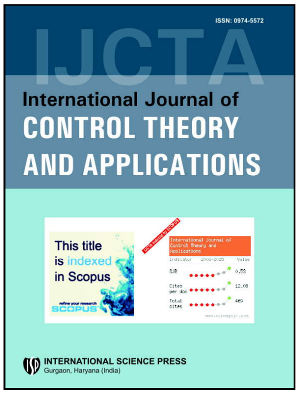

International Journal of Control Theory and Applications

ISSN : 0974-5572

© International Science Press

Volume 10 • Number 13 • 2017

Tunable all Optical Single Channel Drop Filter for DWDM Application using One Dimensional Nonlinear-Plasma Photonic Crystal

Arun Kumar[1]

[1] *AITEM, Amity University, Uttar Pradesh, India, Email: arun_mtech@yahoo.co.in*

Abstract: The transmission characteristics of one-dimensional nonlinear-plasma photonic crystal structure have been investigated. Polystyrene has been chosen as the nonlinear material. As the refractive index of nonlinear material is a function of intensity, the central wavelength of transmission is also a function of intensity of the controlling wave. Using this property, one can tune the central wavelength at a desired wavelength within certain range. This property can be exploited in the designing of tunable all optical single channel drop filter for multichannel DWDM system in optical communication.

Keywords: Nonlinear Photonic Crystal, DWDM, Filter, Plasma.

1. INTRODUCTION

Photonic crystals, which are the structured materials attracted much attention of researcher due to their unique properties, which are not offered by the bulk materials [1-8]. Different types of materials are considered for the design of photonic crystal structures. Replacing the dielectric material(s) by nonlinear material in the conventional one dimensional photonic crystal can change the transmission characteristic of these photonic crystals. When material of alternate layers of the conventional one dimensional photonic crystal are taken as non-linear refractive index material, the optical characteristics of the structure got changed and such structures become transparent at high intensity in that region of frequency for which the composite material is opaque at low intensity. Hence, in this manner it can work as an optical switch [9-11]. Wavelength division multiplexer (WDM) is the key component of modern optical communications systems. This component is used to divide and combine different wavelength channels each carrying an optical data signal. Channel drop filters may be used in DWDM network to drop a single channel. Various schemes are studied and proposed for demultipexing the DWDM/CWDM channels [12-15]. But size of these devices should be on the order on centimeters to achieve a large number of sufficiently spaced wavelength channels, which is very large in comparison integrated optical components. In this regard, optical devices based upon photonic crystals offered attractive solutions. They have huge potential of applications in modern high speed optical communication because of their unique characteristics and this may lead the design of miniaturized optical integrated components and devices with sizes on the order of several wavelengths [16-19]. Cedric et al gave the design of a tunable demultiplexer using logarithmic filter chains [20]. This multiplexer uses an apodized one dimensional photonic crystal structure on a ridged semiconductor waveguide. Gerken et al fabricated the wavelength demultiplexer using the spatial dispersion of multilayer thin film structures [21]. They use a single 66-layer non-periodic thin film stake to separate four wavelength channels by spatial beam shifting. They demonstrate that this device can demultiplex the channels with spacing of approximately 4nm in the first transmission window of optical communication i.e. at 850nm wavelength.

In this present paper, a high-resolution and a tunable all optical single channel drop filter for DWDM application using one dimensional nonlinear photonic crystal has been presented. Its operational principle is based on a shift of the transmission band of the fundamental PBG mode in a one dimensional nonlinear photonic crystal. The shift is realized by varying the intensity of the controlling wave. Here we considered that electromagnetic wave incident perpendicular to the layers. The controlling wave, which produces the nonlinear effect, is propagating perpendicular to the direction of propagation of the incident wave. Also, we considered that the amplitude of the controlling wave much higher than the amplitude of the incident wave thereby we can safely neglect the nonlinear effect of the incident wave on nonlinear layers. We shall rather confine our study around 1550nm wavelength which is the lowest loss wavelength for optical communication. The structure proposed has another advantage compared to earlier designs as it does not require apodization and the number of layers in the structure is also less. So, the fabrication of the proposed structure will be comparatively easier. Also, the line-width of transmission is also less in our case, which is suitable for DWDM application.

2. THEORETICAL MODEL

We consider one-dimensional nonlinear-plasma photonic crystals having alternate layers of nonlinear material and micro-plasma as shown in Figure 1.

