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Fractal Structure Ring Resonator Based Channel Drop Filter for Optical Networks using InP Dielectric Material

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Abstract: In the present study, the simulation and analysis have been presented for novel optical wavelength channel drop filter based on 2D fractal ring resonator structure using photonic crystal technologies. The design of 2DPC (two Dimensional Photonic Crystal) channel drop filter is done using FDTD (Finite Difference Time Domain) method. The photonic bandgap is obtained with the help of Plane Wave Expansion (PWE) method. The parameters of channel drop filter have been optimized for 1591 nm mostly used telecommunication wavelength with refractive index of 3.16 using (InP) Indium Phosphide dielectric material. The number of rods in X and Z directions are taken as 21 and 20, respectively with lattice constant of 540 nm and radius of dielectric rod as 0.1 μm. From the simulation, it found that, by varying the parameters of Photonic Crystal Ring Resonator (PCRR) (i.e., scatter rod radius). The proposed design gives around 100% dropping efficiency at 1591 nm wavelength with a good quality factor about 352. The ultra-compact structure is proposed which can be valuable for communication applications and PICs.

Key words: FDTD method, ring resonator, PWE method, photonic band gap structure, photonic crystal, design

INTRODUCTION

Photonic Crystals (PC) are periodic simulated structures. They are called photonic because they follow up on light and crystals, therefore of their periodic arrangements. Photonic crystals happen when the order of periodicity is not precisely equal to the light wavelength. PhCs may confine the propagation of certain extent of wavelengths in it is conceivable that one heading or in each one of the direction, giving the probability to tie and trap the light (Yablonovitch, 1987; Joannopoulos *et al*., 1995). At a particular recurrence range, electromagnetic waves can't go through the structure; this recurrence extent is known as the Photonic Band Gap (PBG). In this manner by making the imperfections either point surrender or line deformity in the crystal light can be incredibly kept at this recurrence range. Numerous optical devices have been planned by the analysts bunches the world over. Because of the electromagnetic wave properties the field of photonic crystals is becoming much popular these days which promotion uncommon capacities to them either by: altering, controlling and directing the stream of light (John, 1987).

Scientists around the world presented numerous PhC based devices like channel drop filters, add-drop filter (Chhipa and Dusad, 2016a, b; Andalib and Granpayeh, 2008; Robinson and Nakkeeran, 2011; Kumar *et al*., 2004; Chhipa and Rewar, 2015; Chhipa, 2014), multiplexers (Manzacca *et al*., 2007), power combiners, demultiplexers (Chhipa, 2015) and band pass filter (Chao *et al*., 2007), Mach-Zehnder interferometer (Geng *et al*., 2011), logic gates (Christina and Kabilan, 2012), power splitter (Ghaffari *et al*., 2008) using dielectric materials like: Silicon (Si) (Chhipa *et al*., 2014a, b). The silicon is row bust material and easy to available in the nature.

For optical communication networks Channel Crop Filter (CDF) is an important device which is used to drop the desired channel without disturbing the other channels that are travel along the fiber (Sharma *et al*., 2016; Chhipa *et al*., 2016). The channel drop filter's schematic view is shown in Fig. 1, it is composed of two waveguide naming as bus waveguide and dropping waveguide and coupled with Photonic Crystal Ring Resonator (PCRR) (Chhipa, 2014a, b).

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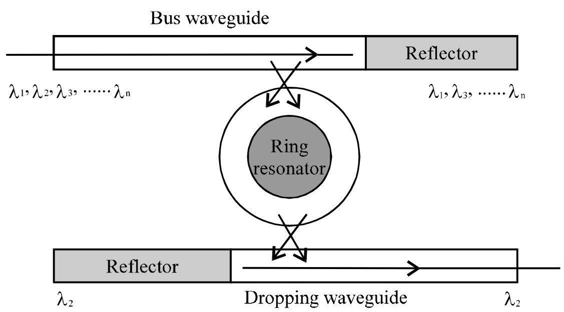

Fig. 1: Schematic diagram of designed channel drop filter

The input signal is travelled to output port directly at condition of resonance occurrence the input signal is transferred from bus waveguide to ring resonator which in turn ring resonator to dropping waveguide without troubling other channels.

