All-optical Wavelength Conversion Using Optical Injection Induced Wavelength Switching in V-cavity Laser

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Abstract— In this paper, we present a simple, efficient, and cost-effective all-optical wavelength converter using injection-induced wavelength switching in widely tunable V-cavity laser. When an external signal beam is injected at a wavelength corresponding to one of the sidemodes with a small detuning of about 0.1 nm, the lasing wavelength is switched from the original main mode to the side mode. By filtering out the main mode of the V-cavity laser, a data-inverted wavelength conversion is achieved. This wavelength converter can offer a non-return-to-zero (NRZ) channel-to-channel conversion with converted signal approximately at 200 GHz away from the input signal. A 2.5 Gb/s non-return-to-zero (NRZ) conversion is experimentally demonstrated with an extinction ratio over 4 dB and SMSR of 36 dB.

1. INTRODUCTION

The rapid growth of high-speed data networking calls for a lager optical communication bandwidth. Without optical-to-electrical-to-optical (OEO) involved signal processing procedure, all-optical packet routing (AOPR) can overcome electrical bottleneck, which is one of the most important restriction for the optical networking bandwidth, and improve the blocking performance.

One of the major components to realize AOPR is the all-optical wavelength conversion (AOWC). So far, a lot of methods for AOWC have been published, including nonlinear optical gating based on fiber loop, cross-phase modulation, cross-gain modulation, four-wave mixing based on semiconductor optical amplifiers [1–4]. One of the goals of AOWC research is to develop simpler, amplifier-free and cost-effective chip with submilliwatt input power. The method of injection induced wavelength conversion of the single-mode laser is a promising approach. Multimode (MM) Fabry-Pérot laser diode (FP-LD) used for AOWC has been reported, which are principally based on either injection locking with an external probe light [5, 6] or transverse-magnetic (TM) mode absorption modulation which is highly-polarization-sensitive [7]. The external probe light, highly-sensitive polarization beam splitter and other associated components all increase the cost of the system and make it hard to integrate the wavelength converter as a chip.

In this paper, we demonstrate a quite simple, cost-effective WC based on V-cavity laser [8]. The V-cavity laser is a single-mode (SM) tunable laser with carefully designed tuning wavelength grid, which ensures a channel-to-channel conversion. The dominant mode of V-cavity laser works as probe light. Only −6 dBm pump signal is required. A 2.5 Gb/s non-return-to-zero (NRZ) conversion is experimentally demonstrated, the chirp-management technique is explored to increase the extinction-ratio (ER).

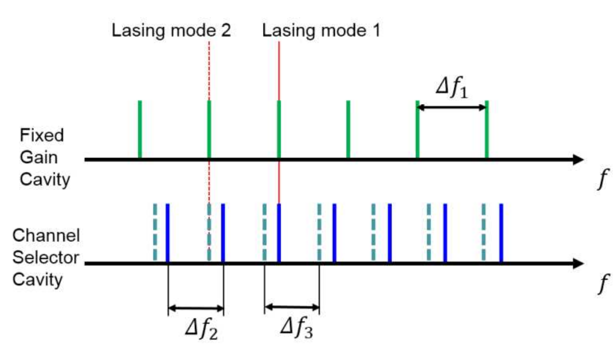


Figure 1: Schematic diagram illustrating the Vernier effect in wavelength conversion process, the dashed line is the mode comb with pump light injection, the channel spacing $\Delta f_1 > \Delta f_2 > \Delta f_3$.

2. SYSTEM PRINCIPLE

The working principle of the proposed wavelength converter is based on the injection-induced wavelength switching of the V-cavity laser. When an external pump light injected into V-cavity laser, the pump light is resonantly amplified, the process of stimulated emission consumes carrier, so the refractive index increases while carrier density decreases. In our experiment, the light is injected into the long cavity, namely the channel selector cavity. Based on Vernier effect, the mode of longer wavelength (lasing mode 2) is more likely to be stimulated, as shown in Fig. 1. In addition, the material gain spectrum is red-shift with light injection.