The Maxwell wave equations for electromagnetic wave propagation along the x-axis in one-dimensional nonlinear-plasma photonic crystal may be written as

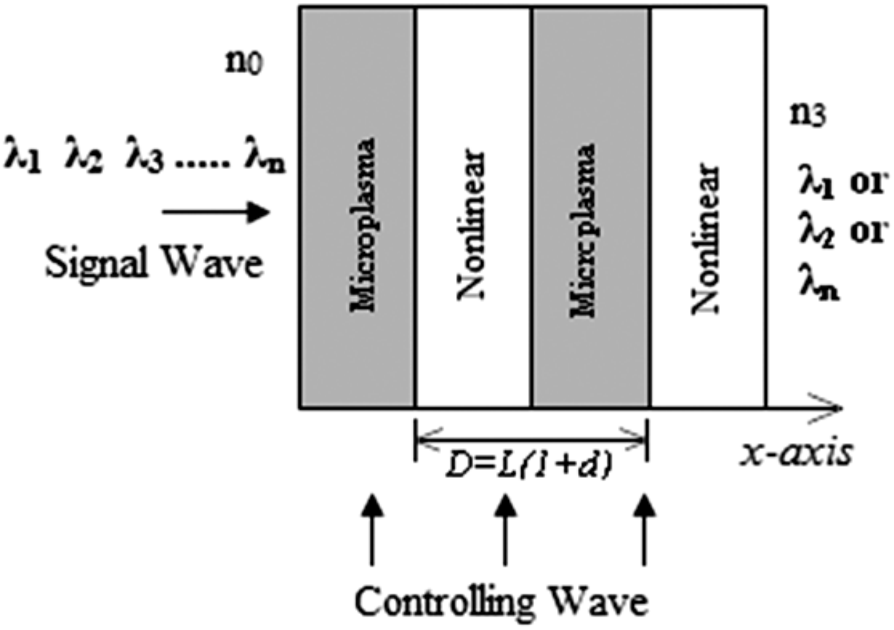

Figure 1: Schematic diagram of a tunable all optical single channel drop filter for DWDM application using one dimensional nonlinear-plasma photonic crystal.

$$\frac{d^2E}{dx^2}+{k_0}^2\varepsilon(x)E(x)=0 \tag{1}$$

With

$$\varepsilon(x)=\begin{cases}1-\dfrac{{\omega_p}^2}{\omega^2}, & -Ld\le x\le 0,\\ n_0+\Delta nI, & 0\le x\le L\end{cases} \tag{2}$$

and

$$\varepsilon(x)=\varepsilon(x+D) \tag{3}$$

where, $k_0=\omega/c$ is the wave frequency,

c is the speed of light,

$\omega_p=(e^2n_p/\varepsilon_0m)^{1/2}$ is the electron plasma frequency with density n_p

$n_0+\Delta nI$ is the refractive index of the nonlinear material.

The schematic diagram of the spatial variation of micro-plasma and nonlinear material is given in Figure 1, where D = L(1 + d) is the lattice period with the widths of nonlinear and micro-plasma being L and Ld respectively.

The general transfer matrix method [22] could not deal with the non-linear propagation problem in the presence of other high intensity controlling wave. Hence, we adopted an approximate approach to considering the nonlinearity. When the intensity of the controlling wave is high, the refractive index of nonlinear material could be calculated with the consideration of the optical Kerr effect. Therefore, with the calculated refractive index of polystyrene, the transmittance of the proposed photonic crystal at different intensities of the controlling wave could be calculated. Xiaoyong et al. [23] has confirmed the convergence and the correctness of this approximate approach. They pointed out that this approximate approach could lead to the right results. In this simulation work, the wavelength of the controlling wave is considered to be centred at 1550 nm.

3. RESULTS AND DISCUSSION

In this section, working and transmission spectra for a one-dimensional nonlinear-plasma photonic crystal for different intensities of the controlling wave have been presented. Polystyrene has been chosen as a nonlinear material. Refractive index of polystyrene is taken as $\eta_1=1.59+\Delta n_1I$, where Δn_1 is the Kerr Coefficient of polystyrene, $\Delta n_1 = 1.12\times10^{-12}$ cm^2/W [24]. The thickness of plasma layer is taken as L*d with plasma frequency 5.6×10^{11} Hz. Thickness ratios (Ld/L=d) has been take 0.01. In the proposed structure, we have taken the number of layers for each material, N to be equal to 10 and thickness of polystyrene 7.5×10^{-5} m and of plasma 7.5×10^{-5}xd m. Here, "I" represents the intensity of controlling wave.

