360° Tunable Microwave Phase Shifter Based on Silicon-on-Insulator Dual-Microring Resonator

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Abstract—We demonstrate tunable microwave phase shifters based on electrically tunable silicon-on-insulator dual-microring resonators. A quasi-linear phase shift of 360° with ~2dB radio frequency power variation at a microwave frequency of 40GHz is obtained.

Keywords—Integrated optics devices; microwave photonics; radio frequency photonics; silicon microring resonator.

I. INTRODUCTION

Microwave photonics has lately received increasing interests [1]. Photonic components, providing compact size, large bandwidth, immunity to electromagnetic interference and low weight, have been widely demonstrated in microwave systems. Microwave phase shifters with a full 2π phase shifting range are key components in many microwave applications, such as microwave filters. So far, several schemes for phase shifting including wavelength conversion [2], stimulated Brillouin scattering [3], slow-light effects in semiconductor devices [4] have been reported. Recently, silicon-on-insulator (SOI) microring resonators (MRRs) have also been used as phase shifters [5,6]. A 0-260° shifting range was realized in [5] with thermo-optical tuning from a high-power control light. Previously, we also demonstrated an electrically tunable phase shifter based on MRR with a phase-shifting range of 0-336° in [6]. However, it is difficult to realize a full 2π phase shift by using a single MRR. Furthermore, the radio frequency (RF) power varies dramatically during the phase shifting operation. Here, we demonstrate microwave phase shifters with tuning range larger than 2π by using two cascaded MRRs with independent electrically controllable micro heaters. A quasi-linear phase shifting rang of 0~360° with only 2dB RF power variation is obtained. These devices can be easily integrated with photonic and electronic circuits.

II. DESIGN

Fig. 1(a) shows the schematic drawing of an all-pass dual-microring resonator (DMRR). The two cascaded rings are designed to have identical geometries. Figs. 1(b) and 1(c) illustrate the transmission and the phase for the DMRR at the through port with different resonance offsets (ω_{MRR2}-ω_{MRR1}) between the two MRRs. As shown in Fig. 1(c), the optical phases experience a monotonic phase change from negative to positive detuning. If, in this case, an optical signal carrying a microwave signal with two peaks of the desired frequency spacing is input to the DMRR, the phase difference of the two peaks of the transmitted field can be tuned by changing the resonance frequency, and thus realizing a microwave phase shift. As shown in Figs. 1(b) and (c), the transmission spectrum and the phase curve can be altered by offsetting the resonances between the two MRRs. Here, amplitude coupling coefficient κ, power transmission coefficient a² and the ring diameter are assumed to be 0.2, 0.99 and 35μm, respectively.

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The measured RF phase shift and RF power variation as a function of the applied electrical power on both micro heaters are also shown in Fig. 3(a). A continuously tunable RF phase shift is demonstrated, and the maximum RF phase shift of 540° is achieved with the RF power variation of ~4dB. However, if the device is operated within the gray region shown in Fig. 3(a), one can obtain not only a quasi-linear phase shift of 360°, but also an RF power variation of only 2dB. In this case, the total required operation power is ~2mW. We also tested another DMRR with a smaller ring-to-waveguide gap of 100nm which corresponds to a lower quality (Q)-factor for the resonator. As shown in Fig. 3 (b), a phase shift larger than 360° is still achieved. Although the maximum phase shift is reduced from 540° to 390°, the total RF power variation in the whole tuning range is only 1dB which is smaller than that of the high-Q device.

IV. CONCLUSION

We have introduced microwave phase shifters based on electrically tunable SOI DMRRs. A quasi-linear 360° phase shift has been achieved at a microwave frequency of 40GHz with 2dB RF power variation. A phase shift of 390° has also been demonstrated with only 1dB RF power variation using a DMRR with lower Q-factor. These devices are believed to be potentially useful in microwave applications.

REFERENCES