MATERIALS AND METHODS

Bang gap diagram and analysis: The crevice between the carrier and the dielectric line in the scattering connection of the PC framework is known as the Photonic Band Gap (PBG) basically. The Plane Wave Expansion (PWE) Method is utilized for the computation of PBG (Photonic Band Gap) of the outlined channel drop filter structure (Leung and Liu, 1990; Berenger, 1994). The diagram of proposed configuration is appeared in Fig. 2 at refractive file 3.16. At the point when the electromagnetic waves go through the photonic crystal, there is a connection between the frequencies and the wave vectors, i.e., scattering connection. So, this connection is called as the band diagram (Chhipa, 2016):

$$e(r) = e(r+R) \tag{1}$$

where, e(r) is a periodic function (Leung and Liu, 1990). Deformities like line defect and point defect are used to design this filter. The PBG for the design extends from 0.593336-0.831069 1/λ as shown in Fig. 1 whom corresponding range of wavelength extends from 1203-1685 nm, this range of photonic band gap covers the whole range of CWDM telecommunication wavelength from 1271-1611 as we know that as per ITU-T G.694.2 CWDM (Recommendation, 2003) there are around 18 wavelengths with 20 nm spacing, so with the band gap calculations this material is appropriate for the CWDM (Coarse Wavelength Division Multiplexing) application.

Design and analysis of CDF: The dielectric rods is having refractive index of 3.16 for the structure and 0.1 μm is radius of dielectric bars. To create ring resonator structure center rods radius is taken as 0.5 μm and other fractal structure centre radius taken as 0.2 μm and rest of the hexagonal radius is taken as 0.1 μm the same as the other radius of the structure. The lattice constant is taken as 540 nm. In the designed diagram the no of rod are 21 in z direction and 20 in x direction. The rods of dielectric material are suspended in air with refractive index n = 1. In the structure, there is a one input port, one photonic crystal ring resonator and having one output port for the measurement of power spectrum and transmission spectra. Two observation point focuses are set at the two observation ports (Chhipa and Rewar, 2015).

Different researchers around the world have designed CDF using PCRR. The importance of this novel design is that here we have used new concept of fractal structures in PCRR. Filter shown in Fig. 3a and refractive index view profile is shown in Fig. 3b.

Both point and line disfigurements are utilized to framework this channel drop channel. The proposed CDF is made out of one input port and one yield ports and the photonic crystal ring resonator is arranged between them. One observation point is put at the one yield port. The channel drop filter involves square framed structure using fractal ring resonator and waveguides. To drop the desired channel or wavelength we have designed structure in such a way that conatins drop waveguide below to the ring resonator.

It is clear from the Fig. 4 that in the designed filter structure there is one input vertical plane source to transmit the Gaussian modulated continuous wave to the structure. To get the simulation result a 32 bit OptiFDTD design simulator is beneficiary to see the output response of the designed filter. About 10000 time steps were used to run the design (Taflove, 1995). There is different way to see the desired output response like; time, DFT and FFT in which DFT Ey view is used to see the output spectrum by the FDTD method (Cangellaris, 1993). The time view and the DFT view of the design channel drop filter at 1591 nm resonating wavelength is shown in Fig. 4a and b.

The electric field perspective of the composed channel drop filter is shown in Fig. 5 and 6. Facilitate, the examination is reached out by fluctuating the radius of scatterer rods to improve dropping effectiveness and quality component for the outline.

