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On-Chip All-Optical Passive 3.55 Gbit/s NRZ-to-PRZ Format Conversion Using a High-Q Silicon-Based Microring Resonator *

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We report the experimental result of all-optical passive 3.55 Gbit/s non-return-to-zero (NRZ) to pseudo-return-to-zero (PRZ) format conversion using a high-quality-factor (Q-factor) silicon-based microring resonator notch filter on chip. The silicon-based microring resonator has 23800 Q-factor and 22 dB extinction ratio (ER), and the PRZ signals has about 108 ps width and 4.98 dB ER.

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Silicon photonics has a great development in the past decade with the merits of compatibility with complementary metal-oxide-semiconductor (CMOS) microelectronics fabrication processes and potentiality of large-scale photonics circuit integration on a silicon chip. A microring resonator, which has advantages of high Q-factor[1] and ultra-compact device footprint,[2] has also been used to fulfill many functions, such as all optical switches,[3] modulators,[4] tunable filters,[5] and all-optical logic gates.[6]

It is well known that clock recovery and extraction from NRZ signals, which do not carry clock component in principle, is very important in fiber communication systems. The wildly-used methods of converting NRZ-to-PRZ data format in fiber communication systems include a fiber Bragg grating (FBG) filter for compressing the NRZ carrier frequency components[7] and nonlinear optical effect in a semiconductor optical amplifier (SOA).[8] However, the above two methods cannot be used for on-chip photonics circuit integrations. Therefore it is required to find out a new method of NRZ-To-PRZ signals format conversion for on-chip photonics circuit integrations. In this Letter, we demonstrate a new method to solve this problem using a single passive silicon microring resonator.

The principle of all-optical NRZ-to-PRZ data format conversion using a silicon microring resonator has been analyzed in Ref. [9]. The silicon microring resonator can be used as a frequency spectrum filter. When the NRZ signals at the resonance wavelength of the microring resonator passes through this filter, the carrier frequency component will be cut off by the resonator and the signals at the through port will be changed into the PRZ format signals in time domain. In Ref. [9], a p-i-n diode is embedded in the device. The resonance wavelength can be tuned by controlling forward-bias voltage on the p-i-n diode. However, when free carriers are injected into the waveguide, thermal effect happens obviously with the recombination between electrons and holes. Because a microring resonator is very sensitive to thermal effect, the resonance wavelength is difficult to be stable. To avoid these negative effects, we fix the resonance wavelength of the resonator and change the carrier wavelength around it by tuning the tunable laser accurately.

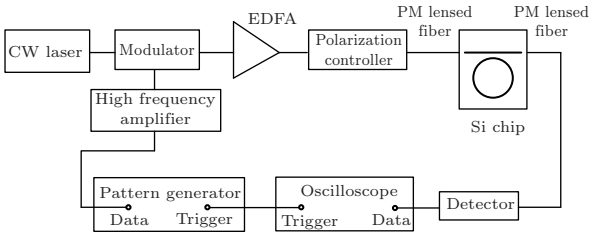


Fig. 1. This is our schematic experimental setup. CW: continuous wave; Modulator: $LiNO_3$ electro-optic (EO) modulator; EDFA: erbium-doped fiber amplifier; PM: polarization-maintain.

The schematic of experimental setup is illustrated in Fig. 1. A tunable laser is used as the light source, and the output cw laser light is modulated by a $LiNO_3$ EO modulator at a data rate of 3.55 Gbit/s, which is limited by our pattern generator. An EDFA is used to compensate for the insertion loss induced by the $LiNO_3$ EO modulator. The modulated laser light is turned into TE mode by the polarization controller, and then coupled into the bus waveguide through the input PM lensed fiber. At the output of the SOI device the light is also coupled from the bus waveguide into the output PM lensed fiber. Finally the optical data is collected by the 12 GHz detector and converted into electronic signals, and this electronic signal is displayed on oscilloscope. We can tune this tunable laser to accurately determine whether the light wavelength

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is at on-resonance or off-resonance of the microring resonator.

The microring resonator used in our experiment is provided by Jiang Xiao-qing in Zhejiang University, and it is fabricated by the standard commercial complementary-metal-oxide- semiconductor (CMOS) process. The cross section of the waveguide is rib waveguide, the waveguide width is 0.68 μm and height is 1 μm, and the slab height is 0.59 μm. In this waveguide structure, only TE fundamental mode is the guiding mode and other modes are radiated when they propagate along the waveguide. The microring resonator radius is 300 μm, and the gap between the bus waveguide and the curve waveguide is 1.43 μm. At both the input and output of the bus waveguide, we use tapered coupler to reduce coupling loss between waveguide and PM lensed fiber. The total insert loss is about 13.3 dB. Most of the total insert loss is induced by coupling loss between the fiber and the waveguide. Because we have not used any method to measure the propagation loss of the waveguide, we can not accurately measure the propagation loss of the waveguide and the fiber-to-waveguide coupling loss.

