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Microwave Photonic Phase Shifter Based on Tunable Silicon-on-Insulator Microring Resonator

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Abstract: We demonstrate a microwave photonic phase shifter based on an electrically tunable silicon-on-insulator microring resonator. A continuously tunable phase shift of up to 315° at a microwave frequency of 15GHz is obtained.

OCIS codes: (060.5625) Radio frequency photonics; (130.3120) Integrated optics devices; (230.5750) Resonators;

1. Introduction

Microwave photonics for processing microwave and millimeter-wave signals in the optical domain has lately received increasing interests [1]. Photonic components, providing compact size, large bandwidth, fast tunability, immunity to electromagnetic interference and low weight, have been widely implemented in microwave systems. Microwave phase shifters as key components in many microwave applications such as phased-array antennas [2] and microwave filters [3] have gained much interest. So far, several schemes for phase shifting including wavelength conversion [4], stimulated Brillouin scattering [5], and slow-light effects in semiconductor devices [6,7] have been reported. Recently, silicon ring resonators were also used as phase shifter to realize a 0-260° phase-shifting range [8]. In this paper, we demonstrate a tunable microring resonator based phase shifter with a larger phase-shifting range of 0-315° and much lower power consumption. This device is easily integrated with photonic and electronic circuits and offers stable tuning characteristics.

2. Measurement

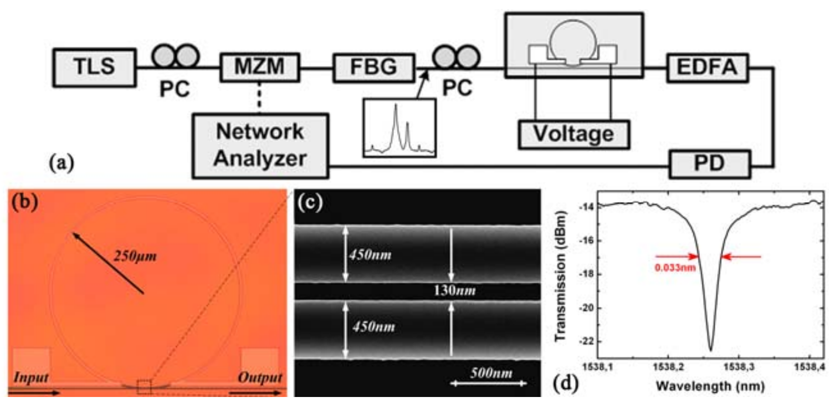

Fig. 1. (a) Experimental setup for phase shift measurements. (b) Top-view optical microscope picture of the fabricated microring resonator with micro heater. (c) Scanning electron micrograph picture of the coupling region between the waveguide and the microring. (d) Transmission spectrum of the microring resonator around 1538nm for TM mode.

The experimental setup used to measure the microwave phase shift with a microring resonator is schematically shown in Fig. 1(a). Light from a tunable laser source (TLS) was modulated through a Mach-Zehnder modulator (MZM) by a microwave signal from the network analyzer. A fiber Bragg grating (FBG) filter was used to filter out one of the sidebands of the modulated signal. After that, the optical signal, with the envelope modulated at the microwave frequency in the time domain and with two peaks of the desired frequency spacing in the optical spectral domain, was generated and sent into a microring resonator with micro heater as shown in Fig. 1(b). The microring resonator was fabricated in SOI material with a top silicon thickness of 340nm and a 1μm buried silicon dioxide. The waveguides in the device are 450nm wide and the gap between the ring and the bus waveguide is 130nm as illustrated in Fig. 1(c). The polarization of the input light was adjusted to the quasi-TM mode with a fiber polarization controller (PC). Figure 1(d) shows the transmission spectrum of the microring resonator for TM mode. The optical phase of the output field from the microring resonator experiences a π shift on resonance, and the full phase shifting range of 0-2π can be achieved near the resonance [8]. By applying a voltage to the micro heater, the resonance frequency of the ring can be tuned with respect to one of the peaks of the optical signal to change the

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phase difference between the two peaks. Amplified by an erbium-doped fiber amplifier (EDFA), the output signal was detected by a high-speed photo detector (PD). Due to the beating between the two optical frequencies at the high-speed PD, the optical phase change will be finally converted to the microwave signal. Then the network analyser was used to extract the information of phase and power changes of the microwave signal carried by the optical beam.