The injection beam needs to be TE polarized, with a longer wavelength than dominant mode, near the side mode with a small wavelength detuning instead of at the side mode to avoid unstable situation. For a stable locking, the wavelength detuning [9] can be used from 0.05 nm to 0.12 nm with a corresponding injection threshold power of −6.3 dBm to −4 dBm. Without the injection beam, power level of the dominant mode is high as logic "1". Once the injection beam is on, V-cavity laser locks to the injection beam, the original lasing mode (lasing mode 1 in Fig. 1) suppressed to a very low level as logic "0". By filtering out the dominant mode, an out-phase wavelength conversion is achieved.

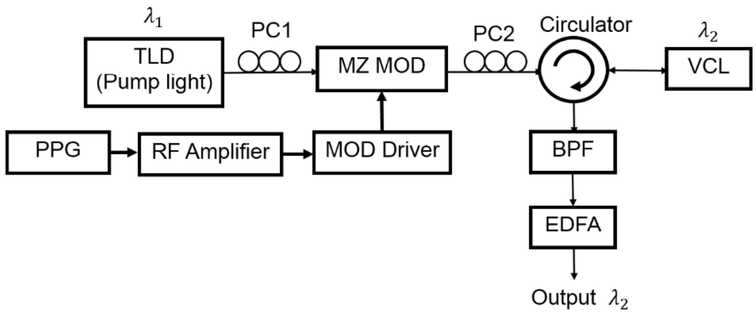


Figure 2: Experimental setup for the proposed wavelength converter based on V-cavity laser. PPG: pulse pattern generator. MZ MOD: Mach-Zehnder modulator. BPF: optical band pass filter. VCL: V-cavity laser.

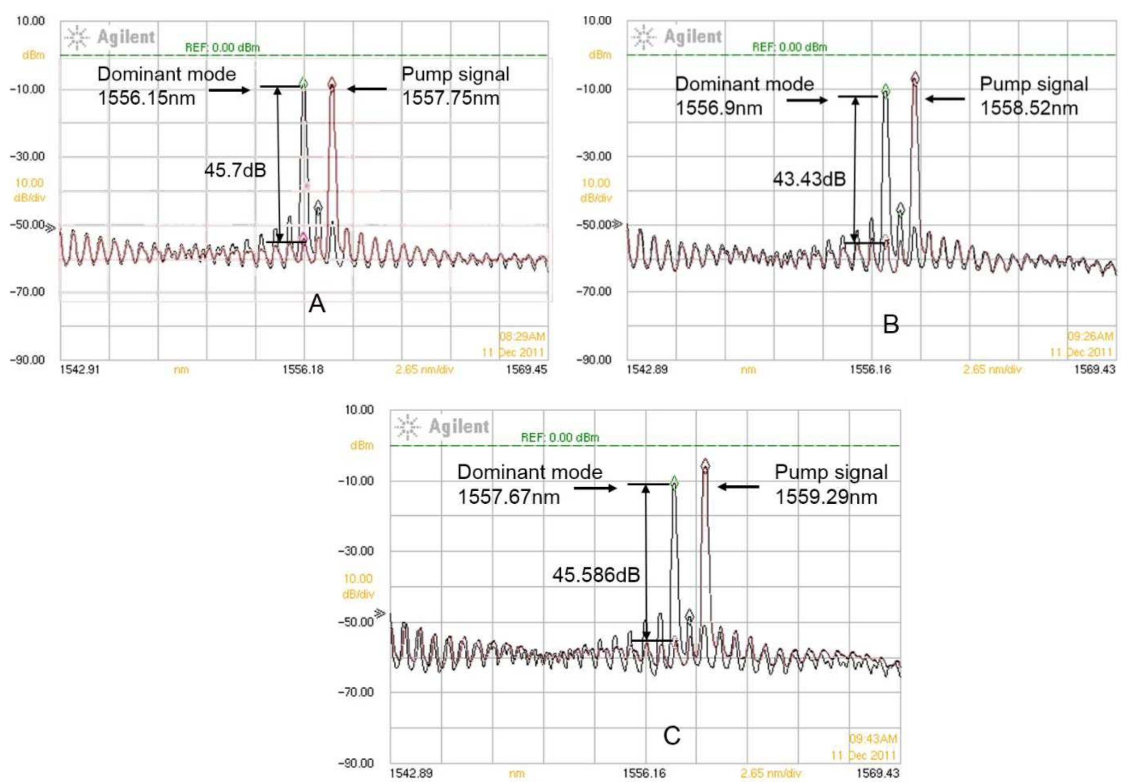


Figure 3: Optical power spectra of VCL with (red)/without (black) injection light in three conditions: A: Dominant mode is 1556.15 nm. B: Dominant mode is 1556.9 nm. C: Dominant mode is 1556.15 nm.

