Performance of a silicon-microring slow-light delay line for advanced modulation formats

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Abstract: We experimentally demonstrate a delay line in silicon microring resonator with a 20-μm radius. The delay performances of six advanced modulation formats are investigated, including NRZ, RZ, DPSK, CSRZ, RZ-DB and RZ-AMI.

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1. Introduction

On-chip optical delay lines may have significant applications in future optical interconnections and packet-switching systems. The recently developed silicon-on-insulator (SOI) structure has been proved to be an excellent platform for monolithic integration of photonic devices due to its high index contrast between the silicon core and the silica cladding, which allows strong light confinement and dramatic reduction in device size. Some on-chip delay lines based on silicon waveguide have been demonstrated including cascaded micro-ring resonator based all-pass filters (APF) configuration, and coupled resonator optical waveguides (CROW) configuration [1]. On the other side, significant progress has been made in the advanced modulation formats [2] for the state-of-the-art communication systems to provide superior performances and meet diverse requirements. However, to the best of our knowledge, no thorough experimental studies have been carried out on the performances of various formats through silicon based slow-light devices.

In this paper, we experimentally investigate the performances of a delay line in a silicon microring resonator for non-return-to-zero (NRZ), return-to-zero (RZ), differential-phase-shift-keying (DPSK), carrier-suppressed return-to-zero (CSRZ), RZ-duobinary (RZ-DB), and RZ-alternate-mark-inversion (RZ-AMI) modulation formats.

2. Experiment

The microring resonator used in this work is fabricated in a commercial SOI wafer with a 3-μm-thick silica buffer and a 250-nm crystalline silicon top layer. The radius of the ring is 20 μm. The waveguide cross-section is 450 × 250 nm^2. The air gap between the waveguide and the ring is controlled at 120 nm. Fig. 1(a) shows the scanning electron microscope (SEM) photos of the microring. The waveguide is slowly tapered to a width of 10 μm at both ends, and then gold gratings are added to couple light near-vertically from single mode fibers. The measured fiber-to-fiber coupling loss is ~20 dB. Fig. 1(b) shows the spectral response of the microring resonator. The black dots and red curves denote the measured and Lorentzian fitted resonance, respectively. The resonance at 1552.869 nm has a ~10-dB notch and the 3-dB bandwidth is ~0.1 nm. By changing the temperature to shift the resonance, the delay can be continuously tuned [3]. Such a ring resonator is the basic building block for cascaded slow-light structures with larger delays.

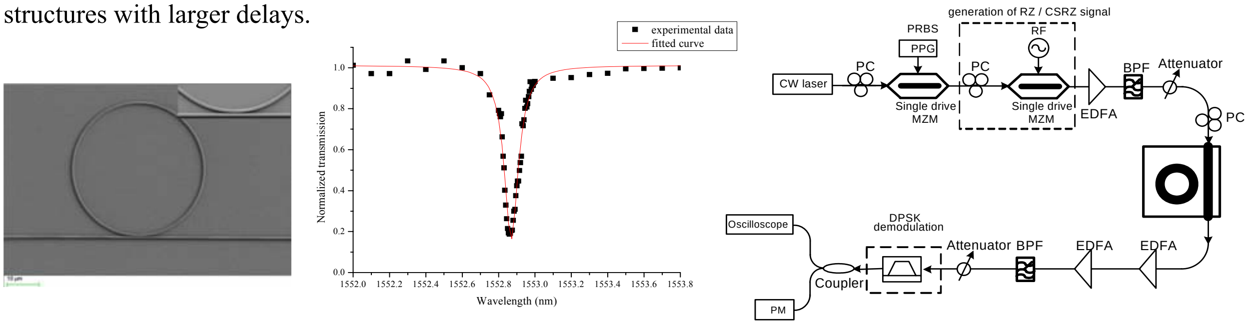

Fig.1 (a) SEM photo of the SOI micro-ring resonator, (b) the resonance spectrum, (c) experiment setup

The experiment setup is depicted in Fig. 1(c). A first MZM is modulated by a pseudorandom bit sequence (PRBS) signal of length 2^{15}-1 generated by a pulse pattern generator (PPG) to generate NRZ or DPSK signal. A second MZM which acts as a pulse carver is sinusoidally driven by a synchronized RF signal to generate CSRZ or RZ signals. The first single diver MZM is replaced by a dual-drive MZM when generating RZ-DB and RZ-AMI signal. The generated signal is amplified by an erbium-doped fiber amplifier (EDFA) and then filtered by a tunable band-pass filter (BPF) with a bandwidth of 1.6 nm. The power sent into the fiber is controlled at 0 dBm.