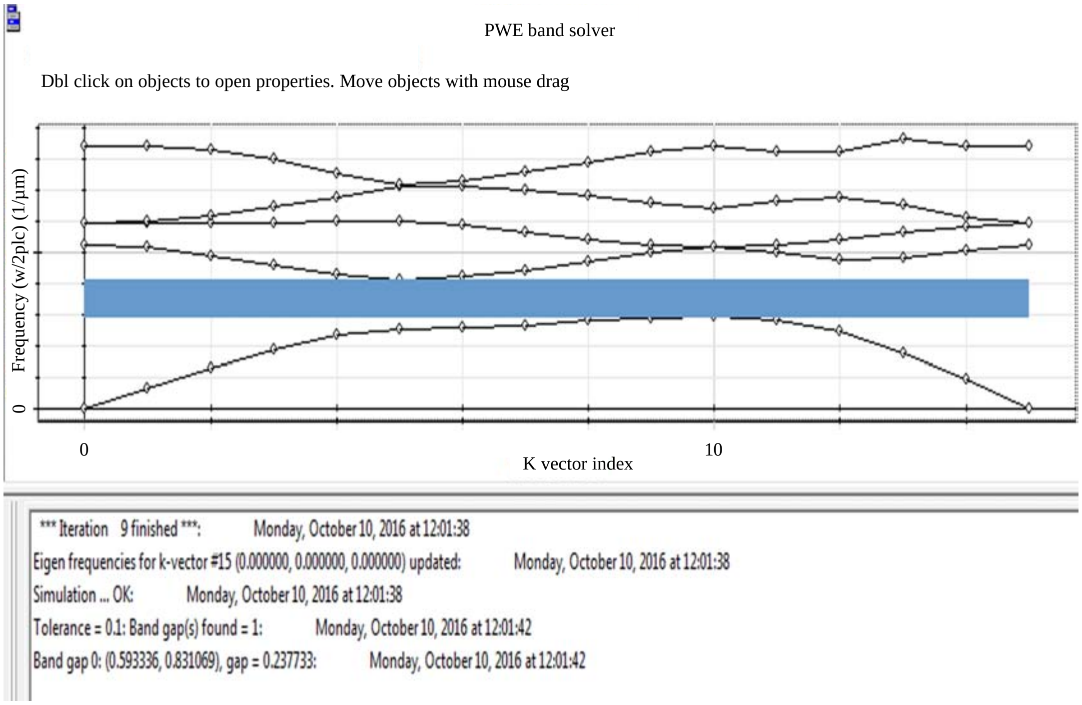

Fig. 2: Photonic band gap analysis using indium phosphide material

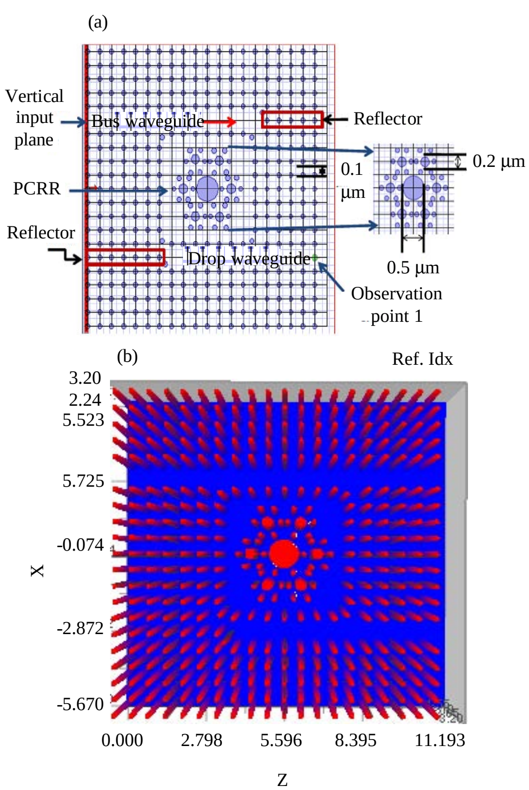

Fig. 3: a) Designed channel drop filter and b) refractive index profile view of filter structure

