Box-like Filtering Effect in Resonant Structure

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***Abstract*—We investigate the filtering properties of double ring resonator compared with single ring resonator. Double-ring resonator not only could generate strong absorption dip similar to the dip in single ring resonator. It also produces box-like filtering effect with high contrast ratio and flatness bandwidth. The box-like filtering effect could be optimized and applied as novel filter by adjusting coupling condition of each ring. It is benefit for the fields of optical information processing and optical communication.**

***Keywords*—ring resonator; filter; flatness bandwidth**

I. INTRODUCTION

Filter is one important component which contributes to the wavelength-division multiplexing (WDM). It is widely applied in optical signal propagation field. Ring resonator-based optical devices have been further investigated. They can be used as optical sensor[1], optical buffer[2], optical modulator[3] and optical switch[4]. In addition, data processing and data storage need more box-like filter[5] in order to tolerate wavelength shift during environmental change, especially for band-pass and band-stop filter. That means more broaden bandwidth with large extinction ratio is need. Here, double-ring resonator based box-like filtering effect are investigated compared with single ring resonator. The ring near to straight waveguide is defined as ring1 and the ring far from the waveguide is defined as ring2. Coupled resonance induced absorption (CRIA) appears when ring1 is in under coupling and ring2 is in critical coupling. Broaden box-like spectra occur when ring1 is in over coupling and ring2 is also in critical coupling. By changing the internal parameters of each ring, the optimized box-like lines with high contrast ratio and flat bandwidth could be realized. Ring resonator-based filter, which possesses box-like filtering properties, could be useful in the fields of optical information and optical communication.

II. THEORY

We analyze double-ring resonator illustrated in Fig.1 using directional coupling theory[6]. The ratio of output field to input field is expressed as:

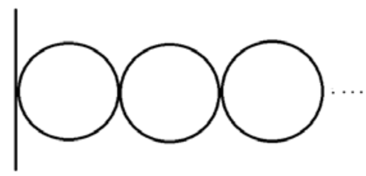

FIGURE I. CONFIGURATION OF COUPLED RING RESONATORS

$$\tau_2(\omega) = \frac{E_7}{E_4} = \frac{r_2 - a_2\tau_1 \exp(i\varphi_2(\omega))}{1 - r_2 a_2 \tau_1 \exp(i\varphi_2(\omega))} = \sqrt{T_2}\exp\left(i\varphi_2^{eff}(\omega)\right) \quad (1)$$

Where τ_1, τ_2 are complex transfer function of resonator and $\tau_1 = r_1 - \alpha_1 \exp(i\phi_1)/1 - r_1\alpha_1 \exp(i\phi_1)$ and $\phi_1 = \frac{\omega_1 L_1 n}{c}, \phi_2 = \frac{\omega_2 L_2 n}{c}$ ($\tau_0 = 1$) are the single-pass phase-shift of each ring, in which L_1, L_2 are the length of ring1 and ring2, $n = 1.458$ is the refractive index, $T_2 = |\tau_2|^2$ is the output light intensity and ϕ_2^{eff} is the effective phase shift. a_1, a_2 are loss factor and r_1, r_2 are reflection parameter.

III. ANALYSIS RESULTS

There are three coupling conditions in single ring resonator, which are set as under coupling ($r_1 > a_1$), over coupling ($r_1 < a_1$) and critical coupling ($r_1 = a_1$). As shown in Fig.2, the green solid line represents the output spectral line in case of critical coupling. The gray line and the dotted line overlap closely, which correspond to the spectra in case of under coupling and over coupled, respectively. The transmission is equal to zero in critical coupling and it means the total energy is stored in the ring resonator. There is no output light at resonant wavelength. However, the transmitted intense of under coupling and over coupling is hardly equal to zero at central frequency. Critical coupling has more sensitive filtering properties compared with other two couple conditions in sing ring resonator.

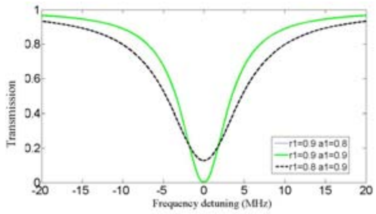

FIGURE II. THE TRANSMITTED LINES IN CASE OF UNDER COUPLED, OVER COUPLED AND CRITICAL COUPLED

The output spectra are all in case of critical coupling with different parameters as shown in Fig.3, in order to distinguish frequency absorption range. Spectral range becomes narrower with an increase in the loss factor and transmission coefficient simultaneously. Especially, yellow line reveals better filtering effect and wavelength selection characteristic when a_1=r_1=0.99.

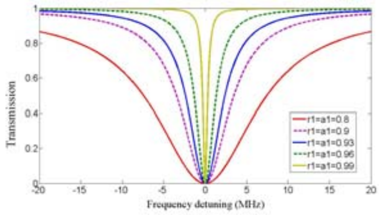

FIGURE III. TRANSMISSION IN CASE OF CRITICAL COUPLED WITH DIFFERENT PARAMETRS FOR SINGLE RING

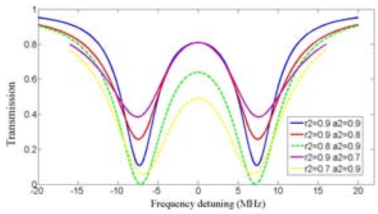

FIGURE IV. THE TRANSMISSION WITH DIFFERENT COUPLED CONDITON OF RING2

We investigate output spectral lines of double-ring resonant structure further in order to enlarge the filtering frequency-band. The ring far from the waveguide is defined as ring2 and the ring near to the waveguide is set as ring1. As shown in Fig.4, transmitted spectra are plot in case of different couple conditions of ring2 when r_1=a_1=0.9. Higher contrast ratio at resonance appears when ring2 is in critical coupling compared with lower contrast ratio at central transmission when ring2 is in the under coupling and over coupling. Thus, it is benefit for spectral filtering response when ring2 is in the critical coupling.

