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50-nm Wavelength Tunable Ultra-Flat Comb Generation Using Single-Stage Mach-Zehnder Modulator

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Abstract
50-nm widely wavelength tunable ultra-flat comb generation was demonstrated, where a highly stable electro-optic comb generator consisting of a standard dual-driven Mach-Zender modulator was used. 10-GHz-spaced comb with 21 components was generated within 5-dB bandwidth.

1 Introduction

Recently, electro-optic (EO) modulation using $LiNbO_3$ waveguide modulator are increasingly attractive for optical frequency comb generation [1],[2],[3] due to an improvement of modulation bandwidth and a decrease in the driving voltage of the modulator [4][5]. Introducing a high-voltage radio-frequency (RF) signal into the modulator, higher-order frequency components of the driving signal are promptly generated, which can be used as the frequency comb signal. Unfortunately, however, it is difficult to generate a frequency comb with good spectral flatness since each frequency component obeys Bessel function of different order. To solve this problem, proceeding reports proposed to utilize two optical modulators, where an optical phase modulator and a Mach-Zehnder modulator (MZM) should be cascaded in tandem [3].

Instead of the conventional technique, we found the optimal operating condition for flatly generating an optical frequency comb by using only a set of conventional MZM [6]. Therein, a continuous-wave (CW) light is EO modulated using an MZM dual-driven with in-phase signals but have slightly different amplitudes. The generated comb is spectrally flattened if the MZM is driven under the condition of $\Delta A+\Delta\theta=\pi/2$,

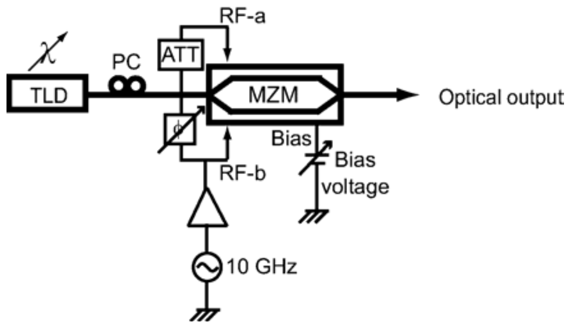

Fig. 1. Experimental setup;
TLD: tunable laser diode, PC: polarization controller, ATT: RF attenuator

where ΔA and $\Delta\theta$ denote amplitude difference of the driving signals and the bias condition of the MZM, respectively.

In this paper, we report on widely wavelength tunable ultra-flat comb generation using a conventional $LiNbO_3$ MZM. 10-GHz spaced ultra-flat optical frequency comb generation over ~200-GHz bandwidth was successfully demonstrated. Spectral ripple was less than 1.1 dB for 11 number of frequency comb components; 21 components were generated within a 5-dB bandwidth. The operation was almost wavelength-shift free: 50-nm wavelength tunable operation was demonstrated.

2. Widely wavelength-tunable ultra-flat comb generation

Fig. 1 shows the experimental setup for ultra-flat optical frequency comb generation using an MZM. The optical frequency comb generator consisted of a wavelength tunable external cavity semiconductor laser diode (TLD) and a $LiNbO_3$ dual-drive MZM having half-wave voltage of 5.4 V. A CW light was generated from the TLD with the intensity of 5.8 dBm and its

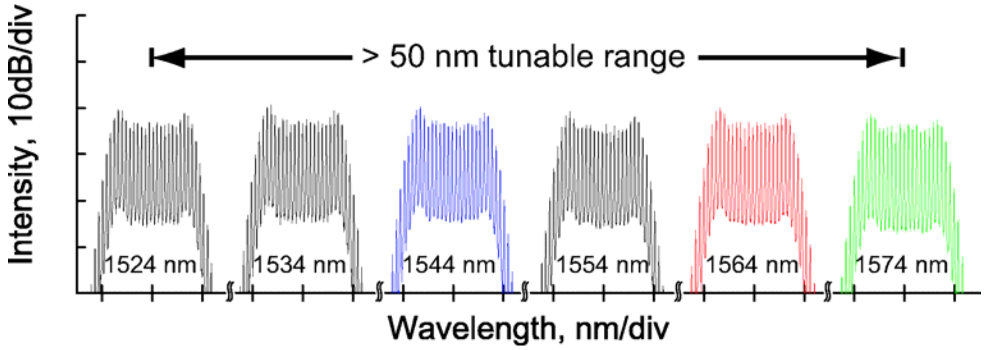

Fig. 3. 50-nm wavelength tunable operation: Measured optical spectra whose centre wavelength are at (a) 1524 nm, (b) 1534 nm, (c) 1544 nm, (d) 1554 nm, (e) 1564 nm and (f) 1574nm, respectively.

wavelength tuning range was 1524 nm-1574 nm. The CW light was introduced into the modulator through a polarization controller to maximize modulation efficiency. The MZM was dual-driven with sinusoidal signals with different amplitudes (RF-a, RF-b). The RF sinusoidal signals at a frequency of 10 GHz were generated from a synthesizer, amplified with a microwave booster, divided half with a hybrid coupler, and then fed to each modulation electrode of the modulator. The intensity of RF-a injected into the electrode was attenuated a little by giving loss to the feeder line connected with the electrode. The input intensities of RF-a and RF-b were 35.9 dBm and 36.4 dBm, respectively. The phase difference between RF-a and RF-b was aligned to be zero by using a mechanically tunable delay line, which was placed in the feeder cable for RF-a. The spectra obtained from the frequency comb generator were measured with an optical spectrum analyzer.

Fig. 2 shows optical spectra obtained from the comb generator, where modulator was dual driven under the optimal condition of $\Delta A+\Delta\theta=\pi/2$. The frequency spacing and 5-dB spectral width of the generated comb were 10 GHz and 210 GHz, respectively. The optical conversion loss from the input CW light to the average power of the generated comb ($-\eta$) was about 18 dB. The measured spectrum had good flatness under the operating condition. The number of frequency components for <1.1-dB spectral ripple was 11. 21 components of the comb were flatly generated within the 5-dB bandwidth. In addition to the demonstration of ultra-flat comb generation, Fig. 2 demonstrates widely wavelength tunable operation of the comb generator. The optical spectra were measured when the centre wavelength was tuned in the range between 1524 nm and 1574 nm, (the spectra were plotted with the wavelength interval of 10 nm.) This confirms that ultra flat frequency combs were generated over the whole wavelength tuning range of the input CW laser source.

3 Summary

In this paper, we have demonstrated widely wavelength tunable ultra-flat optical frequency comb generation using a conventional MZM. Widely wavelength tunable operation over 50 nm was also demonstrated.

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