Box-like filter response of two-dimensional array of microring resonator fabricated in silicon-on-insulator technology

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Abstract- **We show theoretically and demonstrate experimentally that box-like response can be obtained using 2D arrays of microring resonator. The box-like response is manifested from the complementary photonic bandgap properties of the column and row configurations. The observed sidelobe suppression is ~10dB, while the usable bandwidth can be as high as 500 to 750 GHz.**

I. THEORY

Micoring resonator has been extensively explored as switching, sensing, and filtering devices due to its resonant behavior [1]. Integrating each of these rings in array fashion has been proposed and demonstrated for synthesizing high order filters that has box-like response [2-9]. Two array geometries have been proposed for these filters.

The first configuration [3-6], which we refer as Type 1, is an array of evenly spaced identical resonators indirectly coupled to two waveguide buses [see Fig. 1(a)]. This configuration is identical to Bragg grating with each ring cavity functioning as frequency dependent 'mirrors'. As the light resonates in the ring, the light is dropped from one bus to the other and interferes with other dropped light from other rings. The flat top response can be realized when the intercavity interference is constructive, that is when the intercavity spacing is half the cavity length (ring circumference) or $2L_B = L_{CAV}$. The limitation of this approach is, while constructive intercavity interference produces flat-top spectrum around resonance, it also produces sidelobes off resonance in the Drop (D) spectrum. In the Through (T) output, one has the inverse situation in which the response is of high contrast but with ripples at the band of interest.

The second configuration [7-9], which we refer to Type II, is shown in Fig. 1(b). This configuration is analogous to cascade of Fabry Perot mirrors. Here the ring cavity only interacts with its adjacent rings, and the input/output waveguide buses are only coupled to the first and last rings. The intercavity interaction causes resonance splitting and the number of split resonances is equal to the number of cavities in the configuration. The flat top response can be obtained when the coupling coefficients between the rings and between the waveguide and the ring are set to different values [9]. For the drop channel, the light will have to go through all the rings, hence all the rings need to have identical resonance in order to make the resonance splitting occur as expected. Since the flat band is produced by means of resonance splitting, the contrast is generally high. But the limitations are the coupling coefficients need to be tuned separately and the rings have to be identical.

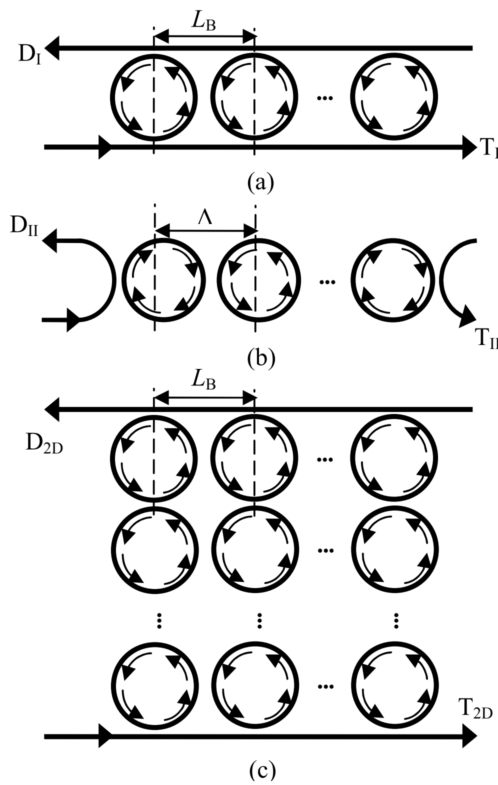

Fig. 1. Two conventional geometric array for high order filter response: (a) Type I and (b) Type II. (c) The proposed 2D array.

The Type I and Type II configurations may be considered as photonic crystal structures [10], with the reflection bands in the Drop spectrum representing photonic bandgaps where light cannot propagate through the structure. The photonic bandgaps of Type I and Type II structures exhibit complementary features. First, Type I's photonic bandgap is centered around the ring resonance while Type II's bandgap

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occurs when the rings are off resonance. Second, the bandgap width for Type I is proportional to the coupling strength between the waveguide and the ring; the stronger the coupling the stronger the optical feedback and this results in a more rapid formation of photonic bandgap. In Type II structure, the bandgap is formed by interference between successive reflected lights from the ring-ring interfaces, hence the bandgap width is inversely dependent on the coupling strength between adjacent rings, because the stronger the coupling strength, the weaker the 'reflectivity' (optical feedback) between the rings.