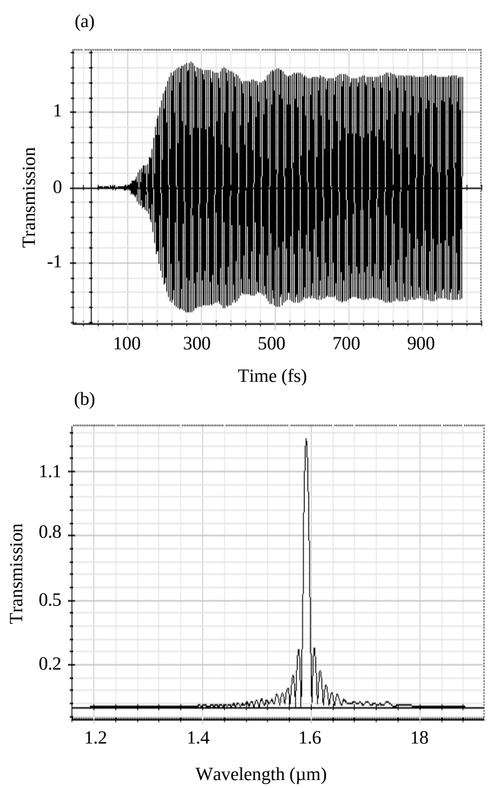

Fig. 4: a) Transmission spectra of 1591 nm dropped wavelength time view and b) DFT view of CDF

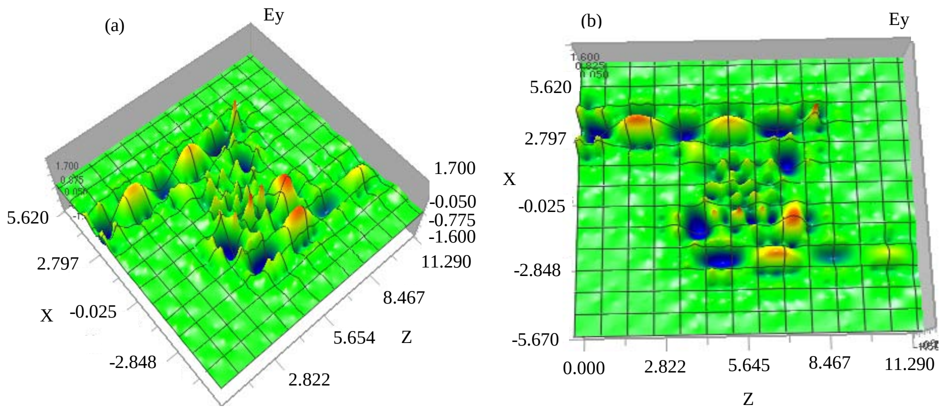

Fig. 5: a) Side view of the electric filed view of the designed filter and b) Top view of the electric field view of dropped wavelength

