Cascaded passive silicon microrings for large bandwidth slow light device

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Abstract. Slow light devices have important applications in the areas of data buffering, signal processing, and phased array antenna. Cascaded microring resonators structure can obtain large delay and also enhance the bandwidth, which was considered as a potential approach for future on-chip optical buffer. In this paper, we demonstrated a large bandwidth slow light device using cascaded Silicon-on-insulator (SOI) based microring resonators. With carefully designed the gap between the bus and the ring waveguides and the distances between the adjacent rings, a 57 ps group delay was observed and 83 Gbps maximum allowable bit rate is suggested according the measured 3 dB spectral bandwidth in the 8-stage cascaded microrings.

Keywords: slow light; cascade microring; silicon-on-insulator

1. Introduction

Slow light, which means reducing the light propagation velocity in media and structures, has become a rapidly growing field with great scientific value and a lot of potential applications. Especially, the recently research indicated that slow light device has good potential applications in optical buffers of high-capacity communication networks, optical pulse synchronization and reshaping, ultrafast all-optical information processing, true-time delay (TTD) in a phased-array antenna (PAA) [1-4], etc. There are several effects and structures can be used to obtain the slow light, including Bose–Einstein condensates, low-pressure metal vapors, solid crystal materials, optical fibers, semiconductor quantum wells and quantum dots, photonic band-gap structures and so on.[5-10]. Among these, silicon based microring structure is regarded as the ideal structure for the on-chip optical delay line or optical buffer for the merits of small footprint, fabrication compatibility with the CMOS technology and so on.

For a single SOI microring resonator, the delay time and the bandwidth is in contradiction. In order to get an optical delay line with large delay time and bandwidth simultaneously, cascaded microring structures, such as coupled resonators optical waveguide (CROW) and side-coupled integrated spaced sequence of resonators (SCISSOR) structure, are usually introduced for SOI-based devices. In this paper, we demonstrate a SOI 8-microrings optical delay line with a SCISSOR structure. A 57ps delay time is measured at 3Gbps; however, the 3dB spectral bandwidth shows that the device’s theoretical maximum allowable bit rate is 83 Gbps.

2. Design and fabrication

Among the factors affecting the performance of a SOI cascaded microring slow light device, the gaps between the bus and the ring waveguides and the distances between the adjacent rings are much more important because they determine the spectrum shape and therefore the delay time and wavelength of the device. Transfer matrix is employed here to get the transmission characteristics of the structure and the coupling coefficients can be, optimized.

The device is fabricated on a commercial SOI wafer with a 340-nm-thick silicon and 2 µm buried silica layer. Grating couplers are introduced to decrease the coupling loss on the input and output ports.
Electron-beam-lithography (EBL, RAITH150) process is used to transfer the device pattern into the PMMA mask and the pattern is etched into the silicon layer by inductively-coupled-plasma (ICP) etching process.

The SEM images of the 8-stage single channel SCISSOR device are shown in Fig. 1. The radii of the microrings are 6 µm with the rib width of the bus waveguide and ring waveguide 460 nm and 590 nm, respectively. The grating’s period is 620 nm with a filling factor of 0.5.

![Fig.1 The SEM image of the 8-stage single channel SCISSOR.](image1)

3. Results and discussions

The optical spectrum is measured by coupling a TE-polarized light from a tunable laser into the bus waveguide and the output light was coupling into an optical spectrum analyzer at the same time. Fig.2 shows the spectra response of the 8-stage cascaded microring. There is an apparently broaden spectrum than a single microring, while there is also a spectra split. The spectra splits and resonance broaden can be explained by deviation of the coupling, the width of the waveguides, and the resonators’ perimeters of different resonances. The maximum on-resonance insertion loss is about 24.7 dB at 1554.5nm and the 3 dB bandwidth is 1.326 nm, which theoretically means an 83 Gbps maximum allowable bit rate for the device.

![Fig.2 The spectra response of the 8-stage cascaded microring](image2)

The delay time is measured in a system shown in Fig.3. At first, light at a off-resonant wavelength from a tunable laser is modulated by a commercial LiNbO$_3$ modulator and then is detected by the detector and oscilloscope as a reference. Then, the wavelength of the input light is tuned to one of the broadened resonances, so the light will transmit through the microring resonantors and be detected. By comparing the two waveforms, the delay time is obtained. As shown in Fig.4, a 57ps optical delay is measured when the modulation frequency is 3Gbps.
4. Conclusion
We have experimentally fabricated optical delay lines based on SOI cascaded microrings and demonstrated their pulse delay performances. The cascaded microrings devices are provided with both broader bandwidth and larger group delay than single microring. The maximum delay we have measured is 57 ps at 3Gbps bit rate with 8-stage cascaded microrings, and the 3 dB spectral bandwidth suggested maximum allowable bit rate is large as 83 Gbps.

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