A microring resonator with 0.033nm 3-dB bandwidth (quality(Q)-factor ~ 46,000) was first tested in the experiment. Figure 2(a) shows the measured maximum phase shifts with different microwave frequencies modulated on the optical beam. The maximum phase shift increases linearly as the frequency increases. The measured RF phase shift and RF power variation as a function of applied electrical power to the micro heater is also shown in Fig. 2(b). A continuously tunable RF phase shift, through changing the applied electrical power, is demonstrated, and the maximum RF phase shift of 315° for a microwave frequency of 15GHz is achieved. However, the relatively large RF power variation (about 7dB) due to the high extinction ratio of the resonator hampers the application as a phase shifter. These problems can be resolved by using a lower Q-factor microring resonator with lower extinction ratio. We also tested another ring resonator with 6dB extinction ratio and ~0.067nm 3-dB bandwidth which corresponds to a lower Q-factor of 23,000. The RF power variation is ~5dB smaller than the high-Q ring resonator (see Fig. 2(c)). Though the maximum phase shift of ~205° is smaller than that of high Q ring resonator, the phase shift is more linear. The small power variation and phase shifting linearity with applied control power make the lower Q ring resonator a more practical option for the microwave applications.

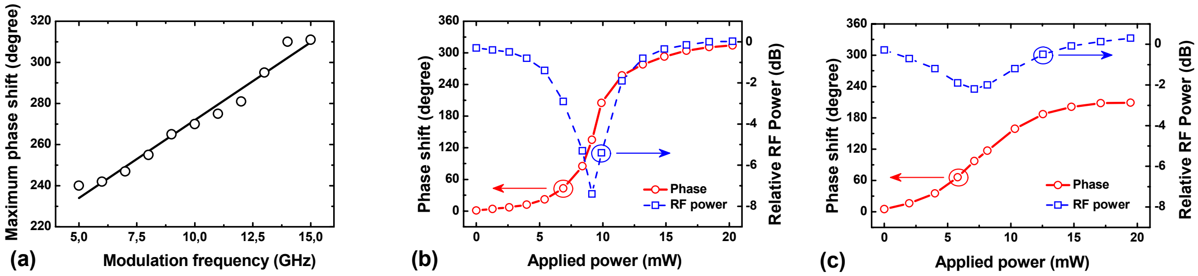

Fig. 2. (a) Measured maximum RF phase shift versus the microwave frequencies with the microring resonator of 46,000 Q-factor. (b,c) Measured RF phase shift and relative RF power versus the applied power to the micro heater on the microring resonator with a Q-factor of 46,000 (b) and 23,000 (c).

Compared to the device in [8] where the microring resonator was tuned by a strong optical power, our device is more energy efficient and offers larger phase shift and simpler control. Only a small electrical power of 11mW is needed to obtain ~260° (~4.6 rad) phase shift which is one third of the optical power in the previous device. In addition, our device can be easily cascaded and controlled independently to realize a relatively linear full 2π phase shift (360°).

3. Conclusion

We have introduced electrically tunable SOI microring resonator based microwave phase shifters. A phase shifting range of 0-315° has been achieved at a microwave frequency of 15GHz with a microring resonator of 46,000 Q-factor. A smooth phase shift of up to 205° has also been demonstrated with only ~2dB RF power variation for a microring resonator of 23,000 Q-factor. The results indicate that it is possible to realize a continuously tunable 360° RF phase shifter with small power consumption by cascading two microring resonators.

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