In this paper, we show that a combination of Type I and Type II configurations is able to produce a flat-top response with high contrast. As shown in Fig. 1(c), the 2D configuration is composed of Type I in the x direction and Type II in the y directions. The key principle of the 2D array is to harness the complementary features of the photonic bandgaps of Type I and Type II so as to suppress *both* the ripples and sidelobes in and outside the reflection bands. The coupling coefficients are made identical so that the photonic bandgap in x and y directions are complementary. The number of rows in the y direction has to be odd in order to provide optical feedback from one column to the other. Around the ring resonance, the propagation in the x directions is forbidden because of the destructive interference in Type I. At the same time, the propagation in y direction is encouraged due to the constructive interference in Type II. Similarly around the anti-resonance, the propagation in x direction is encouraged and the propagation in y direction is forbidden. This complementary bandgap suppresses the interaction between columns so as to suppress the sidelobes or ripples in Type I and Type II structures.

II. EXPERIMENT

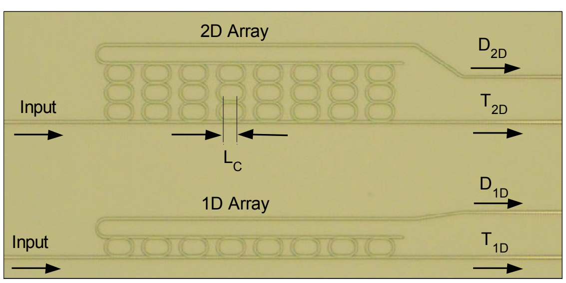


Fig. 2. The Fabricated 1D and 2D Array.

In order to demonstrate the sidelobe suppression in the 2D array, we fabricated 1x4, 1x8, 3x4, 3x8 configurations, with 1x8 and 3x8 shown in Fig. 2. The devices are fabricated using deep-UV (DUV) CMOS process [11] in silicon-on-insulator (SOI) technology. The waveguide width is 450nm and the silicon thickness is 200nm. The ring radius is 5µm. The couplings between the rings and between the waveguide and the ring are introduced by racetrack coupling of length L_C=8µm. In the measurements, the coupling from the external light source to the optical waveguide is facilitated by the use of second order grating that has been integrated with the device. The fiber is butt-coupled to the grating 10^o off vertical. The coupling efficiency has a Gaussian spectral profile with a bandwidth of about 30nm. The device is excited with a broadband source. The output is then passed through a 90:10 splitter, where 10% power goes to fiber power meter (FPM) for alignment purpose and the rest goes to the optical spectrum analyzer (OSA) for normalization of the spectrum.

Fig. 3 shows the measured Through (T) and Drop (D) spectrum for 1x4 and 3x4 configurations. As demonstrated in the right panel, the sidelobes are suppressed by ~10dB. Such sidelobe suppression in D corresponds to the flattening in the T spectrum, as shown in the left panel. The usable filter bandwidth is about 4nm which corresponds to $\Delta f \sim \Delta\lambda c/\lambda^2$=500GHz. The observable contrast is ~30dB. The slope of the band edge of the T spectrum has increased from 12.5dB/nm to 21dB/nm. Simulations suggest that the 8µm racetrack length corresponds to ~50% power coupling. This is verified from the independent measurement of a fabricated one microring resonator coupled to two waveguide buses with the same racetrack length.

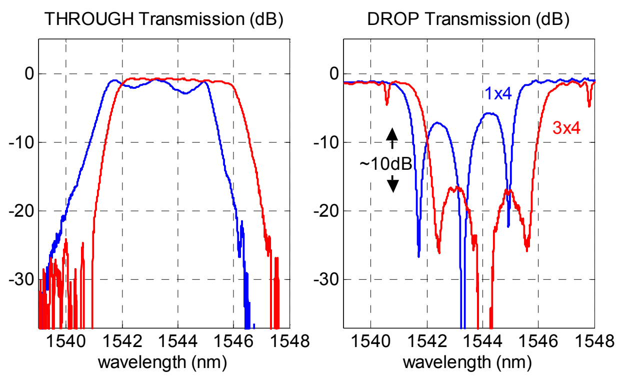
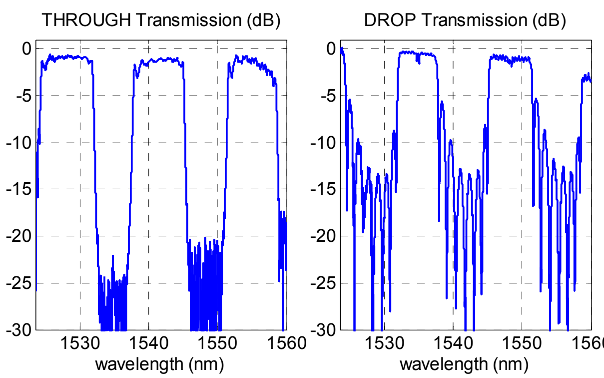


