80 Gb/s photonic temporal differentiator based on cascaded SOI microring resonators

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***Abstract*: A photonic temporal differentiator based on cascaded microring resonators is proposed. By approaching the critical coupling condition of through port of the cascaded microrings, first order all-optical differentiation functionality can be realized. The proposed scheme is experimentally verified by Gaussian-like pulse trains with data rate up to 80 Gb/s.**

1. Introduction

All-optical signal processing is an integral part of future high-speed optical communication networks, as it can overcome the inherent speed limitation of conventional electronics. A promising approach toward the implementation of all-optical circuits is to design and implement the photonic counterparts of the fundamental devices that form "basic building blocks" in electronic circuits[1]. One of the basic building blocks of all-optical signal processing is optical temporal differentiator, which provides differentiation of the time-domain complex envelope of an arbitrary input optical signal. Recently, different schemes of all-optical temporal differentiators have been proposed, including integrated-optical transversal filter structures[2], interferometers[3], long period fiber grating (LPG)[4], phase-shifted fiber Bragg grating (PSG)[1], single silicon microring resonator[5], as well as wavelength-selective directional couplers[6]. In particular, the silicon microring resonator based optical differentiator proposed in Ref. [5] has the advantages of compactness, on-chip integration and compatibility with electronics. In this paper, cascaded microring resonators structure is employed as an all-optical temporal differentiator to process much higher data rate compared with single microring. A 3-stage double channel side-coupled integrated spaced sequence of resonators (SCISSOR) device based on silicon-on-insulator (SOI) is fabricated and its differentiation performance is assessed by Gaussian-like pulse trains with different data rates. The results show that the fabricated device can be used as a differentiator for 80 Gb/s optical time domain multiplexing (OTDM) signal with good performance.

2. Operating principle

A first-order temporal differentiator is essentially a linear filtering device providing a spectral transfer function of the form $H(\omega-\omega_0)=i(\omega-\omega_0)$, where ω is the optical frequency, and ω_0 is the optical carrier frequency of the signal to be processed[4]. This transfer function indicates that the first-order temporal differentiator's transmission is dependent linearly on the frequency detuning from the central frequency $\omega-\omega_0$ and an exact π-phase shift in the phase response at the central frequency ω_0.

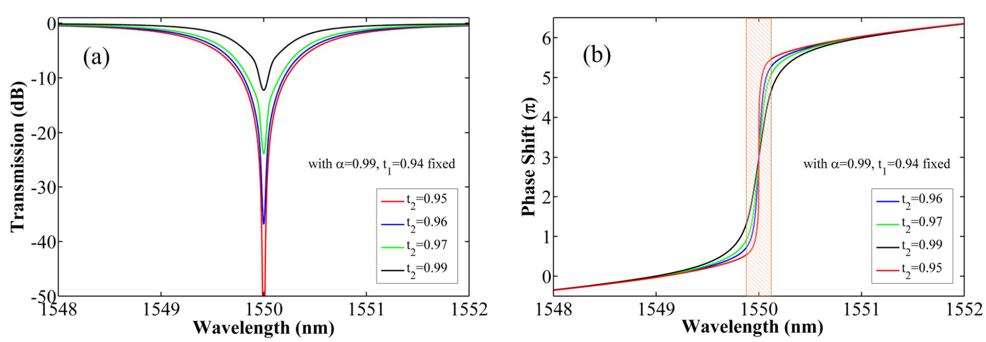

Fig. 1. Simulation results of (a) transmission and (b) phase responses of 3-stage double channel SCISSOR with different transmission coefficients t_2.

