High-index-contrast microphotonics, from concept to implementation

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Abstract: We review major developments that have led to a high performance, polarization independent, microphotonic circuit. The design and fabrication of complex high-order microring-resonators, along with techniques to freely manipulate polarization states on-chip are presented.

OCIS codes: (130.3120) Integrated optics devices; (230.5750) Resonators; (230.7370) Waveguides.

1. Introduction

In recent years significant progress has been demonstrated in the development of the components necessary to implement microphotonic circuits. The strong confinement offered by high index contrast (HIC) waveguides has enabled the formation of tight, low loss, waveguide bends promising dense packing of optical components on-chip [1]. The use of low-Q coupled cavity design principles borrowed from microwave engineering has enabled broadband and low loss T-splitters and crossings [2] while adiabatic transitions have led to nearly lossless coupling to single-mode fibers. Moreover, microring-resonator-based filters have been demonstrated with sharp-rolloffs and flat passbands [3,4]. Still, many applications, such as optical add-drop multiplexers, require larger free-spectral ranges (FSR) and thus even higher index contrast waveguides. Yet, as index contrasts are increased, maintaining filter performance and achieving polarization independence becomes increasingly difficult.

2. Discussion

Here, we review the approach taken to enable the use of higher index contrasts and larger FSRs while maintaining high performance filter characteristics and achieving chip-level polarization independence. The design, fabrication, and measured performance of complex high-order microring-resonator filters will be discussed. Examples include high order multistage filters [5] and filters with two-point coupling [6] to obtain deep through-port extinction and

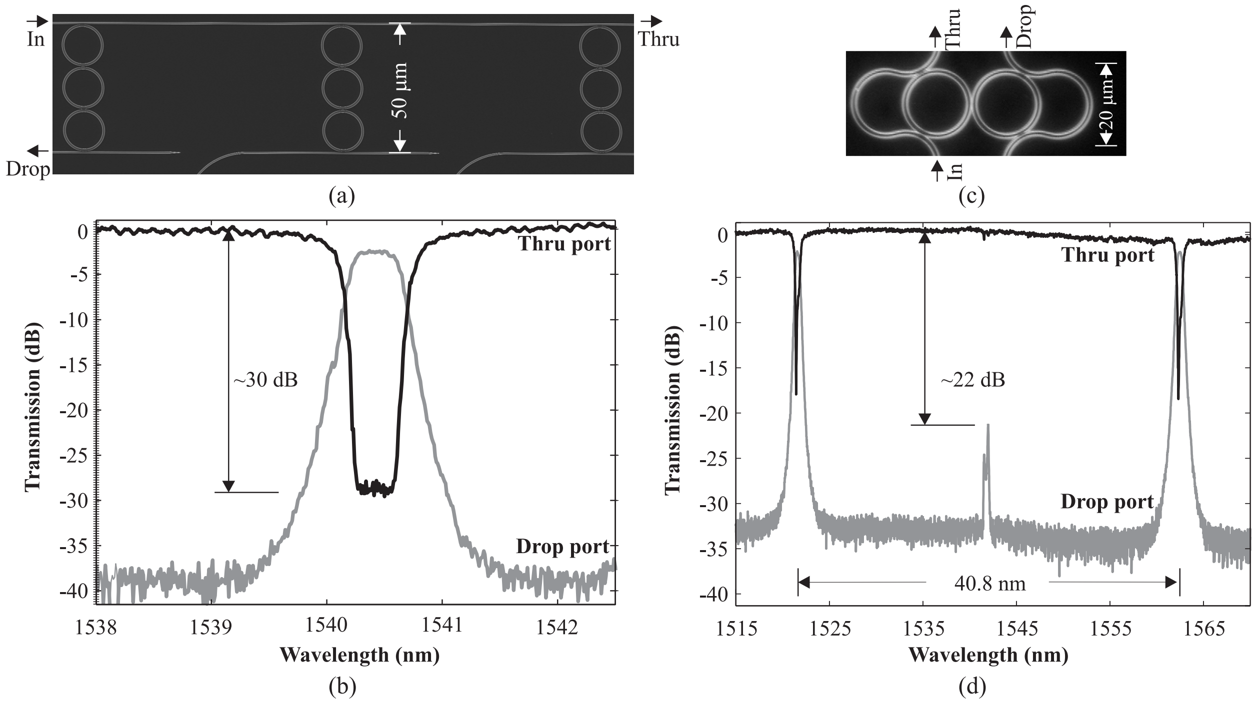

Fig. 1. (a) Micrograph of a multistage 3rd order microring resonator filter with (b) its measured performance [5]. (c) Micrograph of a 2nd order filter with two-point coupling used to double its FSR and (d) its measured performance [6]. Both filters have silicon-rich silicon nitride cores ($n_c = 2.2$) with air upper/lateral and lower thermal oxide claddings ($n_{cl} = 1.445$)