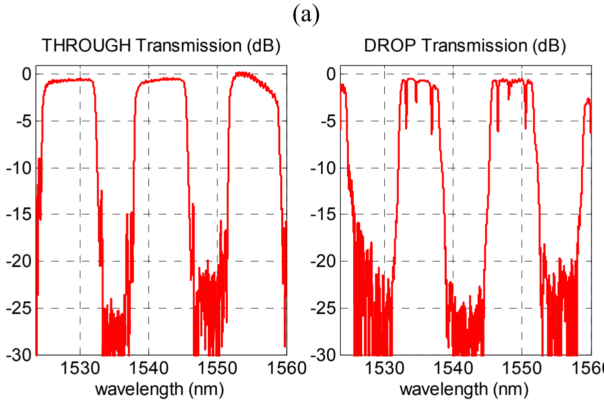
Fig. 3. The comparison between 1x4 and 3x4

In Fig. 4, we show the measurement results for 1x8 and 3 x 8 configurations with the same coupling (racetrack length). The Through response of 1x8 exhibits high contrast (~25dB) with the ripples ranging from ~0.5dB to ~3dB. The slope of the band edge increases by approximately twice to 27dB/nm compared with the 1x4 array, as expected from the fact that the structure has twice the number of rings. For the 3x8 configuration, the sidelobes in the spectrum cannot be observed due to the limitation of our equipment. However, the ~10dB suppression still can be seen if one compares the drop of 1x8 and that of 3x8. This is consistent with the comparison of 1x4 and 3x4. Due to the limitation of our equipment, the observable contrast is only 25dB, however simulation shows the contrast can reach 50dB while the sidelobes is at -25dB. The usable bandwidth of 3x8 structure is ~6nm, corresponding to ~755GHz bandwidth. The measured slope at the band edge is ~ 43dB/nm, again this is about twice that in the 3x4 structure.

We note that the spiky features in the Drop spectrum for both 1x8 and 3x8 arrays are attributed to the mismatch between the inter-coupling spacing and the cavity length. There are two kinds of bandgap in this structure. The first kind is the Bragg Gap that arises from Bragg mechanism whose resonance wavelength depends on the ring spacing distance ($2nL_B = m\lambda_{RES}$). The second kind is the resonator gap that arises from the individual rings. This bandgap is located at every ring resonance ($L_{CAV}=m\lambda_{CAV}$). These two bandgaps overlap only when the spacing (L_B) is half the cavity length (L_{CAV}), and this results in a more rapid forming of flat response. Simulations have confirmed that deviation of L_B/L_{CAV} from 0.5 could separate the Bragg Gap from the Resonator Gap, thereby forming narrow spikes in bandgap region.



(a)



(b)

Fig. 4. The measured spectra of (a) 1x8 array, and (b) 3x8 array.

The suppression of the sidelobes can still be made higher in the weaker coupling situation. However, the spiky features from the mismatch of L_B and L_{CAV} can be more dominant, thus care must be taken to ensure the matching of the ratio L_B/L_{CAV}=0.5. Note that increasing the contrast (or sidelobes suppression) may decrease the usable filter bandwidth, since the bandwidth is proportional to the coupling strength. However, such changes can be compensated by adjusting the ring size. Thus, it is possible to have independent control of contrast (from sidelobe suppression) and usable bandwidth.

In conclusion, we have verified our earlier theoretical prediction of realizing box-like filter using 2D microring arrays. We have demonstrated the sidelobe suppression of 10dB for device that has 50% power coupling. The filter has usable bandwidth of 500 to 755 GHz with the edge sharpness of ~21dB/nm to ~43dB/nm for 3x4 and 3x8 arrays, respectively. To improve the performance we have to reduce the mismatch between the ring spacing and the cavity length, and we could use weaker coupling strength in realizing the same filter.

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