

Proposal of a wavelength filter with a cut corner based on Equilateral-Triangle-Resonator

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Abstract: We propose an equilateral triangle resonator filter with an output waveguide and analyzed by the finite-difference time-domain technique. The filter can realize directional output with a high Q mode by means of the mode-field coupled into the output waveguide, which results a reduction in the scattering loss at the vertices. In addition, to the deformed equilateral triangle resonator filter, an optimum parameter with a cut corner of 0.23 μm , which is equal to that of the input waveguide and can be an optimal cut, is found to help increase in finesse, Q factors, extinction ratio and the output intensity on resonance of the drop port normalized with the through port.

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1. Introduction

Optical micro-resonators with the merits of ultrasmall cavity volume and high quality factors (Q-factors) whispering-gallery (WG) modes or WG-like modes have attracted great attention, they can be applied in photonic integrated circuits such as optical add-drop filters and sensors [1–4]. However, micro-resonator filters based on disk and ring resonators are difficult to achieve in directional output and high output efficiency due to the circular symmetry [5–7].

The numerical simulation results show that some deformed micro-resonators with WG-like modes can still have high-Q factors and high output coupling efficiencies [8–11]. The WG-like modes can also be confined in equilateral triangle resonator (ETR) due to the total internal reflection on the boundaries of the resonators [12]. It has been recognized that the filters based on polygonal-type micro-resonators have the advantage of flat resonator sidewalls, which introduce a long interaction length, but can also have shortcomings of cavity loss due to diffraction at sharp cavity corners [13]. Due to the reason that the off-resonance signal also drops down to the drop port as an on-resonance signal in the strong dispersive coupling region [14], the extinction ratio, defined as the ratio of the dropping power on resonance to the nearby off-resonance power, and finesse, defined as the ratio of the free spectral range (FSR) to the full width half maximum (FWHM) of the on-resonance peak, are greatly reduced, which are fatal to the practical applications of the ETR filters. Hence, it is necessary to find a way to avoid this problem.

In this letter, a filter based on the ETR with a directional output waveguide has been proposed and investigated by the two-dimensional (2D) finite-difference time-domain (FDTD) method, and a deformed ETR filter with a cut corner at one of the vertices connected to the output waveguide is introduced to improve the device performances. We calculate the mode field distribution by the FDTD method for the transverse magnetic (TM) modes in the deformed ETR filter, and analyze the modes in ETR with a straight directional output waveguide at one of the vertices. And then demonstrate that an ETR filter with a cut corner equal to the width of input waveguide can improve the performances in Q-factors, finesse, extinction ratio and intensity ratio of the on-resonance transmission significantly.

The light ray varies as it transmits inside the cavity, and will refract out of the micro-cavity forming a direction output as the incident angle is less than the critical angle of the total internal reflection. For the light rays inside the ETR, it can be assumed that the ETR is equivalent to a deformation of the Fabry-Perot cavity. Total internal reflection will occur as long as the angle of incidence on the boundaries of the triangle is greater than 30 degree due to the conditions of the total internal reflection. The optical path is just the product of the effective refractive index and the perimeter of the triangle which equals to $3a$, where a is the side length of the ETR [15].

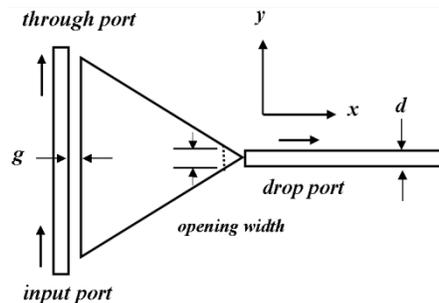


Fig. 1. Schematic of an ETR filter with an output waveguide at one of the vertices.

The schematic diagram of the ETR filter is plotted in Fig. 1, where an input waveguide parallels to one side of the ETR and an output waveguide is connected to one of the vertices. The input, through and drop ports are indicated. Both the refractive indices of the resonator and the waveguides are 3.2 and that of the external areas is 1. In the simulation, the parameters are set as follows: the side length $a = 6 \mu\text{m}$, the width of the input/output waveguides $d = 0.23 \mu\text{m}$, and the air gap between the input waveguide and the resonator $g = 0.20 \mu\text{m}$.

2. FDTD simulations of ETR and deformed ETR

2.1 Field distributions

Under a single-mode exciting source at the input port, we simulate the mode-field distribution of $\text{TM}_{0,22}$ mode for the ETR and of $\text{TM}_{0,20}$ mode for deformed ETR with a cut corner of $0.23 \mu\text{m}$ at resonant wavelength of $1.4845 \mu\text{m}$ and $1.4799 \mu\text{m}$ by the 2D FDTD technique, respectively. For the triangular resonator, there is a directional output on deformed cavity due to the large curvature at the cavity region, which leads to its unique characteristics of high output efficiency. FDTD simulations of field distributions for the ETR filter with an output waveguide connected to one of the vertices show that the modes with weak field distribution at the vertex can result in high Q-factors and a directional output [16]. The mode fields are confined in the ETR and guided by the output waveguide, and the field distributions are very weak at the vertices of the ETR, thus, an output waveguide connected to one of the vertices can introduce directional output based on high-Q confined in the ETR [17], and will not bring a large loss. Hence, directional output ETR filter can be fabricated by connecting an output waveguide to the triangle resonators at the area of weak mode-field distribution directly.