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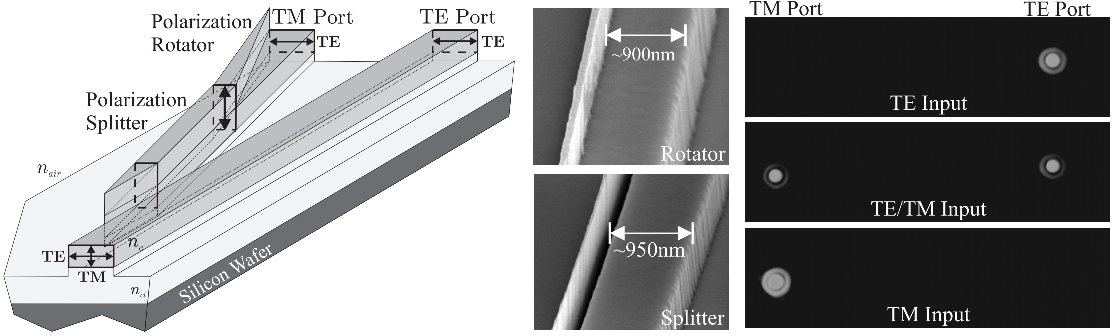
doubled FSRs, respectively, formed with silicon-rich silicon nitride cores ($n_c = 2.2$) with air upper/lateral and lower thermal oxide claddings ($n_{cl} = 1.445$). Micrographs of each are depicted in Fig. 1. The designs began by using a full-vector finite-difference cylindrical modesolver to ensure the microring-resonators had both high Q and large FSR. The filter responses were then modeled using a transfer matrix approach and the coupling gaps obtained from three-dimensional finite-difference time-domain (FDTD) simulations. The filters were then fabricated using a process similar to that described in [7] based on direct-write scanning-electron-beam lithography (SEBL) with strict dimensional control obtained by careful calibration. For the 3rd order filters, a higher e-beam dose was applied to the center ring to compensate for coupling induced frequency shifts (CIFS) and e-beam proximity effects. For the multistage filters the desired 40GHz 1dB-passband was obtained with a ~ -3dB drop loss and 30dB extinction in the through port, the highest reported in a microring filter (Fig. 1b). Moreover, the two-point coupling strategy successfully demonstrated the ability of doubling the FSR of a filter from 20.4 nm to 40.8 nm (Fig. 1d).

Achieving polarization independence directly in an index contrast as high as the silicon nitride to air material system would require angstrom-level control on the waveguide dimensions. Rather than attempt to achieve such strict dimensional control, we chose to implement a polarization diversity scheme with all functionality realized on-chip. To do so, integrated polarization splitters and rotators were designed [8,9] and fabricated [10]. A diagram depicting the device along with SEMs of the structure, and IR images of the output as a function of the input polarization state are presented in Fig. 2.



(a) (b) (c)

Fig. 2. (a) Diagram of a polarization splitter-rotator (PSR) fabricated in the silicon nitride material system, (b) micrographs of fabricated polarization splitters and rotators and (c) IR images of the output for various states of the input polarization indicating the functionality of the PSR [8-10]. These devices also have silicon-rich silicon nitride cores ($n_c = 2.2$) with air upper/lateral and thermal oxide lower claddings ($n_{cl} = 1.445$) and guide geometries compatible with the filters of Fig. 1.

3. Conclusions

Complex, high performance, HIC microring resonators were designed and fabricated in silicon-rich silicon nitride. To overcome the innate polarization sensitivities of these HIC devices, mating polarization splitters and rotators were designed and fabricated to enable a single on-chip polarization. Recently, the filters and PSRs have been integrated to create a polarization independent optical add-drop multiplexer. Preliminary measured results indicate nearly ideal performance, providing a path for polarization independent HIC microphotonics.

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