In the proposed structure, we have taken the number of layers for each material, N to be equal to 10. We have analyzed the structure at four different intensities of controlling wave 0GW/cm^2 (low), 2.5GW/cm^2, 5GW/cm^2 and 7.5GW/cm^2. Transmission spectra of the proposed multilayer structure at different intensity of controlling wave have been shown in Figure 2 and the corresponding data is tabulated in Table 1. Thus from Figure 2 and Table 1, it is clear that if input radiation comprising different wavelengths ranging from 1545nm to 1555nm is incident normally on the proposed structure in absence of controlling wave (i.e. I=0GW/cm^2), then it will only pass a very narrow band of wavelength having a linewidth 0.44 nm and 1546.35 nm as the central wavelength; and all other wavelengths will be reflected. So, we can extract a single channel from multi-channel system, hence it can work as a single channel wavelength demultiplexer. More interestingly, this wavelength can be tuned to a desired wavelength by varying the intensity of controlling wave. From Figure 2 and Table 1, it is clear that the transmission peak centred at 1546.35 nm in absence of controlling wave has been shifted to 1549.07 nm,

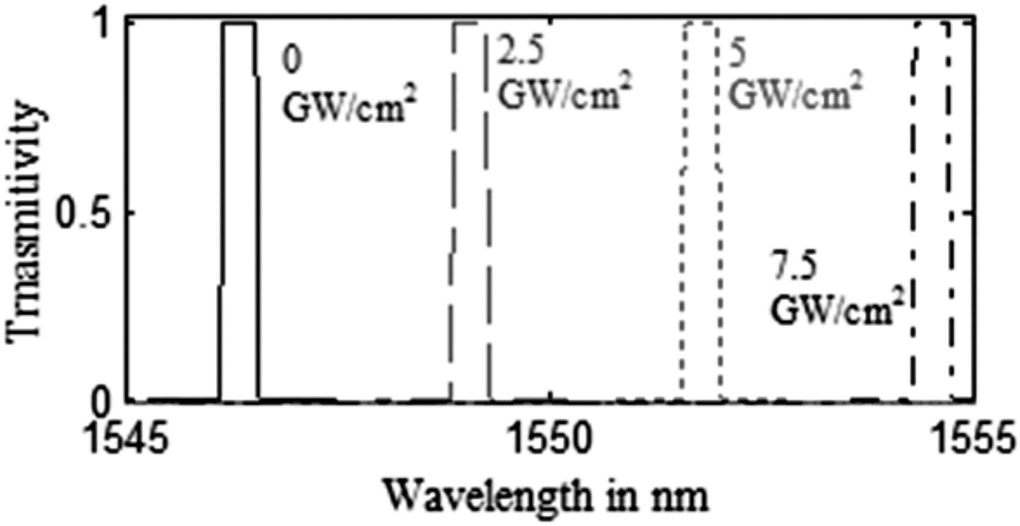

Figure 2: Transmission spectra of proposed structure at different intensity of controlling wave.

1551.8 nm and 1554.52 nm corresponding to different values of the controlling intensity, namely, 2.5GW/cm^2, 5GW/cm^2 and 7.5GW/cm^2 respectively. Here, in this simulation work intensity of controlling wave has been taken arbitrarily, so the central wavelength of the transmission narrow band can be tuned at any desired wavelength by varying the intensity of the controlling wave. Further, it is also clear that as we increase the intensity of controlling wave, the transmission narrow band shifts towards the higher wavelength region.

The variation of central wavelength of transmission with intensity of controlling wave has been shown in Figure 3. It is found that the central wavelength of transmission changes almost linearly with the intensity of the controlling wave. The average change in central wavelength of transmission is 1.09nm/(GW/cm^2). Thus, by changing the intensity of controlling wave, we can extract a desired wavelength. Here, in this simulation work intensity of controlling wave has been taken arbitrarily, so we can tune centre of the transmission at any desired wavelength within certain range by changing the intensity of controlling wave. Hence, the proposed structure may be used as a single channel tunable dense wavelength division dimultiplexer. As the line-width of the transmitted wavelength is 0.44 nm, so the proposed structure may be used to demultiplex the signal with 0.8 nm separation, which corresponds to the ITU grid for DWDM.

