Design a Photonic Crystal Narrowband Band pass Filter for Fiber Optic Communication Applications

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Research Article

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Abstract

The optical communications have been the backbone of the most dramatic developments in telecommunications systems in the past two decades, so that the current world of communications is unthinkable without the infrastructure of fiber optic networks. Also, the speed and bandwidth of optical devices have expanded the development of optical telecommunication systems, so the design, simulation and fabrication of optical devices have become more and more respected by researchers in this field. In this paper, a design for optical narrow Band Pass Filter (BPF) using two-dimensional (2D) photonic crystals (PCs) is presented that are suitable for applications in optical fiber communications (third window) in Wavelength-Division Multiplexing (WDM) systems. BPF was simulated by a two-dimensional timing method (FDTD) Finite-difference time-domain (FDTD). Also, the plane-wave expansion (PWE) method was used to evaluate the bands and calculate the Photonic Band Gap. Simulation results show this desired structure, acts as a very sharp optical BPF in the central wavelength of 1550 nm (In order to minimize attenuation). Normal voltage transmission efficiency, full width at half maximum (FWHM), and Focal Plane Module (FPM) for proposed BPF were 94.8%, 2583 and 0.6 nm, respectively.

1. Introduction

In the world today, the expansion of communicative devices and the growing need of the human community to establish a diverse, fast and low-cost communication on the one hand, and the speed and broadband of optical devices on the other, have led to the development of optical communication systems. Therefore, the design, simulation and fabrication of optical devices have been more and more respected by researchers in this field [1]. At present, photonic crystals are one of the important goals of light and photonic electronics researchers. In recent years, these crystals have attracted great attention in many cases due to their use in electronics, telecommunications, and optical information processing [2]. In these years, photonic crystals based on photonic crystals have been very much considered due to photonic crystal features such as low losses, very low bandwidth, flexibility in shape and dimensions, as well as suitability for integrated circuits in Nano scale dimensions [3, 4]. In general, crystals photons structures of dielectric materials, and given that the refractive index of one, two and three dimensions periodically with a period of about a wavelength of light varies, divided into three main groups, the next one, two-dimensional and three -dimensional. This variation in the refractive index results in the formation of a prohibition band in the band's structure of these structures, which is the most important feature of photonic crystals [5, 6]. The banned band in these structures has a large number of frequencies in which no electromagnetic wave can be embedded inside structure, so using this intrinsic property can be used to design optical filters. Indeed, optical photon crystals have been of great interest to researchers, in view of their unique properties (such as high transmittance, low losses, proper output, high quality, selectivity, and adjustability) compared to conventional filters [7, 8].

Photonic crystals are Nano scale materials, in which the periodic periodicity of dielectric constant creates a photonic band gap. This type of structure provides a method for controlling the photon or, in general, electromagnetic waves in a dielectric environment. A photon, with a particular wavelength, or specific energy, cannot be transmitted through crystal. This means that control of the passage of the photons, which is mainly provided by creating a defect in photonic crystals, is available to the designer. The defect in the photonic crystal is caused by the change in dielectric radius or sex, or the removal of the rod [9, 10]. Defects in photonic crystals may be used to create a waveform that can pass light through a given path as an optical channel. Also, it may be used to build micro cavities in order to concentrate photons [11]. Basically there are three different types of wavelength filter: resonance type, numerical coupling type, and diffraction type. What has recently become more prominent is the study of high-speed high - speed transmissions and the preservation of light emission in photonic crystal structures. The cavities are designed in photonic crystals so that the frequency of resonance in the network is prohibited, which produces high-quality optical modules [12]. The most flexible type of wavelength filter in photonic crystals is the resonance type filters. In a photonic crystal, a point defect can act as a small hole to exacerbate a particular wavelength. In order to target a resonant frequency, the defect size should be controlled accurate in the nanometer range [13]. The optical data transmission space is optical fiber. In optical WDM systems, multiple optical waves combined with different wavelengths are sent as a set into an optical fiber, which will increase the capacity (number of channels) of the optical network. These channels have different central wavelengths, therefore, optical filters play a vital role in channel selection and the removal of remaining channels [14, 15]. Also, filters with a high-quality factor are used to prevent diffraction phenomena when transmitting information from optical fibers [16, 17].

2. Materials And Methods

In this research, writers have presented a method that works at a wavelength of 1550 nm, with the goal of the lowest losses, as a highly sharp transient optical pass filter with a high transmission domain in optical WDM systems. The proposed filter has an inverted quasi-waveguide and a quasi-wavelet output that are coupled by a annular resonator.

In this structure, the wavelength selection operation is performed by the resonator ring, and the selected wavelength is guided through the quasi-wavelet output to the outside of the structure [18,19]. The analysis and simulations related to the proposed filter and the extraction of the bundle of photonic crystals for the crystal base structure, have been accomplished by time-domain finite difference (FDTD) and flat-wave expansion (PWE) methods, respectively. The proposed method for filter design consists of two general phases as shown in figure 1.