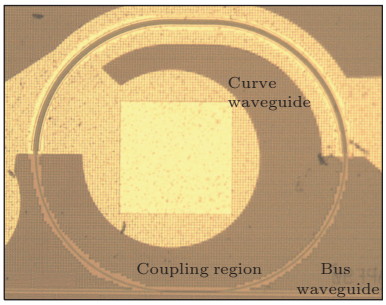


Fig. 2. Picture of the microring resonator. The input light is coupled into the bus waveguide through the PM lensed fiber. Some part of the light power is coupled into the curve waveguide in the coupling region.

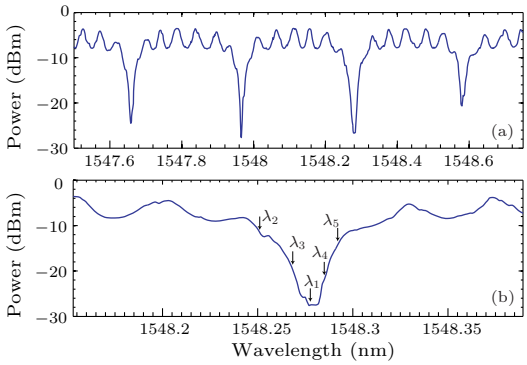


Fig. 3. (a) The optical spectrum of the microring resonator. The 3 dB bandwidth is about 0.065 nm; the ER is about 22 dB; the FSR is about 0.3 nm. (b) The optical spectrum around a resonant wavelength. Here $\lambda_1 - \lambda_5$ are different carrier wavelengths when we turn the carrier wavelength around this resonant wavelength discretely.

Figure 3 (a) shows the static optical spectrum of the microring resonator. The free spectrum region (FSR) is about 0.3 nm, and the ER is about 22 dB. Because of the loss of the ring waveguide including propagation loss, curve loss and side-scattering loss, the Q-factor of the resonator is about 23800. We can see that there is a parasitical F-P resonance stripe on the optical spectrum of the microring resonator. This is ascribed to reflections of the two parallel sides of the waveguide, which are formed when the silicon chip is cleaved from the SOI wafer. We can further deposit anti-reflective coating on the sides of the silicon chip to take away this parasitical F-P resonance.

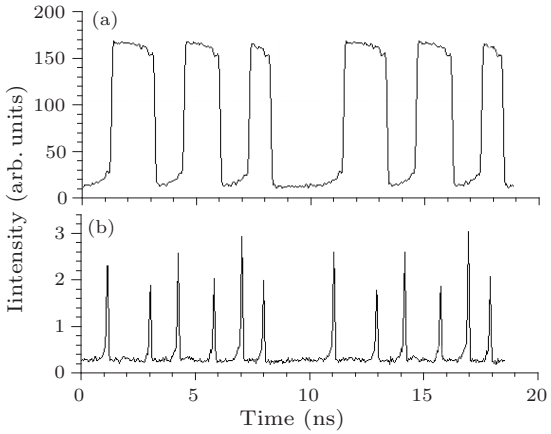


Fig. 4. (a) Because carrier wavelength is at off-resonance, the NRZ data series is not converted by the MRR. (b) When carrier wavelength is at on-resonance, the NRZ data series is converted into PRZ format.

Here we introduce our experiment of on-chip all-optical NRZ-to-PRZ data format conversion. Figures 4(a) and 4(b) show the result of NRZ-to-PRZ data format conversion at 3.55 Gbit/s. Figures 5(a)–5(f) show the change of output optical waveform with the wavelength tuning from the blue to the red side of the resonance wavelength. The principle of NRZ-to-PRZ format conversion is mainly analyzed in Ref. [9]. The influence of the factors such as ER and phase response has been discussed. Figure 5(a) shows the NRZ signals on the off-resonance wavelength. In Fig. 5(b), when the carrier wavelength is tuned to on-resonance wavelength λ_1, at which the ER is the maximum, the NRZ signals are mainly converted into the PRZ signals. The width of converted PRZ signals is 108 ps, and the ER is 4.98 dB. As long as the carrier wavelength is not at the center of the resonance, the converted PRZ waveform is distorted. From Figs. 5(c) and 5(d) we see that the "0" level of the PRZ signals rises due to the deviation of the carrier wavelength from the resonance wavelength; and the larger the deviation is, the greater the "0" level rises. We ascribe it to the reduction of dc and low-frequency components of NRZ signals coupled into the microring resonator. We also see that with the carrier wavelength tuned

