nm, 15.8nm, 14.4nm, respectively, for a total of 40.3nm. The currents of two cavities both vary from 20 mA to 150 mA. Three wavelength tuning ranges are shown in Table.1. The laser which working at higher temperature outside the range from 16ºC to 65ºC cannot realize good performance, nor does it work at lower temperature. The wavelength and SMSR performance of full

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C-band wavelength quasi-continuous tuning are shown in Figure.6 and Figure.7, respectively. The SMSR over full band mostly above 33 dB and can be as high as 39 dB.

Table 1. Wavelength quasi-continuous tuning range and SMSR of three temperature steps

Temperature(℃)	wavelength(nm)	SMSR(dB)
16	1533.997-1544.126	35.3-39.0
35	1544.126-1559.946	33.2-37.7
65	1559.946-1574.332	33.6-37.3

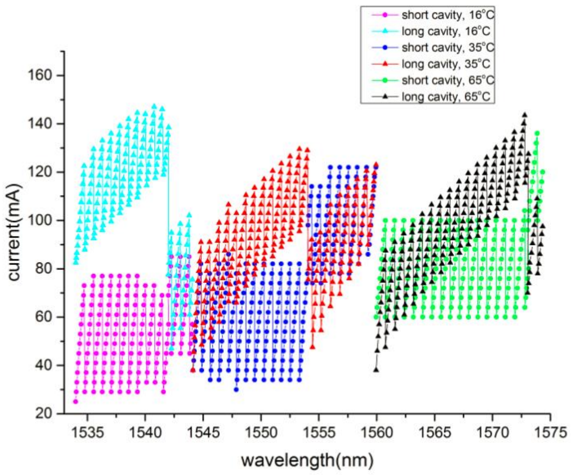

Figure 6. Quasi-continuous tuning curve for full band.

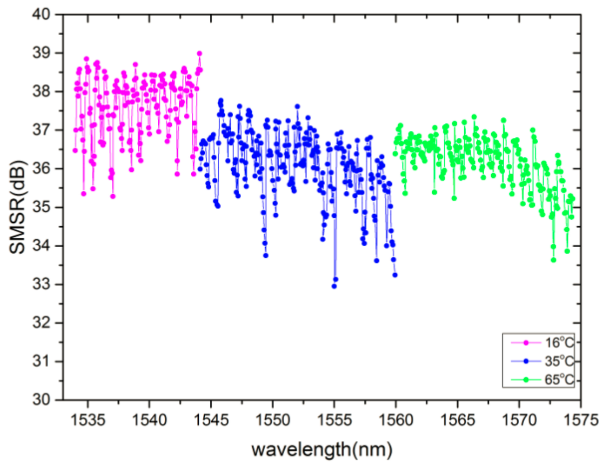

Figure 7. SMSR of full band quasi-continuous tuning.

4. Conclusion

In conclusion, we have realized the quasi-continuous tuning of the all-active V-cavity tunable laser. 16nm tuning range is achieved at a fixed temperature, 40nm tuning range is achieved at three temperature steps, with good single mode performance respectively. Simple tuning algorithm with two electrodes control allows the V-cavity semiconductor laser to be potentially used for dense wavelength division multiplexing (DWDM) networks, biomedical sensing and spectroscopy applications.

5. Acknowledgment

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