Tunable Reflective-Type Microring Resonator Optical Delay Lines with Large bandwidth and Low Power Dissipation

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Abstract: We present a reflective-type delay line using side-coupled integrated spaced sequence of resonators (SCISSOR) terminated with a Sagnac loop reflector. With 13 microrings, group delay of ~150 ps is achieved with 170 GHz bandwidth.

OCIS codes: (230.3120) Integrated optics devices (230.5750) Resonators

1. Introduction

On-chip tunable delays have widely been used in data buffering, signal processing, and phased array antennae [1-3]. Among the various structures for on-chip tunable delays, microring resonators have the key merits of compact size, simple structure, and large delay etc. [4]. However, for a single microring resonator, the delay-bandwidth product is fixed at approximately 2/π for an all-pass filer (APF) configuration. To further improve the delay performance, cascaded microring resonator structures can be employed, which is a feasible approach for many practical applications. One of the commonly used cascaded microring structures is the side-coupled integrated spaced sequence of resonators (SCISSOR) [5]. In this structure, the resonance frequencies and coupling coefficients of the microring resonators should be well controlled, which imposes a great challenge to device fabrication.

In this paper, we present a novel reflective-type delay line consisting of a SCISSOR structure terminated with a Sagnac loop reflector at one end. The Sagnac loop reflects the incoming light back to the SCISSOR, and thus all the microrings in this structure are utilized twice. In other words, the degenerate resonance modes (clockwise and counter-clockwise modes) are both excited in each microring. In this way, the delay-bandwidth product is doubled without adding more resonators. Note that the gain is more valuable when the number of resonators is large. The improved microring utilization efficiency can release the fabrication requirement and lower the power consumption in delay tuning. Group delay is tuned by p-i-p thermal resistors [6] integrated inside the microring resonators.

2. Device Design and Fabrication

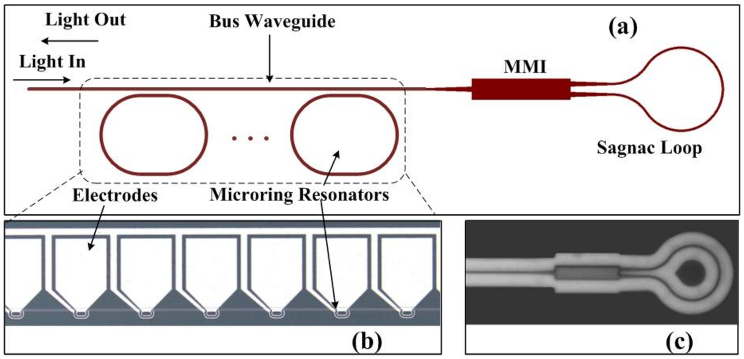


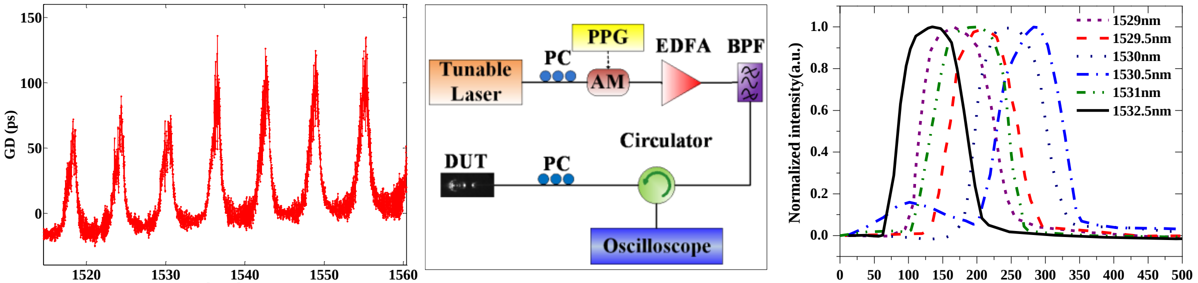
Fig. 1. (a) Schematic of the reflective-type SCISSOR delay line. (b) Optical microscope image of the tunable microrings with electrodes. (c) Optical microscope image of the Sagnac loop reflector.