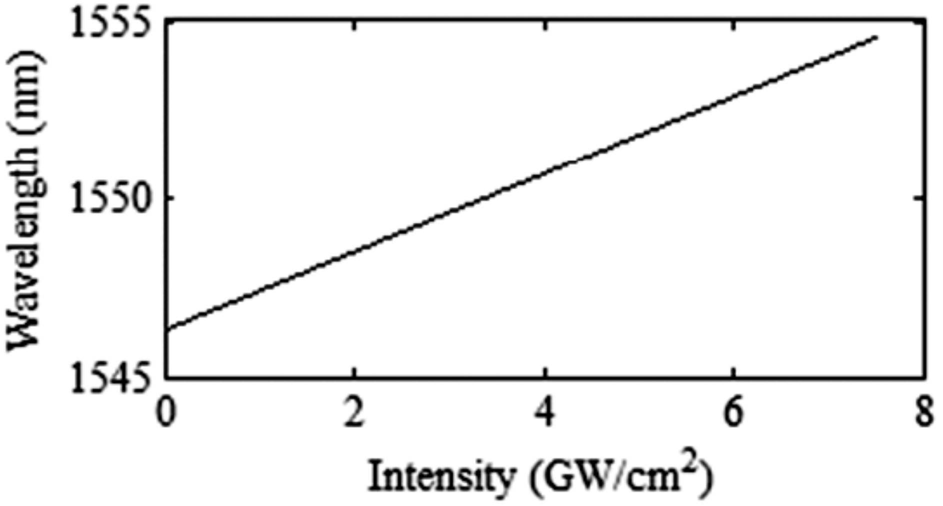

Figure 3: Variation of central wavelength with intensity of controlling wave.

Table 1
Central wavelength and linewidth of the transmission range

Intensity of controlling wave (GW/cm²)	*Central wavelength(nm)*	*Line Width(nm)*
0	1546.35	0.44
2	1549.07	0.44
4	1551.80	0.44
6	1554.52	0.44

3. CONCLUSIONS

In conclusion, a simple design of a tunable all optical single channel drop filter for DWDM application has been proposed. The proposed structure is based on the one-dimensional nonlinear photonic structure. It exhibits a shift of the photonic band gap towards longer wavelength side, when the structure is subjected to a high intensity controlling wave. Thus, the tuning of central wavelength has been achieved by the variation of the intensity of the controlling wave, because the refractive index of the nonlinear material depends on the intensity of the wave. It is also found that the central wavelength of transmission changes linearly with the intensity of the controlling wave. So, we can use the proposed device as a tunable all optical single channel drop filter for DWDM application, which can be easily integrated to the standard fibre optic technology. The proposed device may also be used as optical switch, tunable monochromator, etc.

ACKNOWLEDGMENT

I wish to thank Dr. Ashok K. Chauhan, Founder President, Amity University, Uttar Pradesh, India for his interest in research and constant encouragements.

REFERENCES

[1] J. D. Joannopoulos, R. D. Meade, J. N. Winn, Photonic Crystals, Princeton University Press, Princeton, 1995.

[2] M. Scalora, J. P. Dowling, C. M. Bowden, M. J. Bloemer, "Optical Limiting and Switching of Ultrashort Pulses in Nonlinear Photonic Band Gap Materials", Phys. Rev. Lett., vol. 73, no. 10, pp. 1368-1371, 1994.

[3] E. Yablonovitch, "Inhibited Spontaneous Emission in Solid-State Physics and Electronics", Phys. Rev. Lett., vol. 58, no. 20, pp. 2059-2062, 1987.

[4] S. John, "Strong localization of photons in certain disordered dielectric superlattices", Phys. Rev. Lett., vol. 58, no. 23, pp. 2486-2089, 1987.

[5] Y. Fink, J. N. Winn, S. Fan, C. Chen, J. Michel, J. D. Joannopoulos, E. L. Thomas, "A Dielectric Omnidirectional Reflector", Science, vol. 282, no. 5394, pp. 1679-1682, 1998.

[6] M. Ibanescu, Y. Fink, S. Fan, E. L. Thomas, J. D. Joannopoulos, "An All-Dielectric Coaxial Waveguide", Science, vol. 289, no. 5478, pp. 415-419, 2000.

[7] Sanjeev Sharma, Kh. S. Singh, Shashank Dixit, Deepak Kaushal, "ODR Range Using Exponentially Graded Refractive Index Profile of GaAs Based 1D Photonic Crystal," International J. of Photonics and Optical Technology, vol. 2, no. 2, pp. 29-31, 2016.

[8] T. Betsy Saral, S. Robinson, R. Arunkumar, "Two-Dimensional Photonic Crystal Based Compact Power Splitters," International J. of Photonics and Optical Technology, vol. 2, no. 4, pp. 1-5, 2016.

