Full C-Band Tunable V-Cavity-Laser Based TOSA and SFP Transceiver Modules

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ABSTRACT

We report the latest development in tunable transmitter optical sub-assembly (TOSA) and small form-factor pluggable (SFP) transceivers based on simple and compact V-cavity laser (VCL), aiming for low-cost deployment in metro, access and data center networks. The VCL employs a half-wave coupler to achieve high side-mode suppression ratio (SMSR) and the Vernier effect to achieve a wide wavelength tuning range. Full C-band tuning from 1529.55-nm to 1566.31-nm with SMSR above 36 dB is demonstrated. Since the laser does not involve any grating or epitaxial regrowth, and has a simple tuning algorithm, it allows simpler processes for fabrication and testing as compared to other widely tunable laser structures. Compact TOSAs and SFP transceiver modules have been developed for full C-band tuning with up to 93 channels at 50 GHz spacing. Transmission experiments are carried out for direct modulation with data rates from 2.5 Gbps to 8.5 Gbps. The results of reliability tests of the modules are also presented.

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1. INTRODUCTION

Low-cost tunable transceiver modules are key enablers for next-generation wavelength division multiplexing (WDM) based metro, access and data center networks. Currently tunable lasers are mostly deployed in long-haul optical transmission systems due to their high cost resulting from fabrication and testing complexity for structures such as sampled grating distributed Bragg reflector (SGDBR) [1]-[2], superstructure grating (SSG) DBR laser [3], digital supermode DBR [4], modulated grating Y-branch [5], and MEMS based external cavity lasers [6]. For wide deployment of the WDM technology in metro, access networks and data center networks, the cost reduction of tunable transceivers has become a key issue. Recently, a simple and compact tunable V-cavity laser has been proposed and demonstrated [7]-[8]. It does not require complex grating and epitaxial regrowth. Its fabrication process is similar to that of Fabry-Perot lasers with only an additional step of deep etching for cavity mirrors. By using a specially designed half-wave coupler, single-mode operation with high side-mode suppression ratio (SMSR) of 35-40 dB has been achieved. In this paper, we report the latest development of tunable transmitter optical sub-assembly (TOSA) and small form-factor pluggable (SFP) transceiver modules based on the V-cavity laser, aiming for low-cost deployment in metro and access networks. The chip structure is improved, including output from a single mode waveguide branch for better fiber coupling, instead of output from the coupler side as in previous reports. The back side of the laser is metal-coated for high-reflectivity to reduce the threshold and improve the slope efficiency. Full C-band tuning of 93 channels with 50 GHz spacing has been demonstrated for the first time. The results of transmission experiments and reliability tests are also presented.

2. DEVICE STRUCTURE AND OPERATION PRINCIPLE

Figure 1 shows the top-view microscope photograph of the V-Cavity laser chip. It was designed and fabricated in InGaAsP/InP multiple quantum well structure without epitaxial regrowth or bandgap engineering. The detailed layer structure and fabrication process of this laser have been described in [8]-[9]. The V-cavity laser consists of two Fabry-Perot cavities with slightly different optical path lengths. The length of the fixed gain cavity is designed to be 450 μm to match its resonantwavelengths to the ITU grid of 100 GHz spacing. The channel selector cavity is 5% longer so that the Vernier effect can be used to extend the tuning range and achieve a large free spectral range (FSR) of about 20 channels. The two cavities are coupled through a half-wave coupler which is designed to have phase difference between bar-coupling coefficient and cross-coupling coefficient in the operating wavelengths to achieve high SMSR [10],[11]. In order to control the cavity lengths precisely, three deep etched facets are used as cavity mirrors. The output is emitted from the etched facet of the channel selector cavity.

The back facets on the coupler and on the fixed gain cavity are coated with high-reflective Au film after surface passivation. Three electrodes are deposited on the top surface while a common ground electrode is deposited on the back side. The channel selector electrode on the long cavity is used for wavelength tuning and the other two electrodes provide gain. The wavelength tuning is accomplished by current injection induced thermo-optic effect, which causes the refractive index change. The coupler electrode is also used for direct modulation. The ratio between the length of the waveguide covered by the coupler electrode and the cavity length are designed to be the same (e.g. 60% in the current design) for the two cavities [12], in order to minimize the wavelength chirp induced by the direct modulation and to avoid mode hops. Standard fabrication process for ridge waveguide Fabry-Perot lasers is used with the additional step of deep etching to make the reflective mirrors. The chip size is only about 500 mm * 350 mm.