away from the resonance wavelength, the amplitude of the PRZ signals at the NRZ leading edge becomes greater than that at the trailing edge. The ER reduction renders signal distortion. This analogous distortion also exists when the carrier wavelength is at the red side of the resonance wavelength. However, as shown in Figs. 5(e) and 5(f) the larger amplitude of PRZ signals happens at the trailing edge of NRZ signals and the smaller amplitude happens at the leading edge. This difference is ascribed to different phase responses discussed in Ref. [9]. When the microring resonator is under the under-coupling condition, the larger amplitude is at leading edge; and when the device is under the over-coupling condition, the larger amplitude is at the trailing edge. These two different coupling conditions correspond to the fact that the carrier wavelength is at the blue side and the red side of the resonance wavelength respectively. In general, our experimental result is consistent with the theoretical analysis.

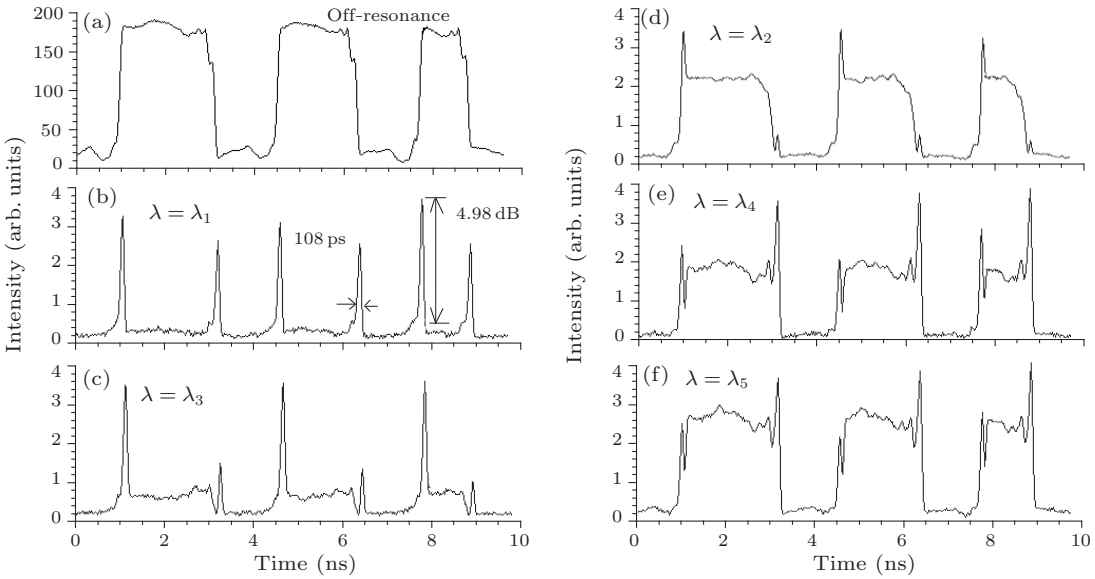


Fig. 5. (a) The NRZ data series waveform when carrier wavelength is off-resonance. (b)–(f) The converted waveforms from the NRZ data series for various carrier wavelengths tuned discretely around resonance wavelength, with λ_1 set on the on-resonance wavelength, λ_2 and λ_3 on the blue side of the on-resonance wavelength, λ_4 and λ_5 on the red side of the on-resonance wavelength, respectively, as depicted in Fig. 3(b).

In summary, we have reported our experimental result of NRZ-to-PRZ data format conversion at 3.55 Gbit/s using a passive microring resonator on a silicon chip. The width of the converted PRZ signals is 108 ps and the ER is 4.98 dB. Because of the bit rate limitation of our pattern generator, the data rate is 3.55 Gbit/s. This method can still be competent at higher speed data rate. The converted PRZ signals will be used to extract clock signals on a single silicon chip in our next work.

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References

[1] Baehr-Jones T, Hochberg M and Scherer A 2004 *Appl. Phys. Lett.* **85** 3346
[2] Xu Q F, Fattal D and Beausoleil R G 2008 *Opt. Express* **16** 4309
[3] Almeida V R, Barrios C A and Lipson M 2004 *Opt. Express* **29** 2867
[4] Almeida V R, Xu Q F and Lipson M 2005 *Opt. Express* **30** 2403
[5] Nawrocka M S, Liu T and Panepucci R R 2006 *Appl. Phys. Lett.* **89** 071110
[6] Xu Q F and Lipson M 2007 *Opt. Express* **15** 924
[7] Li X U, Kim C and Li G F 2004 *Opt. Express* **12** 3196
[8] Slovak J, Bornholdt C and Sartorius B 2006 *IEEE Photon. Technol. Lett.* **18** 844
[9] Zhou L J, Chen H, Poon A W 2008 *J. Lightwave Technol.* **26** 1950