The stable field distributions of $\text{TM}_{0,22}$ mode for the ETR and $\text{TM}_{0,20}$ mode for the deformed ETR with a cut corner of $0.23 \mu\text{m}$ are demonstrated in Fig. 2, respectively. Comparing to Fig. 2(a), the field distributions of the $\text{TM}_{0,20}$ mode, as is shown in Fig. 2(b), can be more easily coupled into the output waveguide and result in high-Q mode directional output. From the results we can conclude that in the ETR, only the modes with a weak distribution in the vertex connected to the output waveguide can keep high coupling efficiency, which results in a reduction in the scattering loss at the vertices and high-Q confined modes. In fact, the Q factor can be adjusted by the width of the cut corner to the connected output waveguide, and directional output can be obtained from the ETR.

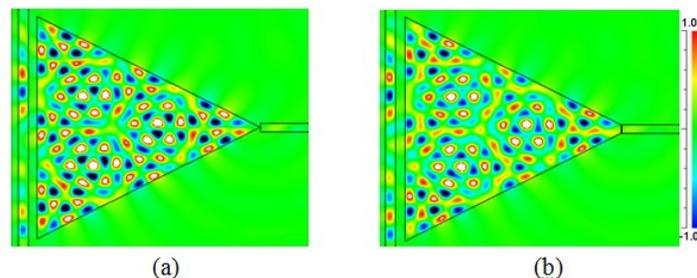


Fig. 2. The stable field distributions with a single frequency exciting source by the FDTD simulation at the wavelength of (a) $1.4845 \mu\text{m}$ in the ETR filter and (b) $1.4799 \mu\text{m}$ with a cut corner of $0.23 \mu\text{m}$ in the deformed ETR filter, respectively.

2.2 Simulated spectra

For the width of the input/output waveguides $d = 0.23 \mu\text{m}$, the spectral distributions of the normalized amplitude for TM modes at the through port and drop port are plotted as the blue lines and green lines in Fig. 3(a), respectively, where two dips of the transmission around $1.55 \mu\text{m}$ are observed. The mode frequencies and Q factors are calculated from the obtained intensity spectra.

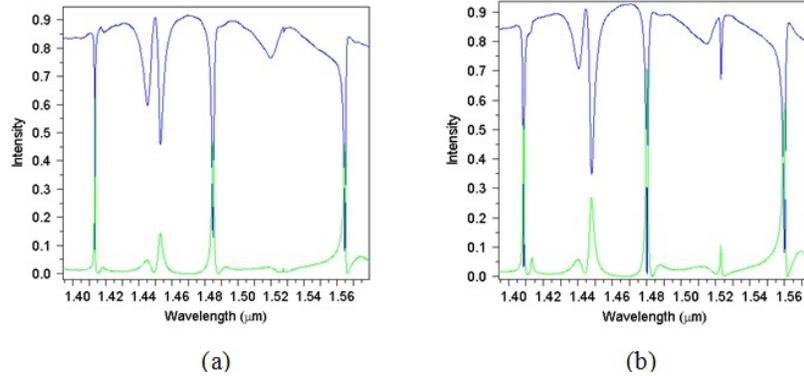


Fig. 3. Transmission spectra at the through (blue curve) and drop (green curve) port for (a) ETR and (b) deformed ETR filter with the side length $a = 6 \mu\text{m}$, $d = 0.23 \mu\text{m}$, $g = 0.20 \mu\text{m}$.

The results show that the power drops to the drop port at the on-resonance wavelengths of $1.4845 \mu\text{m}$ and $1.5646 \mu\text{m}$ in Fig. 3(a), respectively, with the FSR larger than 80 nm . These distinct peaks are corresponding to the resonant peaks and the peak wavelengths are the mode wavelengths. The ratio of the transmissions on-resonance at the drop port to the through port is 5.6 dB , and most power at the off-resonance wavelength of $1.4693 \mu\text{m}$ tunnels to the through port, while very little power drops to the drop port. Furthermore, the finesse of mode $\text{TM}_{0,22}$ is 50.5 at the wavelength of $1.4845 \mu\text{m}$, while the Q factor is 928 calculated from the local maximum and the width of the spectral distribution.