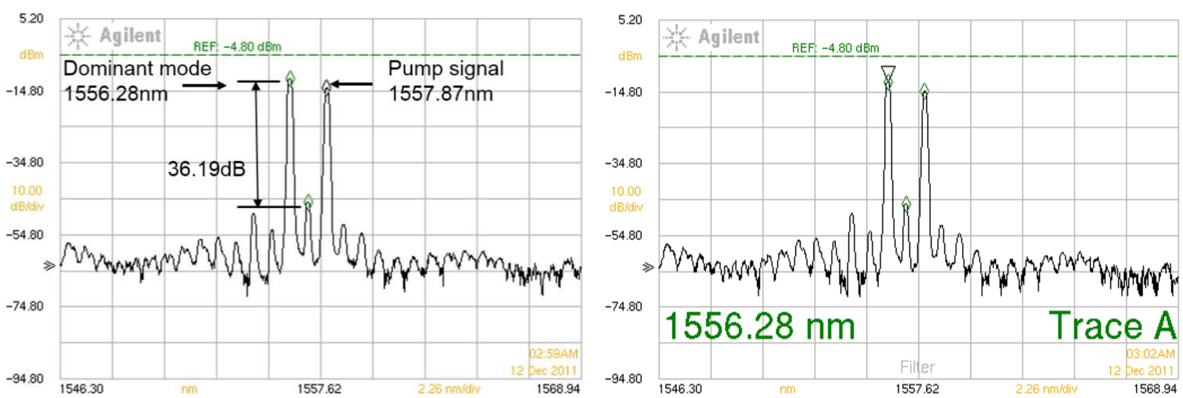
3. EXPERIMENTAL SETUP AND RESULTS

The experimental setup of the proposed wavelength converter is shown in Fig. 2.

The pump signal is a tunable laser (TLD) modulated by 2.5 Gb/s pseudorandom bit sequence of $2^7 - 1$. The Mach-Zehnder modulator is a polarization-dependent device, hence, the polarization controller PC1 is used to minimize power loss in the modulator. PC2 is used to ensure the TE polarized light for injection-locking of the pump signal to the VCL. The VCL is biased at 33 mA, 30 mA, 15 mA on coupler, channel selector cavity and fixed gain cavity respectively. The output power is around −6 dBm with a 6 dB chip-to- fiber coupling loss. The laser has a wide wavelength tuning range by controlling the current injection and operating temperature [8], which makes it possible to operate a wide-band wavelength conversion.

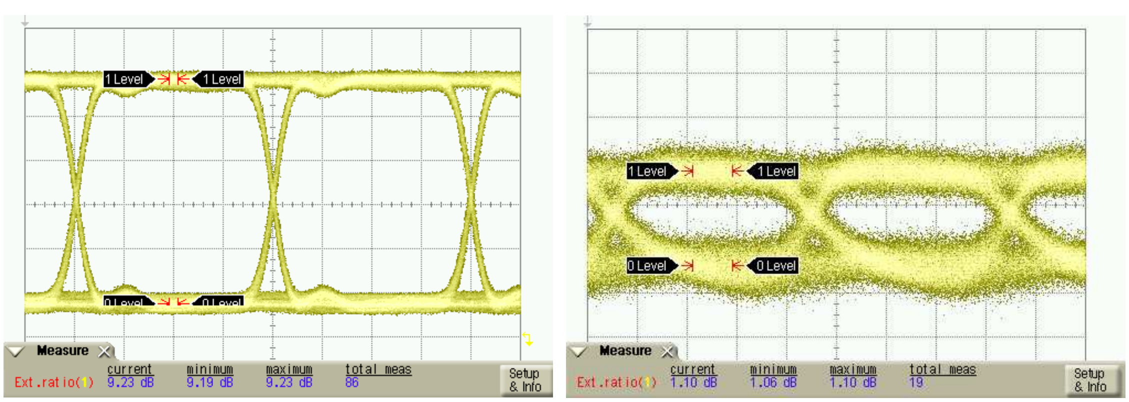
The VCL wavelength spacing of mode comb is 0.75 nm. The experiment was carried out in three cases for different dominant modes, with injection beam 0.1 nm longer than the second right-side mode of each dominant mode, as shown in Fig. 3. When the current of channel-selector cavity changes from 15 mA to 25 mA, the dominant mode is switched from 1556.15 nm, via 1556.9 nm, to 1557.67 nm. The pump signals are all approximately 1.6 nm away from the dominant mode. Thus, the V-cavity laser can offer a 200 GHz wavelength switching, fits ITU grid. The power of pump signal is a little higher in longer wavelength, which results from the deviation of material gain spectrum peak.