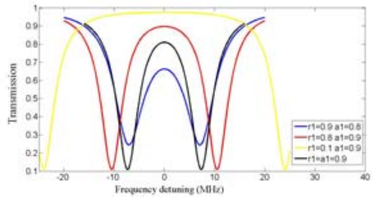

FIGURE V. THE TRANSMISSION WITH DIFFERENT COUPLED CONDITON OF RI

Fig.5 shows different output spectra when parameter match is changed as r2=a2=0.9. Contrast ratio of the total structure becomes bigger and frequency width becomes wider when ring1 is in over coupling compared with spectral lines in case of under coupling and over coupling for ring1. Especially, the yellow line shown in Fig.5 is just like a box, which possesses high constant transmitted intense at resonance. The difference between r1 and a1 becomes larger and the box-like effect of output spectra is apparent. It is useful for double-ring to realize band-pass and band-stop filtering function as novel sensitive filtering device.

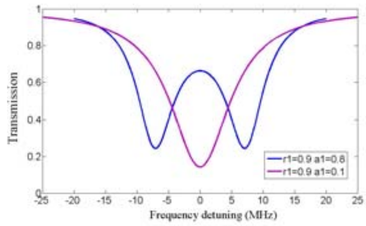

FIGURE VI. COUPLED RESONANCE INDUCED ABSORPTION AND COUPLED RESONANCE INDUCED TRANSMISSION

Particularly, the strong absorption dip (purple solid line) shown in Fig.6 appears when r_1 and a_1 becomes larger, which is based on under coupling for ring1 and critical coupling for ring2. This phenomenon is similar to electromagnetically induced absorption (EIA) in atomic vapor and the green dip shown in Fig.1 for single ring resonator. According to the couple strength between ring1 and ring2, double-ring structure not only possesses transmitted window effect, but also single absorption dip and box-like filtering effect.

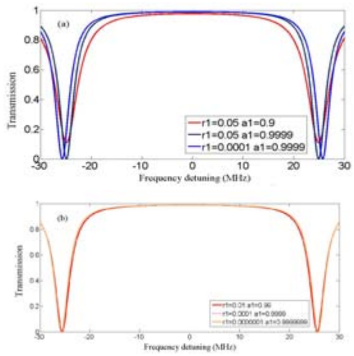

FIGURE VII. THE BOX-LIKE TRANSMISSION AS DIFFERENT PARAMETER MATCHING

The yellow line shown in Fig.5 represents the box-like filtering effect, which is immune to signal interference and improve the filter precision of ring instrument. The full width of central transmission becomes broader on the basis of yellow line with decreasing r_1 due to destructive interference between two rings as shown in Fig.7 (a). It induces that resonator is no longer to absorb light at resonant frequency. Increasing a_1 could enhance the value of transmitted intensity at the resonant range and enlarge contrast ratio of spectra between the maximum and the minimum, which could diminish the loss between ring1 and the waveguide to increase Q factor of total structure. Fig.7 (b) shows box-like spectral lines under three conditions based on yellow line in Fig.5. The overall outline of output spectra has little change even though r_1 and a_1 are allowed to vary widely.

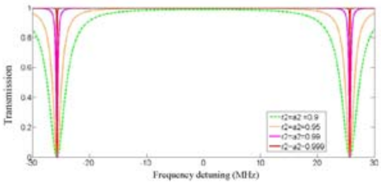

FIGURE VIII. THE BOX-LIKE SPECTRA IS OPTIMIZED BY CHANGING THE INTERNAL CONDITION OF RING2

On a basis of the red line in Fig.7(a), we change the internal condition of ring2, which is still in case of critical coupling in order to improve the outline of box-like effect with two sharp edges at non-resonant frequency area. As shown in Fig.8, the value of central transmission gradually enhances and both edges become steeper with ultra-narrow absorption dip as well as bandwidth becomes flatter with an increase of r_2 and a_2. The ideal box-like filtering effect could be realized in double-ring ring resonator by means of adjusting the condition related to its important parameters of each ring simultaneously.

IV. CONCLUSION

Single ring resonator can generate absorption dip, however, it is used in filtering in some special narrow-band frequency range. Output spectra in double-ring resonator are investigated theoretically in order to optimize filtering properties. The box-like filtering effect appears at the resonant frequency when ring2 is in the critical coupling and ring1 is in the over coupling. It can be improved in order to get the ideal spectral outline with high contrast ratio, wide and flat bandwidth through enlarging the difference between refection coefficient and loss factor and increasing the value of critical condition of ring2. Double-ring resonator comparing with single ring resonator, which is seen as a novel band-pass and band-stop filter due to the ideal box-like effect, is applied in the fields of optical communication and optical information processing.

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