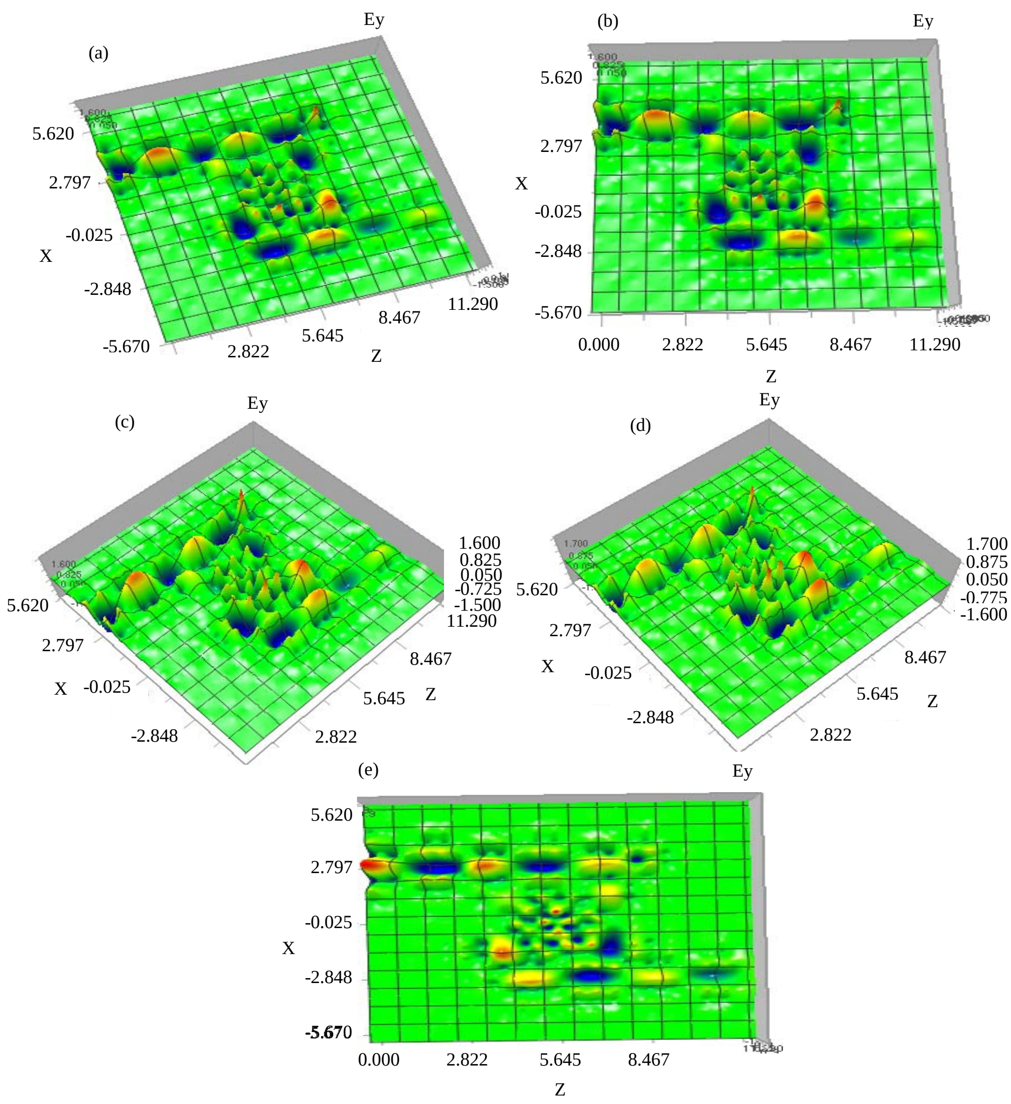

Fig. 6: a-e) Electric field view of designed filter at scattere rod radius analysis at different radius with 0.1 μm difference

Table 1: Scatterer rod radius analysis

Scatter rod radius (μm)	Resonant wavelength (nm)	Dropping efficiency (η) (%)	Quality factor (Q)
0.12	1596.4	93.7	392
0.11	1593.7	97.4	370
0.10	1591.0	100.0	352
0.09	1588.2	96.3	348
0.08	1585.6	91.8	326

RESULTS AND DISCUSSION

Scatter rod radius anslysis: In the previous study, we have discussed the resonance wavelength as a function of rod refractive index. For the index 3.16, we obtained 1591 nm resonating wavelength. Now in this study, we will study filter by varying the radius of scatterer rods. Table 1 shows the channel drop filters properties for different values of scatterer rods (Rakhshani and MansouriBirjandi, 2012; Chhipa *et al*., 2017).

From Table 1, we can note that as scatterer rod radius decreases the resonance wavelength is shifted to lower values by 3-5 nm. It is clear from Table 1 that the yield reaction of the CDF is parameter of the scatterer rod radius, through which wavelength shift is occurring and quality factor diminishing and arbitrary variety of dropping efficiency. Figure 6 shows the electric field view at 1591 nm resonating wavelength with r = 0.1 μm at different scatterer rod radius as from 0.08-0.12 μm.

CONCLUSION

The designed channel drop channel structure is designed and simulated using fractal structure ring resonator of dielectric material Indium Phosphide (InP) with 3.16 refractive index. The size of the designed structure is about 11.4×10.8 μm nearly equal to 123 μm^2 which is compact in size. The outlined channel gives 100% dropping efficiency at 1591 nm wavelength with around 352 quality factor. Further to get much better output response and high quality factor the designing parameters can be reconfigured.

SUGGESTIONS

Future work involves to improve more quality factor while changing some designing parameters and to go for the fabrication process for practical applications. So, such sort of devices might be valuable in CWDM networks and Photonic Integrated Circuits (PICs).

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