The dynamic measurements are shown in Fig. 4. The dominant mode of VCL is 1556.28 nm, and the pump signal is 1557.87 nm. Because of the limitation of the sweep time of optical spectrum analyzer, the optical signal is always on the screen and the integral signal power is about 3 dB less than the continuous light. The sidemode suppression ratio (SMSR) of the converted signal is



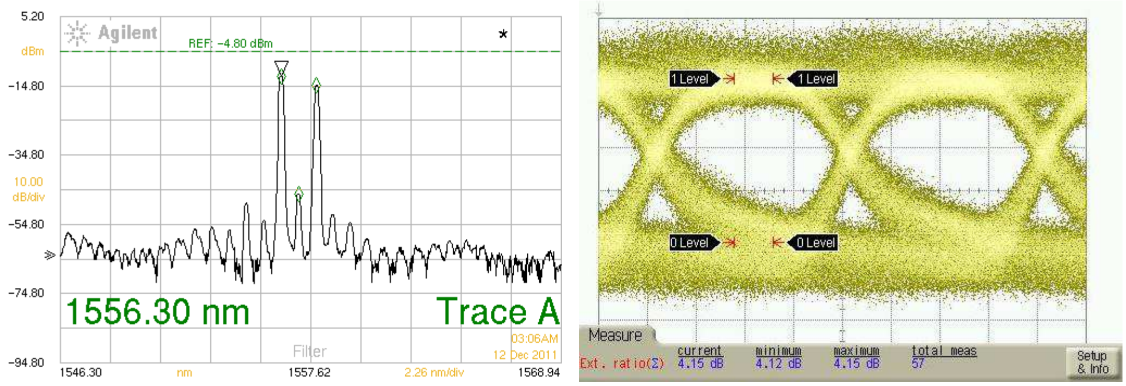
(a) (b)

Figure 4: (a) Optical power spectra for dynamic wavelength conversion measurement. (b) The BPF is placed at the dominant mode with resolution bandwidth of 0.04 nm.



(a) (b)

Figure 5: (a) Eye diagram of input pump signal at 2.5 Gb/s. (b) The converted eye diagram when the BPF is placed at the dominant mode.



(a) (b)

Figure 6: (a) The BPF is of 0.02 nm detuning from the dominant mode with resolution bandwidth of 0.04 nm. (b) The converted eye diagram at 2.5 Gb/s.

36.19 dB. When the BPF is placed at the dominant mode, the extinction ratio of converted eye diagram is only 1.1 dB at 2.5 Gb/s as shown in Fig. 5.

When the BPF moves a little to 1536.0 nm, the extinction ratio of converted signal increases to 4.15 dB, as shown in Fig. 6. Although the chirp of injection-locking laser is small [9, 10], chirp-management technique [11] still helps to improve the quality of converted signal.

4. CONCLUSION

A 2.5 Gb/s non-return-to-zero (NRZ) injection induced wavelength conversion is experimentally demonstrated. The V-cavity laser can accomplish a channel-to-channel wavelength conversion with 200 GHz channel spacing. It is compact, low-energy consumption and cost-effective for wavelength conversion, so is promising to work as part of optical-cross-connect with adoption of energy-band engineering to cover more communication channels.

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