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Quadruple micro optical multiple asymmetric ring resonator performance analysis as optical filter

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ABSTRACT

An analysis of a quadruple ring resonator is attempted in the present article in which transfer function is evaluated in z-domain using Mason's gain formula. Delay line signal processing technique is implemented to find the free spectral range (FSR) from the frequency response spectrum of the transfer function. In this article, a theoretical model of quadruple micro ring structure is proposed where the three asymmetrical micro optical ring is placed inside another micro ring. This model is capable of virtually eliminating crosstalk and providing FSR of about 490.5 THz which meets the ever-expanding demand of wide FSR. Group delay and dispersion characteristics is also presented in the article.

1. Introduction

In last two decades optical ring resonator has proved its significance as optical switching [1], laser resonators, frequency discriminator in frequency division multiplexing (FDM) [2–4], add/drop filter [5] and optical spectrum analyzer [6]. Optical filters are primarily characterized by its frequency response where the variation of magnitude and phase is measured with the variation of frequency. Therefore, it's important to find out the appropriate frequency response of a ring resonator so that it can be used as an optical filter. Performance characteristics of double ring resonators with different ring size are previously reported in [7]. Moslehi et al. developed the z-domain relationship for basic optical circuit element for its use in filters [8]. Mandal et al. developed the Z-domain model to analyze the frequency response of Triple Ring Resonator (TRR) [9], Quadruple Optical Ring Resonator (QORR) [10] as well as Pentuple Optical Ring Resonator (PORR) [11] and it is found that with each increase in number of rings there is a corresponding increase in the FSR and correspondingly the crosstalk is suppressed up to 30 dB representing that the secondary peaks got reduced significantly [14]. Two techniques i.e. chain matrix formulation and delay line signal processing techniques are available to compute the transmittance of the ring resonator. Delay line signal processing technique along with signal flow graph method is implemented in our case to analyze the frequency response spectrum. The unit delay is the fundamental element in the modelling approach described in the present article. The unit delay length in z- domain is represented as Z^{-1}. The ring size are selected in such a manner that the length of each ring is integral multiple of unit delay length. Entire optical circuit is represented by discrete multiple of unit delay length. Therefore,

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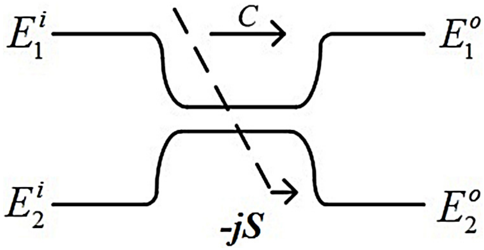

Fig. 1. Directional optical coupler.

the total delay length is the integer multiple of unit delay and the impulse response of an optical filter can be interpreted as discrete sequence. The unit delay length can be mathematically expressed as [12,13]:

$$T = \frac{L_u n_g}{c} \tag{1}$$

where, L_u is the minutest path length and is generally called as unit delay length, "c" the speed of light and "n_g" is the group refractive index and is expressed as:

$$n_g = n_{eff} + f_o (dn_{eff}/df)_{f_o} \tag{2}$$

where, "n_{eff}" is the effective refractive index and "f_o" is center frequency.

The ring resonator frequency response is periodic in nature and one such period in known as Free Spectral Range (FSR) and is mathematically expressed as:

$$FSR = \frac{1}{T} = \frac{c}{L_u n_g} \tag{3}$$

From Eq. (3), it is clear that the smaller the unit delay length the greater the FSR i.e. wider FSR obtained. There is a limitation that the maximal FSR is constrained by the bend radius of a single ring, while enhanced FSR is desirable for its application as an optical filters. Therefore, to increase the FSR, another technique should be incorporated which will not be limited by the bend radius of the ring. Hence, Vernier principle method is used to enhance the FSR using multiple asymmetrical rings of different radii, such that the overall FSR can be expressed as follows [14,15];

$$FSR_{overall} = N * FSR_1 = M * FSR_2 = O * FSR_3 = P * FSR_4 \tag{4}$$

where *N, M, O* and *P* are the co-prime resonant numbers of the corresponding resonators where as FSR_1 is the *FSR* of smallest inner ring, FSR_2 is the *FSR* of the ring having second smallest inner ring radius, FSR_3 is the *FSR* of ring having largest radius among the inner rings, FSR_4 is the *FSR* of the outer ring having largest ring radius among the all rings. The overall FSR can also be calculated using the formula [16];

$$FSR = |M - N| \frac{(FSR_1 * FSR_2)}{|FSR_1 - FSR_2|} \tag{5}$$

where,

$$FSR_i = \frac{c}{2\pi n R_i} \tag{6}$$

where i = 1,2,3,4.

2. Mathematical modelling

When two optical waveguides are brought close enough to each other such that their evanescent field get overlapped on one another, making both waveguides coupled to each other. This arrangement is known as directional coupler which is shown in Fig. 1. The input and output of the waveguides are related by a matrix known as transfer matrix or chain matrix which is obtained from the block diagram shown in Fig. 2. The mathematical expression of the matrix is given as Eq. (7) where E_1^i, E_2^i are the coupler inputs where as E_1^o, E_2^o represents the coupler output.

$$\begin{bmatrix} E_1^o \\ E_2^o \end{bmatrix} = \begin{bmatrix} C & -jS \\ -jS & C \end{bmatrix} \begin{bmatrix} E_1^i \\ E_2^i \end{bmatrix} \tag{7}$$

where, "C" is the common port transmission coefficient of the waveguides and is mathematically represented as;

$$C = \sqrt{1 - K} \tag{8}$$