Fig. 1(a) shows the schematic drawing of the reflective-type SCISSOR delay line consists of a sequence of identical racetrack microring resonators and a Sagnac loop reflector at one end. The waveguide is 500 nm wide and 220 nm high with a slab thickness of 60 nm. The radius of the microring resonators is 10 μm. The coupling length is 16 μm and the gap is 0.25 μm to ensure the resonators work at the over-coupling regime to generate slow-light. The 3-dB multimode interference (MMI) coupler in the Sagnac loop is 5 μm wide and 23.5 μm long.

We fabricate the devices using standard CMOS fabrication processes. The top silicon layer is p-type lightly doped with a resistivity of 10 to 15 Ohm cm (corresponding to a hole concentration of ~10^{15} cm^{-3}). 248-nm deep ultra-violet (DUV) photolithography and plasma dry etched was used to define the device patterns. Ion implantation was used for doping with a concentration of ~10^{20} cm^{-3}. A 1 μm thick silicon dioxide layer was deposited using plasma-enhanced chemical vapor deposition (PECVD) before Aluminum layer was sputtered and patterned.

To actively tune the microring resonators, we designed a p-i-p junction across the ring waveguide to work as a thermal resistor. Since the generated heat directly interacts with the waveguide optical mode, the tuning speed and power efficiency can be potentially improved. The central intrinsic region width of the p-i-p junction is 1.65 μm. Figs. 1 (b) and (c) shows the optical microscope images of racetrack microring resonators and the Sagnac loop reflector, respectively.

3. Experimental Results and Discussion



(a) (b) (c)

Fig. 2. (a) Group delay spectrum of the 13-stage reflective-type SCISSOR delay line. (b) Setup for the pulse transmission experiment. (c) Measured temporal waveforms at various wavelengths. The curves are normalized for better comparison.

Fig. 2(a) shows the measured group delay spectrum of a delay line consisting of 13 microrings integrated with p-i-p thermal heaters. Around 1550 nm, the maximum delay is ~90 ps and the bandwidth is ~170 GHz. The large bandwidth is mainly due to the cascading of microrings, as their resonances are not exactly matched due to various fabrication uncertainties. The background ripple in the curves is due to the Fabry-Perot resonance caused by the waveguide end-facet reflection. This issue can be circumvented by anti-reflection coating the chip facets.

We also measured the pulse transmission though the 13-microrings delay line. The experimental setup is shown in Fig. 2(b). A Gaussian pulse train was generated by modulating a continuous-wave (CW) light using a $LiNiO_3$ amplitude modulator (AM) driven by a 10 Gbit/s pulse pattern generator (PPG). An erbium-doped fiber amplifier (EDFA) was used to amplify the generated signal followed by a tunable bandpass filter (BPF) to suppress the amplified spontaneous emission (ASE) noise. A polarization controller (PC) was inserted before the modulator to make sure that the input signal is TE polarized. The temporal waveforms were recorded by an oscilloscope. The delayed pulses at various wavelengths were recorded. As shown in Fig. 2(c), except 1532.5 nm (off-resonance), all the other wavelengths are located in the slow-light band (see Fig. 2(a)). When the wavelength is tuned to 1530.5 nm, the pulse delay reaches the maximum of ~150 ps. With the fabrication improved, the resonances of the microring resonators can be better aligned, which as a result can increase the delay value yet with a reduced bandwidth. Our next step is to actively tune the resonators so that the group delay can be varied at a fixed wavelength, which might be more useful in practical applications.

4. Conclusion

We presented a novel reflective-type SCISSOR delay line in which a Sagnac loop reflector is used to double the delay-bandwidth product. The optical delay was characterized by using the modulation phase-shift method and the optical pulse transmission experiment. In the 13-stage delay line, the maximum achievable delay is ~150 ps with a bandwidth of ~170GHz. The active tuning experiment is on-going.

5. References

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