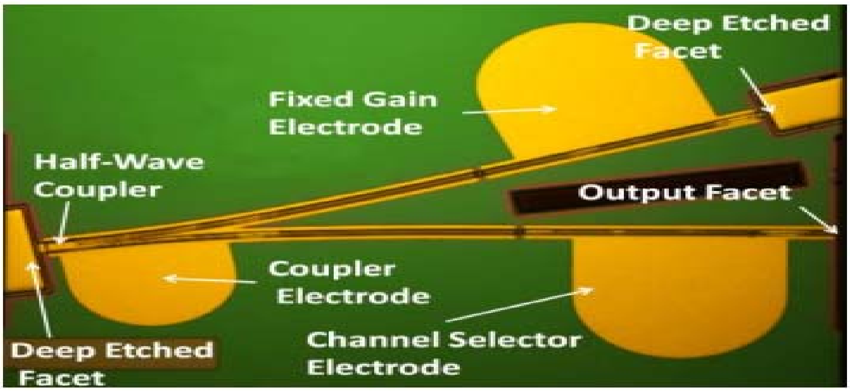

Figure 1. Microscope Photograph of the V-Cavity Laser Chip

3. EXPERMENTAL RESULTS AND DISSCUSSIONS

The laser reaches its threshold when the total current of the three electrodes is about 60 mA. Emission spectrum with 37 dB dynamic SMSR when the laser is modulated at 2.5 Gbps. The fiber coupled power of the module is about 6 dBm. By adjusting the current of the channel selector electrode and the TEC temperature control, we can obtain 47 channels from 1529.55-nm to 1566.31-nm of the ITU grid in 100 GHz spacing, covering the full C band. To access the 50 GHz spacing grid, we change the TEC temperature by about 4-5°C to tune to 46 channels from 1529.94-nm to 1565.9-nm, which are shifted by 50 GHz from the previous grid. By slightly adjusting the current of the coupler electrode, the output power of the channels can be balanced. The overlapped spectra of the 93 channels of the ITU grid with 50 GHz spacing are shown in Figure 2.

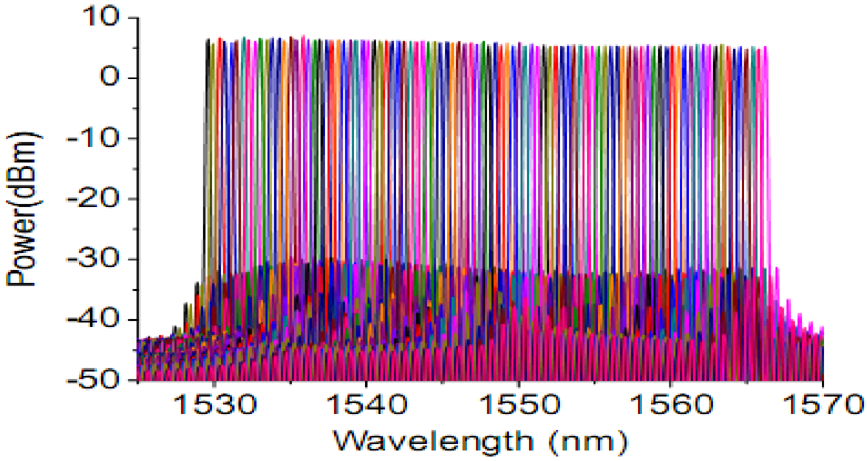

Figure 2. Measured Single Channel Spectrum

The dynamic SMSR is above 36 dB for all the channels when the laser is under 2.5 Gbps direct modulation. Most channels reach 38 dB. The dynamic SMSR degrades with increasing extinction ratio (ER) of the modulated signal. We typically limit the ER to 5~6dB so that the SMSR degradation is limited to 2~3 dB with respect to the static SMSRs when no modulation signal is applied. The wavelengths are tuned to the 93 channels in the ITU grid by adjusting the currents of the channel selector electrode from 25 mA to 148 mA and the TEC temperature between 27 ºC and 78º C. The currents of the coupler electrode and the fixed gain electrode are set at 25 mA and 28 mA, respectively, with small variations for fine wavelength tuning and output power equalization. The fiber coupled power ranges from 5.2 dBm to 6.6 dBm for the 93 channels in this device.

In the bit error rate (BER) test, the results measured at the error detector is plotted against the received power that is measured with an optical power meter. Each BER value is measured with at least 100 errors. Figure 3 shows the measured bit error rate versus received power at 2.5 Gbps, comparing back-to-back (b2b) with 25-km SMF transmission and 50-km transmission. The receiver sensitivity penalty is less than 0.5 dB for 25-km transmission and less than 1 dB for 50-km transmission. The main cause of power penalty is the chromatic dispersion due to wavelength chirp related to the direct modulation.

The measured bit error rate versus received power at 5 Gbps is shows the measured bit error rate versus received power at 8.5 Gbps, comparing back-to-back with 10-km SMF transmission. The power penalty in the above two transmission conditions is about 1 dB, and error free transmission is also achieved in both cases.

