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Cross-Connected Notch Filter with a Flat Stopband and Double Free-Spectral-Range

Chyong-Hua Chen

National Chiao Tung University, Hisnchu, Taiwan,
chyong@mail.nctu.edu.tw

Abstract: A novel cross-connected filter constructed by a microring resonator, a multi-mode interference based crossing and a resonant loop is numerically presented. The microring resonator consists of two arc waveguides with slightly different effective indices to achieve a second-order filtering owing to the existence of the bidirectional propagation modes in the resonator. The device is numerically simulated using the scattering matrix method, functioning as a notch filter with a square stopband and double free spectral range by manipulating the length of the resonant loop and the effective indices of the arc waveguides.

Introduction: In the past decades, microring resonators (MRRs) are promising building blocks in wide applications, such as wavelength-division multiplexing (WDM) communication system, telecommunications, computer interconnects, and biochemical sensing [1-3]. For the applications of an optical channel filters in the WDM system, it is required to have a boxlike spectral shape, large out-of-band signal rejection and wide free spectral range (FSR) to ensure signal fidelity, to enhance the tolerance of signal wavelength shifts and to accommodate large channel counts. Various approaches have been proposed to enlarge the FSR, including reducing the microring radius [4], cascading serial MRRs based on Vernier effect [5-7] and merging Mach-Zehder interferometer with MRRs [8-9]. However, multiply coupled cavities are used to realize a boxlike response, giving rise to the increment of the device's size [5-8]. Here, we propose a novel cross-connected notch filter using a single MRR to realize a flat response and double FSR. This filter consists of a multimode interference (MMI) crossing, a MRR and a resonant loop connecting the throughput- and one drop-ports of the MMI crossing. The MRR is assembled by two arc waveguides with different effective indices to obtain a second-order microring filter with a flat response, and the length of the resonant loop is adjusted to realize double FSR.

Design of the cross-connected notch filter: The configuration of the proposed cross-connected notch filter is schematically depicted in Fig. 1. This filter consists of a MMI crossing and a side-coupled MRR with a radius of R_1. The throughput- and one drop ports of the MMI crossing are connected to form a large resonant loop with a length of L. The MMI crossing design is based on our previous work [10], which is compact, low loss, low crosstalk and broadband. The MRR is comprised of two arc waveguides with subtend angles of θ and $2\pi-\theta$, respectively. Two arc waveguides have different effective indices to allow both forward and backward propagating modes to travel inside the MRR and the resonant loop. The separation distance of the directional coupler between the MRR and the bus waveguide in the throughput/drop port is d, corresponding to the coupling coefficient κ.

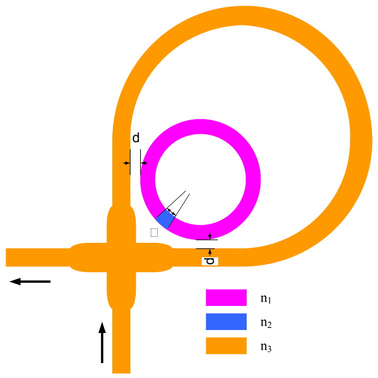

Fig.1. Schematic diagram of the proposed cross-connected notch filter

Scattering matrix approach taking into account the bidirectional coupling among these elements is used to analyze this structure [11]. Suppose that the effective indices of two arc waveguides and the resonant loop are n_1, n_2 and n_3, respectively. The attenuation coefficients for these waveguides are α. From the transfer function at the other drop port, the path length difference between the three quarters of the MRR and the resonant loop has to equal to half path length of the MRR, i.e.,

$$n_3 L - 3\pi n_1 R_1 / 2 = \pi n_1 R_1 \qquad (1)$$

This formulation indicates that the arc waveguide with subtend angle of θ arranged in the lower quarter of the MRR imperceptibly affects the FSR. Consider a structure with the following parameters: R_1=5 μm, n_1= n_3=2.33, n_2=2.53, α=0.0001 and θ=0.5. Then, the corresponding L is 39.3 μm. The coupling coefficient κ is critical to the performance of this device, and κ for each coupler is 0.99 to obtain the minimal transmission in the stopband in this case. Figure 2 shows the transmission spectrum of this structure. The FSR of 61.1 nm and the full width at half maximum (FWHM) of 7 nm are observed. The FSR of this structure is expanded roughly twice that of a single MRR, ~31 nm with a radius of 5 μm. The maximum transmission of roughly 0.97 is obtained due to the propagation loss of MRR and the loop.

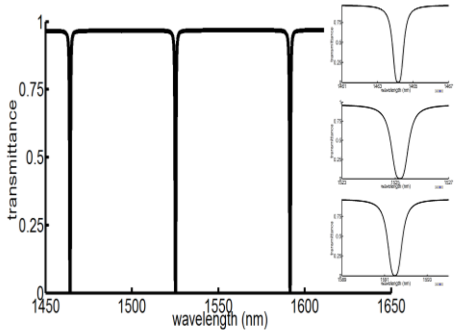

Fig. 2. Transmission spectrum of the designed notch filter

The variation of n_2 on the transmission spectrum is illustrated in Fig. 3. For each n_2, the coupling coefficient κ is optimized to obtain the minimal transmission in the stopband. We observe that a Lorentzian-shaped spectrum is obtained as n_2=2.33, and the FWHM becomes wider and the spectrum becomes U-shaped as n_2 increases. In addition, the resonant wavelength shifts to longer wavelength. As shown in the inset of Fig. 3, FSR remains the same as n_2 varies, but the crosstalk roughly at the wavelength of 1495 nm becomes more obvious owing to the phase mismatch between two resonances.

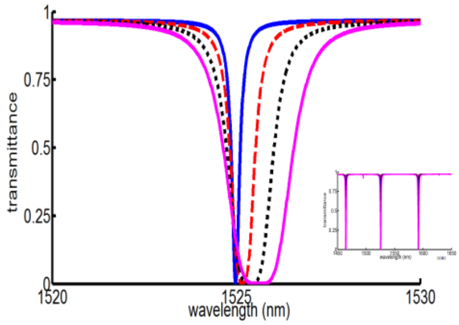

Fig. 3. Transmission spectra for n_2=2.33 (blue curve), 2.53 (red curve), 2.73(black curve) and 2.93 (magenta curve).

Conclusion:

We numerically present a compact cross-connected notch filter with a flat response and the double FSR by using scattering matrix method. This filter consists of a MMI crossing, a MRR and a resonant loop. The MRR consists of two arc waveguides where forward and backward traveling modes propagate, and then a second-order filter with a square response is obtained by adjusting the coupling coefficient κ. The double FSR is realized by controlling the length of the resonant loop roughly equal to the perimeter of five-quarter MRR. The bandwidth of this filter can be controlled by varying the effective index difference between the arc waveguides.

References

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