Due to that the deformed resonator reduces the effective volume of the resonator, a blueshift is observed for the resonance peak occurred at the deformed ETR filter with an cut corner of $0.23 \mu\text{m}$ at one of the vertices, which is just the optimized structural parameter of the deformed ETR filter. As is shown in the Fig. 3(b), most power at the on-resonance wavelength of $1.4799 \mu\text{m}$, which correspond to $\text{TM}_{0,20}$ mode, drops to the drop port, while it behaves to the opposite at the off-resonance wavelength, as is required for a practical filter. Comparing to the transmission spectrum shown in Fig. 3(a), the transmission spectrum can be exactly reflected by the deformed ETR. The ratio of the transmissions on-resonance at the drop port to the through port increases from 5.6 to 19.2 dB , which increases by more than 3 times. Furthermore, the finesse of the transmission spectra increases from 50.5 to 67.5 , which increases by 33.7% . The dropping power exceeds 52.3% and 28.5% at the on-resonance wavelengths around 1.48 and $1.56 \mu\text{m}$, respectively. The spacial Fourier transforms of the field distributions agree with the mode components, as shown in Fig. 2. The performance of the device shows an obvious improvement after the cut corner is introduced, where the extinction ratio increases from 31.8 to 39.9 dB around the wavelength of $1.48 \mu\text{m}$ and the Q factors increases from 928 to 1345 .

3. Results

We show both the transmission spectra of drop port and through port in the ETR filter as functions of the width of cut corner by FDTD simulation in Fig. 4. The finesse and Q factor at the through and drop ports of the deformed ETR filter are plotted as solid and dashed curves with the cut corner increased from 0 to $0.35 \mu\text{m}$, respectively in Fig. 4(a). As is shown in Fig. 4(a), the finesse reach a maximum value at the width of $0.23 \mu\text{m}$, which equals to the width of the input waveguide and be an optimal cut, and finally decreases with the width increases gradually. The profile of the Q factors are similar to the finesse spectrum at the drop port, where the Q factors increases from 928 to 1345 as the cut corner increases from 0 to $0.23 \mu\text{m}$, and finally decreases to 873 as the cut corner increasing. Both the transformation curves of the extinction ratio and intensity ratio in Fig. 4(b) behaves similarly as the spectra of the finesse and Q factors in Fig. 4(a).

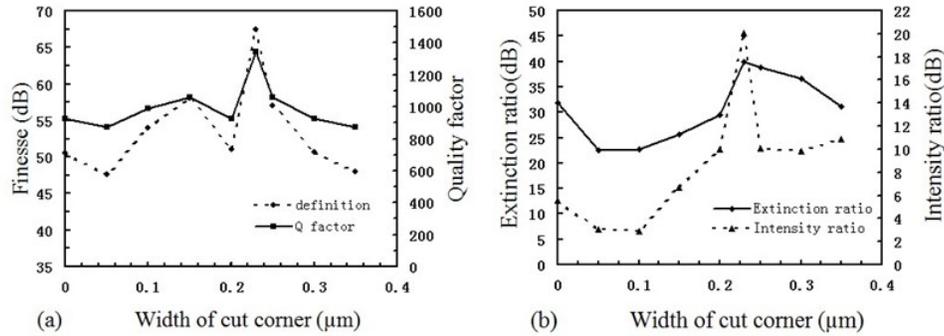


Fig. 4. (a) The finesse, mode Q factors and (b) extinction ratio, intensity ratio of the transmissions on-resonance at the drop port to the through port are plotted as the functions of the width of cut corner at one of the vertices with an output waveguide in the resonators, respectively.

With the optimal cut, the coupling efficiency is higher and result in a reduction in the scattering loss in the resonator. The results shown in Fig. 4 indicate that with the optimal cut the resonant mode is more easily coupled to the fundamental mode of the straight output waveguide. So an efficient and directional output ETR filter with an output waveguide connected to one of the vertices with optimum parameter can be obtained, while the width of cut corner in the ETR is the same as the input waveguide. Furthermore, resonant mode of the ETR with a cut corner at the vertices has maximum Q value. In addition, the mode in ETR and that in straight output waveguide are affected by the width of input and output waveguides. The mode field distributions in the triangular micro-resonators are modulated by the width of cut corner, and the cut corner of 0.23 μm can be an optimum status.

4. Conclusion

In conclusion, a filter based on the ETR has been proposed, directional output and high output efficiency are found, and a deformed ETR filter can make an obvious improvement on Q factor, finesse, extinction ratio and intensity ratio of the transmissions on-resonance at the drop port to the through port. We calculate the mode quality factors and simulate the mode field distribution for above filters. The ratio of the transmissions on resonance increases more than 3 times in a deformed ETR filter with a cut corner of 0.23 μm . While the finesse of the transmission spectra increases by 33.7% and the drop power exceeds 52.3% at the on-resonance wavelength of 1.48 μm . The results demonstrate that the ETR filter with an appropriate cut corner at the vertex connected to an output waveguide can keep a higher Q factor, finesse, and has a merit of efficient and directional output, which is suitable for optical information processing and practical applications.

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