Both all-pass filter (APF) and add-drop single ring provide sharp notches and steep π phase shifts at the through ports near their critical coupling regions[7], which are the required spectral features of a temporal differentiator. In the following, we show by numerical simulations that if each cascaded microring is near the critical coupling, the double channel SCISSOR structure exhibits the spectral characteristics required for a temporal differentiator. Fig. 1 shows the numerically simulated transmission and phase responses of a 3-stage double channel SCISSOR with different transmission coefficients (t_2) at the drop side. In the simulations, the propagation loss of the ring waveguide and the bus waveguide is set to 13.89 dB/cm (i.e. $a = 0.99$). For the transmission coefficients, at the through side, t_1 is fixed to 0.94, while at the drop side, t_2 has different values: 0.95, 0.96, 0.97 or 0.99. As the critical coupling condition of an add-drop ring is $t_1 = at_2$, the case of $t_2 = 0.95$ provides the closest critical coupling condition. It can be observed in Fig. 1 that the transmission curve reaches zero and the phase response has a π phase shift (odd- number times of π phase shift is equally corresponding to a π phase shift) over a relatively narrow bandwidth around the resonance wavelength when the coupling state is very close to the critical point.

3. Design and fabrication

The cascaded microring device is realized on a commercial SOI wafer with a top silicon thickness of 340 nm, using single mode rib waveguide that is easy to integrate with doped active devices[8]. Since cascaded microring structure is sensitive to the fabrication error and to the optical effect of coupling-induced frequency shift (CIFS)[9], elaborate design consideration should be taken into account to obtain frequency-matched resonance[10]. Electron beam lithography (EBL) and inductively-coupled-plasma (ICP) reactive ion etching are used to fabricate the device. Firstly, the device is defined with one step of EBL (Raith150). Then, the pattern is etched into the silicon layer by ICP etching. At last, a 500 nm thick hydrogen silsesquioxane (HSQ) top cladding layer is spin-coated to protect the device. A scanning electron microscopic (SEM) image of the fabricated cascaded microring structure is shown in Fig. 2. The radius of the microrings is 10 μm. The rib widths of the bus waveguide and the ring waveguide are 460 nm and 590 nm, respectively. The slab height is about 130 nm, and measured transmission spectrum of the device is depicted in Fig. 2 (b). The resonance notch centered at 1560.73 nm exhibits a depth of 33.0 dB and a 3-dB bandwidth of 0.642 nm.

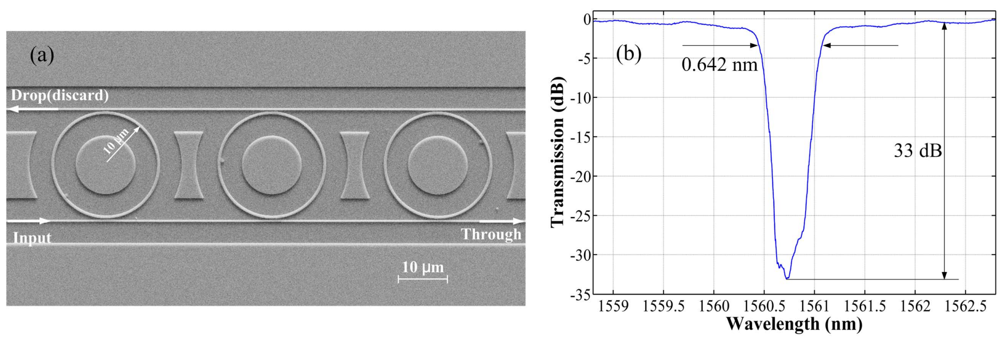

Fig. 2. (a) SEM image and (b) measured transmission spectrum of the 3-stage double channel SCISSOR device.

4. Measurement and Results

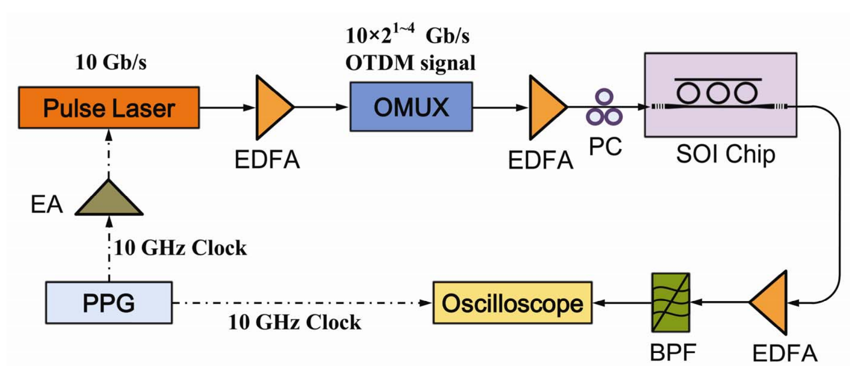

Fig. 3. Experimental setup of the differentiation measurement of the cascaded microrings device.