Fig. 2 shows the waveforms for the 5-Gb/s NRZ, RZ and 1.25-Gb/s demodulated DPSK signals when off resonance and on resonance, respectively. The delays are measured by comparing the positions of the rising edges of the recorded waveforms from the oscilloscope. The maximum delay for the 5-Gb/s NRZ and RZ signals are ~100 ps and ~90 ps, respectively. However, for the NRZ signal, a large overshoot appears in the trailing edge when on resonance, which results from the third order dispersion. For the DPSK signal, the data rate is reduced to 1.25 Gb/s as high-speed signals will be demodulated into AMI format. Fig. 3(c) and (d) show the typical waveforms of the demodulated DPSK signals at the two ports of Mach-Zehnder delay interferometer, respectively. The maximum delay is ~120 ps when the signal is on the resonance.

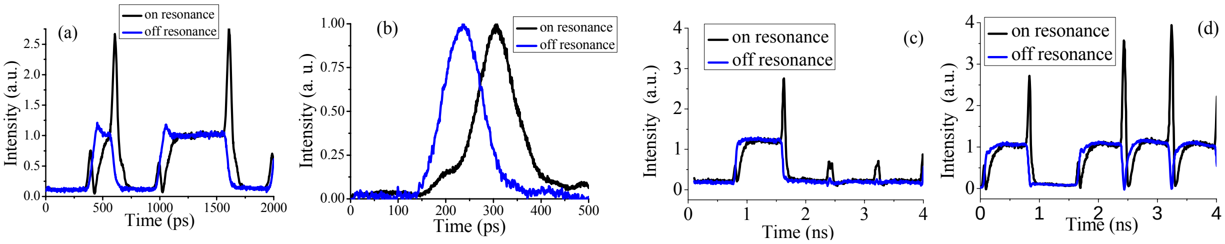

Fig. 2 (a) and (b) are waveforms of 5-Gb/s NRZ and RZ signals. (c) and (d) are waveforms of the demodulated 1.25-Gb/s DPSK signals at two ports of the MZDI

Fig. 3(a)-(f) show the eye diagrams for the 5-Gb/s CSRZ, RZ-DB and RZ-AMI signal when off-resonance and on-resonance, respectively. The delay is defined by comparing the peak points with maximal eye-openings. The maximum delays for the CSRZ, RZ-DB and RZ-AMI signals are ~ 95 ps, ~ 110 ps and ~ 62 ps, respectively. The eye is open for the three eye diagrams when on resonance. Due to the pattern dependence, the "1"-level splitting arises in the eye diagrams for the CSRZ and RZ-AMI signal, which contributes to the degradation of signal quality. Tab. 1 summarizes the results of six modulation formats.

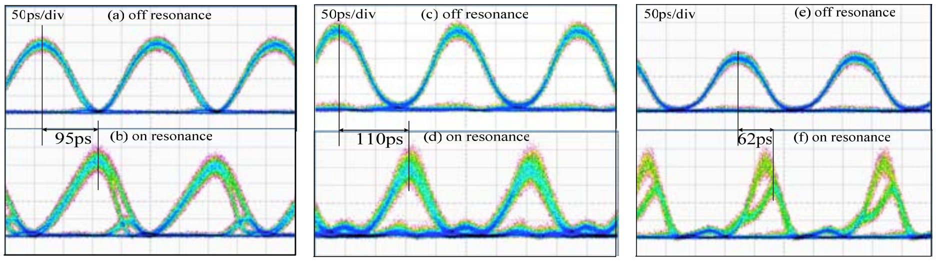

Fig. 3 Eye diagrams for the 5-Gb/s CSRZ，RZ-DB and RZ-AMI signal when off resonance and on resonance

Tab. 1 Delay performances of different formats

Formats	NRZ	RZ	DPSK	CSRZ	RZ-DB	RZ-AMI
Delays (ps)	100	90	N/A	95	110	62

3. Conclusion

We experimentally demonstrate a delay line based on a silicon micro-ring resonator, which is the basic building block for cascaded slow-light structures. RZ-DB achieves the maximum delay, followed by NRZ, CSRZ, RZ, RZ-AMI, while high-speed DPSK signal cannot be maintained through the narrow-band ring resonator. This work was supported by the NSFC (60777040), Shanghai Rising Star Program Phase II (07QH14008), the Swedish Foundation for Strategic Research (SSF) through the future research leader program, and the Swedish Research Council (VR).

4. References

[1] F. Xia, L. Sekaric and Y. Vlasov, "Ultracompact Optical Buffers on a Silicon Chip," Nature Photonics **1**, 65-71(2007)

[2] Fangfei Liu, Yikai Su and Paul L. Voss, "Optimal Operating Conditions and Modulation Format for 160 Gb/s Signals in a Fiber Parametric Amplifier Used as a Slow-light Delay Line Element," in Proc. OFC 2007, paper OWB5

[3] Fangfei Liu, Qiang Li, Ziyang Zhang, Min Qiu and Yikai Su, "Optically Tunable Delay Line in Silicon Microring Resonator Based on Thermal Nonlinear Effect," IEEE Journal of Selected Topics in Quantum Electronics, to appear in May/June 2008