Optical Ring Resonator Based Notch Filter Using Lithium Niobate on Insulator (LNOI)

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Abstract: With this work, we have reviewed structuring of an all optical notch filter using the microring resonator based on Lithium Niobate on Insulator (LNOI) platform. The electromagnetic waves and beam envelopes physics interfaces are utilized to handle the propagation over distances that are many wavelengths long with scattering boundary conditions. The proposed notch filter shows almost zero transmittance at resonance and the notch bandwidth is found as 3.8 nm. The proposed structure is suitable for ultra-fast optical communication networks.

Keywords: Ring resonator, Notch filter, Lithium Niobate on Insulator.

1. Introduction

As time is progressing, the world is quickly moving towards replacing electronics communication system by optical communication system, thus the need of all optical signal processing devices e.g. notch filter, optical add drop multiplexer (OADM), optical switches, etc. has arisen [1, 2]. Several attempts have been made in the past to develop microring resonator based on SOI, Lithium Niobate, etc. [3-6]. In this paper, all optical microring resonator based on LNOI has been proposed [7]. The Optical Notch Filter is important in all optical communication networks for optical signal processing.

1.1 Lithium Niobate on Insulator

Lithium Niobate is a colorless, ferroelectric, insoluble with water and a nonlinear crystal material suitable for a variety of applications [8-9]. It shows an extensive electro-optic (EO), acousto-optic (AO) and thermo-optic (TO) effects, which makes it suitable in cutting edge optics base material. To achieve the high refractive index contrast and to utilize the properties of Lithium Niobate substrate, LNOI is used instead of commonly used Silicon on Insulator (SOI). LNOI can be fabricated by the crystal ion slicing method combined with wafer bonding [10].

2. Modeling of Notch Filter

The simplest Notch Filter based on optical ring resonator as shown in fig. 1 consists of a straight waveguide and a ring waveguide. The two waveguide cores are placed close to each other so that light coupled from one waveguide to the other. When the length of the ring waveguide is an integral multiple of the wavelength, the ring waveguide resonates and the light power stored in the ring builds up.

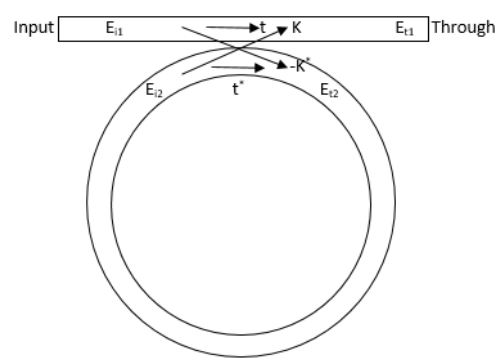

Figure 1. Schematic of an optical ring resonator.

The relation between the transmitted fields and the incident fields is given by eq. 1.

$$\begin{bmatrix} E_{t1} \\ E_{t2} \end{bmatrix} = \begin{bmatrix} t & k \\ -k^* & t^* \end{bmatrix} \begin{bmatrix} E_{i1} \\ E_{i2} \end{bmatrix} \quad (1)$$

Where, E_{i1}& E_{i2} are incident fields, E_{t1} &E_{t2} are transmitted/coupled fields and t & k are transmission & coupling coefficients. The wave is propagating only in one direction so the unidirectional formulation is used and the electric field E, is given by eq. 2.

$$E = E_1 e^{-j\emptyset} \qquad (2)$$

Where, E_1 is slowly varying field envelope function and ϕ is the propagation phase for the wave. Wave Optics Module of COMSOL Multiphysics® simulation software is used for analysis. From the model library, we have used "Optical Ring Resonator Notch Filter". The Electromagnetic Waves, Beam Envelopes physics interface is utilized to handle the propagation over distances that are many wavelengths long. Scattering Boundary Condition is used for outer boundaries.

3. Design Layout of Notch Filter

The design parameters of the optical ring resonator based Notch filter are given in table 1. The 2-D model is designed on COMSOL as shown in fig. 2. In this device core is made up of Lithium Niobate and SiO_2 is used as the cladding material.

Table 1. Design Parameters of Ring Resonator

Name	Value	Description
W_core	0.20 um	Core width
W_clad	2.00 um	Cladding width
R0	7.053 um	Radius of curvature
N_core	2.211	LN refractive index
N_clad	1.444	SiO2 refractive index
Dx	0.72 um	Separation between Waveguides

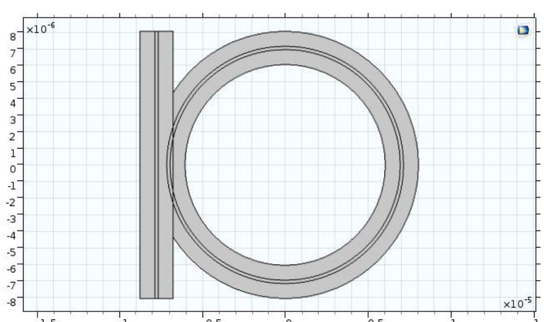

Figure 2. Design of ring resonator.