The experimental setup used to measure the fabricated device is shown in Fig. 3. A 10 Gb/s pulse train with a Gaussian pulse width of ~2.7 ps is generated by a short pulse laser (U2T TMLL1550) with a center wavelength of ~1550 nm. The pulse laser is driven by an amplified 10 GHz radio frequency (RF) clock from a pulse pattern generator (PPG ANRITSE MP1763C). After amplified by an erbium doped fiber amplifier (EDFA), the 10 Gb/s pulse train is multiplexed by a four-stage optical time division multiplexer (OMUX) with variable multiplexing stages to generate 20 Gb/s, 40 Gb/s and 80 Gb/s OTDM signals. The resulting OTDM signal is sent into the cascaded microring device via integrated grating couplers. To compensate the coupling loss of about 15 dB, two EDFAs are employed to amplify the signal before and after the device. Meanwhile, the grating coupler for vertical coupling is polarization-dependent, a polarization controller (PC) is inserted before the SOI chip to make sure that the input light is transverse electrical (TE) mode. A band-pass filter with a bandwidth of 3.2 nm is used to eliminate the spontaneous emission noise from the EDFAs. The differentiated signal is then recorded with a 500 GHz all-optical oscilloscope.

Fig. 4 shows the differentiation results of the OTDM signals at different data rates. The differentiation signals with high quality up to 80 Gb/s can be obtained. The slight asymmetry of each two lobes of the 40 Gb/s and 80 Gb/s differentiation signals results from the third-order dispersion of the microring at the resonance wavelength[11] and the limitation of the device operation bandwidth (~0.642 nm)[12]. In fact, the device operation bandwidth is less than the bandwidth of the ps-pulse (> 1nm), but it can process the ps-pulse trains with slight distortions. Since the speed of the differentiator is mainly limited by the 3-dB bandwidth of the cascaded microring resonators, it can be expected that much higher speed differentiator could be achieved by cascading larger number of microrings, which provides a wider bandwidth.

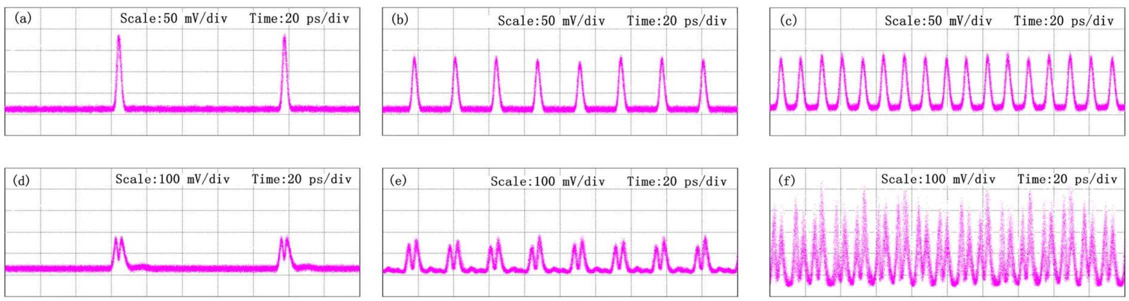

Fig. 4. Original input OTDM signals (a) 10 Gb/s, (b) 40 Gb/s and (c) 80 Gb/s; measured output signals after the optical differentiation at (d) 10 Gb/s, (e) 40 Gb/s and (f) 80 Gb/s, respectively.

5. Conclusion

In conclusion, we have demonstrated an integrated all-optical temporal differentiator based on cascaded microrings in SOI. The cascaded microrings structure has enhanced the operation bandwidth of the device compared with single microring. Differentiations of Gaussian pulse series are obtained at different data rates, and data rate up to 80 Gb/s differentiated signal has been successfully demonstrated.

Acknowledgement

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