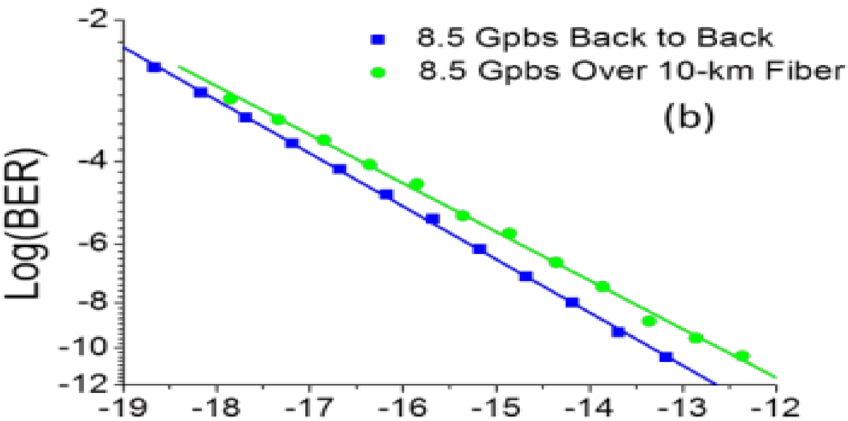

Figure 3. Measured BER Versus Received Power at 5Gbps

The main reason that limits the above development up to 8.5 Gb/s is the frequency response bandwidth of the device, including the laser chip and packaging. The measured 3dB bandwidth of the device is about 5~6GHz for different channels. We are currently developing the laser with Al-containing material system and improved packaging to improve the bandwidth.

For the reliability tests, the optical characteristics of the modules are monitored while they are operated in a test chamber with temperature set at 70 ºC. Since no wavelength locker is used in the TOSA, the wavelength and SMSR stabilities are ofprimary concern. Figure 4 shows the measured wavelength and SMSR variations with time over a 10-day period. It was observed that the wavelength increases by a few picometers in the first five days or so and then gradually stabilize, while the SMSR remains quite stable. The corresponding frequency drifts are in the order of 1GHz in average for 12 modules under test.

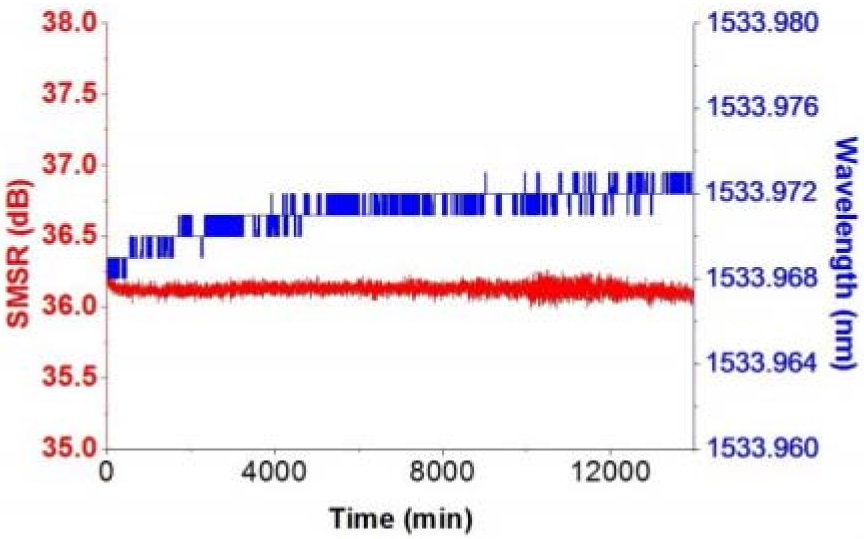

Figure 4. Wavelength and SMSR Stabilities Under Reliability Test

4. CONCLUSION

We have developed tunable TOSA and SFP transceiver modules based on the V-cavity laser. Full C band tuning of 93 channels from 1529.55-nm to 1566.31-nm with 50 GHz spacing is demonstrated. The dynamic SMSR is above 36 dB for all the channels. For the data rate at 2.5 Gbps, error free transmission over 50 km is achieved with excellent measured eye diagrams. The receiver sensitivity penalty is less than 0.5 dB for 25-km transmission and less than 1 dB for 50-km transmission. Error free transmissions are also achieved for 25 km at 5 Gbps and 10 km at 8.5 Gbps. The reliability tests have shown excellent wavelength stability even though no wavelength locker is used, thanks to the built-in Fabry-Perot etalons in the laser. Since the VCL is much simpler and more compact compared to widely tunable lasers currently available in the market, the VCL-based tunable TOSA and SFP modules have great potential for low-cost mass deployment in metro and access networks.

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