[9] P. Millar, R. M. De La Rue, T. F. Krauss, J. S. Aitchison, N. G. R. Broderick, D. J. Richardson, "Nonlinear propagation effects in an AlGaAs Bragg grating filter", Opt. Lett., vol. 24, no. 10, pp. 685-687, 1999.

[10] B. J. Eggleton, C. M. de Sterke, R. E. Slusher, "Nonlinear pulse propagation in Bragg gratings", J. Opt. Soc. Am. B, vol. 14, no. 11, pp. 2980-2993, 1997.

[11] Arun Kumar, Vipin Kumar, B. Suthar, Kh. S. Singh, S. P. Ojha, “Nonlinear transmission and reflection characteristics of plasma/polystyrene one dimensional photonic crystal” Optik – International Journal for Light and Electron Optics, 125, pp. 393-396, 2014.

[12] J. Qiao, F. Zhao, R. T. Chen, J. W. Horwitz, W. W. Morey, “Athermalized Low-Loss Echelle-Grating-Based Multimode Dense Wavelength Division Demultiplexer”, Appl. Opt., vol. 41, no. 31, pp. 6567-6575, 2002.

[13] J. Minowa, Y. Fujii, “Dielectric multilayer thin-film filters for WDM transmission systems”, J. Lightwave Technol., vol. 1, no. 1, pp. 116–121, 1983.

[14] R. Romero, O. Frazao, F. Floreani, L. Zhang, P. V. S. Marques, H. M. Salgado, “Chirped fibre Bragg grating based multiplexer and demultiplexer for DWDM applications”, Opt. Lasers Eng., vol. 43, no. 9, pp. 987–994, 2005.

[15] T. Fukazawa, F. Ohno, T. Baba, “Very Compact Arrayed-Waveguide-Grating Demultiplexer Using Si Photonic Wire Waveguides”, Japan. J. Appl. Phys., vol. 43, pp. L673–675, 2004.

[16] A. Kumar, B. Suthar, V. Kumar, Kh. S. Singh, A. Bhargava, “Tunable wavelength demultiplexer for dwdm application using 1-d photonic crystal”, Prog. Electromag. Res. Letters, vol. 33, pp. 27-35, 2012.

[17] Vipin Kumar, B. Suthar Arun Kumar, Kh.S. Singh, A. Bhargava, “Design of a wavelength division demultiplexer using Si-based one-dimensional photonic crystal with a defect” Optik – International Journal for Light and Electron Optics, 124, pp. 2527-2530, 2013.

[18] K. Venkatachalam, S. Robinson, S. Umamaheswari, “Two Dimensional Photonic Crystal based Four Channel Demultiplexer for ITU.T.G 694.2 CWDM Systems,” International J. of Photonics and Optical Technology, vol. 2, no. 3, pp. 37-41, 2016.

[19] Mayur Kumar Chhipa, Massoudi Radhouene, Ashutosh Dikshit, S. Robinson, Bhuvneshwer Suthar, “Novel Compact Optical Channel Drop Filter for CWDM Optical Network Applications,” International J. of Photonics and Optical Technology, vol. 2, no. 4, pp. 26-29, 2016.

[20] Cedric F. Lam, Rutger B. Vrjen, Patty P. L. Chang-Chien, Daniel F. Sievenpiper, Eli Yablonovitch, “A tunable wavelength demultiplexer using logarithmic filter chains,” J. of Lightwave Technology, vol. 16, no. 9, 1657-1662, 1998.

[21] Martina Gerken, David A. B. Miller, “Wavelength demultiplexer using the spatial dispersion of multilayer thin-film structures,” IEEE Photonics Technology Letters, vol. 15, no. 8, pp. 1097-1099, 2003.

[22] P. Yeh, Optical Waves in Layered Media, John Wiley and Sons, New York, 1988.

[23] H. Xiaoyong, P. Jiang, Q. Gong, “Tunable multichannel filter in one-dimensional nonlinear ferroelectric photonic crystals”, J. Opt. A: Pure Appl. Opt., vol. 9, no. 1, pp.108-113, 2007.

[24] Y. Liu, F. Zhou, D. Z. Zhang, Z. Y. Li, “Energy Squeeze of Ultrashort Light Pulse by Kerr Nonlinear Photonic Crystals”, Chin. Phys. Lett., vol. 26, no. 1, pp. 014208, 2009.