4. Result and Discussion

The electric field distribution along the ring resonator is shown in fig. 2 and fig. 3. At resonance, the electric field intensity is almost zero at the output port and at a non-resonating wavelength, the electric field intensity received at output port is nearly equal to the incident field.

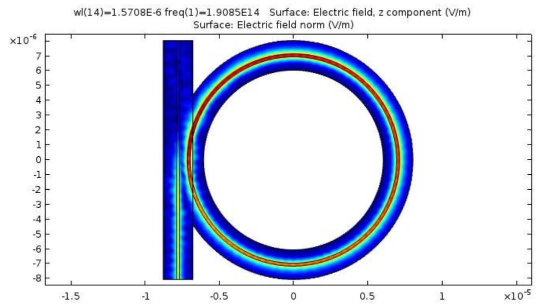

Figure 3. E-Field distribution at resonant wavelength.

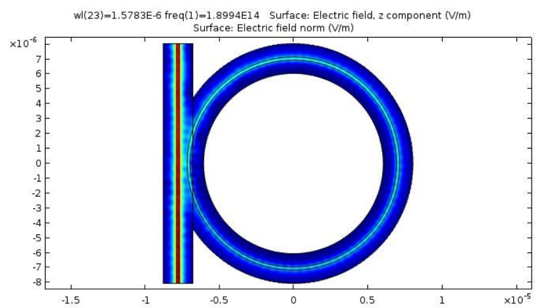

Figure 4. E-Field distribution at non-resonant wavelength.

The transmittance curve at the output port is drawn for the Notch Filter using LNOI as shown in fig. 5 and for the comparison purpose the transmittance curve of the Notch filter given in COMSOL application model is also drawn as shown in fig. 6.It can be seen from the transmittance curve that the Notch filter has zero transmittance at resonating wavelength and has more than 90 % transmittance at non-resonating wavelengths.

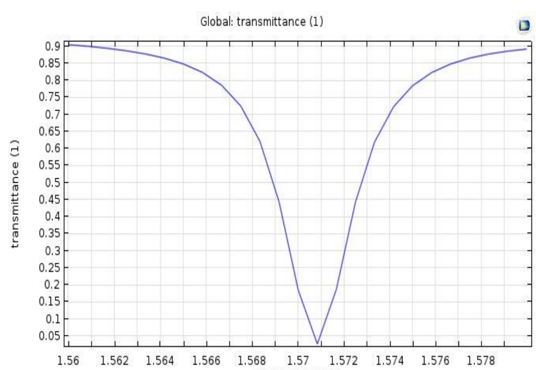

Figure 5. Transmittance curve of notch filter based on LNOI.

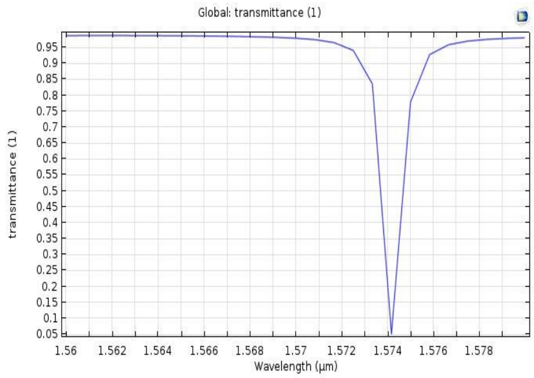

Figure 6. Transmittance curve of ideal notch filter given in COMSOL model.

Table 2 consists of the different resulting properties of the Notch filter design on LNOI platform and the ideal Notch filter given in COMSOL application model. The Notch Bandwidth is 3.8 nm at the resonating wavelength of 1.5709 um. The Q-factor of the Notch filter based on LNOI is 415 which is less as compared to the Q-factor of the Notch filter of the model because the later one neglects all type of losses occurred in the ring resonator.

Table 2. Resulting properties of notch filter

Properties	LNOI Based	COMSOL Model
Resonant wavelength	1.5709 um	1.5741 um
Q factor	415	1574
Notch BW	3.8 nm	1 nm

5. Conclusion

LNOI has become a new platform for high-density integrated optics. It has excellent electro-optic, acousto-optic, and piezoelectric properties in contrast to SOI. Moreover, it can be easily doped with rare-earth ions to get a laser active material. Therefore, LNOI can be used to develop a number of micro-photonic devices.

Optical notch filter can be used to filter out the specific wavelengths and it is mainly used in optical signal processing and optical biosensors. The notch bandwidth of the optical ring resonator based notch filter is 3.8 nm and possesses almost zeros transmittance at resonant wavelength. Q-factor is calculated as 415, which can be improved further as well.

6. Acknowledgement

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