In next sections of article, we'll cover the following [20,21].:

1. Design and configuration of proposed filter structure;

2. Calculating the banned photon band structure;

3. Simulation;

4. Discussion and conclusions on the simulation results;

3. Suggested Filter Design

A 20 * 19 square grid of silicon dielectric rods with a refractive index of 3.4 was used to design intermediate pass filter. The radius of these dielectric and die rods of the photonic crystal structure of the structure shown with the letter a is 0.175a and 514.11 nm, respectively. Figure 2 shows the two-dimensional structure of the desired filter.

4. Calculate The Band Structure

The first step after designing the crystal base structure is to extract the structure band diagram and obtain the area of banned photon band to determine if this structure is desirable with these characteristics for our wavelength. A common numerical method for calculating and extraction of photonic crystalline bundles and their bands is a Plane Wave Expansion (PWE) method. Plane wave expansion method (PWE) refers to a computational technique in electromagnetics to solve the Maxwell's equations. this work do by formulating an eigenvalue problem out of the equation. Figure 3 shows structure of photonic crystal band in the TM and TE modes.

As shown in Fig. 2, the desired band structure has a banned photon band in the TM mode. For the desired structure, there is no banned photon band in the TE mode. The area of banned photon band in the TM mode is between normalized frequencies of 0.3084 to 0.4495, which is set to 514.11 nm in the wavelength range of 1143.73 to 1667.02 nm. The results show that this area is suitable because of the proper bandwidth for fiber optic communication applications in WDM systems. Therefore, we will do all the simulations in the TM mode. In general, the presence of banned bands in the structure band means that the crystal base structure of the filter should be designed in such a way that a range of light frequencies cannot be expressed. As shown in Fig. 1, the filter structure consists of an inverted quasi-wavelet and a quasi-wavelet waveguide that was coupled by a circular resonator ring. The process of selecting wavelengths in optical filters occurs through the resonator ring. In general, in the resonators, the coefficient of refraction and the dimensions of the resonator ring have a direct effect on the resonance wavelength [22, 23]. This structure has two input and output ports, depending on the wavelength of the light, the light wave can be directed to the output port through the resonator ring, or it may not be able to coupler to the resonator ring and to reflect the input port. To calculate the filter output spectrum, power measurement monitors are inserted into the input and output ports, and a Gaussian input signal that covers all the frequencies is applied from the input port to the structure. Finally, the spectral response of the filter power transmission is calculated on each port and normalized to the input port [24, 25].

5. Results

The FDTD method was used to simulate the filter output spectrum. The Finite-Difference Time-Domain (FDTD) method is a rigorous and powerful tool for modeling nano-scale optical devices. FDTD solves Maxwell’s equations directly without any physical approximation, and the maximum problem size is limited only by the extent of the computing power available. Figure 4 is a representation of the output spectrum that is normalized in the proposed intermediate filter. According to this form, the structure at the central wavelength of 1550 nm acts as a very sharp passage filter with a flow efficiency of 94.8% and a quality coefficient of 2583.33. The bandwidth of the filter output spectrum is 0.6 nm (1549.62 to 1550.22 nm). One of the important parameters in the design of photon filters can affect the filter performance is the radius of the dielectric bars. Figure 5 shows effect of crystal dielectric rods radius on output wavelength. According to this form, by increasing the radius of dielectric rods, central wavelength of filter is transferred to higher wavelengths. As shown in the figure 5, the transfer range of some of these filters is higher than our proposed filter, but the quality factor is lower and vice versa. Thus, according to Figure 5, the transmission domain and the filter quality factor with a refractive index of 3.4 at 0.175a radius have a good performance compared to other values of the radius of the bars.

In Figure 6, the light field distribution for the proposed filter structure is shown for wavelengths (A) 1550 nm and (B) 1545 nm. In Figure 6 (a), at a wavelength of 1550 nm, the light wave is dipped into the resonator ring and is guided towards the output port and has a very slight reflection toward the inlet port. However, in Figure 6 (b) at 1545 nm, the light wave cannot be guided through the resonator ring to the outlet, so the entire radiation wave is reflected back to the input port.

The method presented in this research is a comprehensive plan and compared to other methods, it seems reasonable both in terms of size and bandwidth and design cost. Therefore, it can be said that in our proposed method, a compromise has been made and all parameters are in the average range and therefore suitable for practical applications. However, some designs have only sought to improve one parameter, such as bandwidth. Therefore, the final design was not suitable for practical application.

6. Discussion And Conclusion

In recent years, optical communication systems have emerged as a convenient, inexpensive, highly reliable way in the field of telecommunications. Optical filters are one of the main structures of this type of communication and are used in different parts of this system. One of the main applications of optical filters in multiple systems is Wavelength-Division Multiplexing (WDM). These systems are used as one of the main components in information transmission in optical systems. Therefore, designing a suitable filter leads to an overall improvement of the system. In this paper, the design of a two-dimensional optical transmission filter for fiber optic applications (third window) is suitable for wavelength division multiplex systems (WDM). This filter consists of a 20*19 square mesh with a refractive index of 3.4 in the air. This filter operates at a wavelength of 1550 nm with a 0.6 nm bandwidth as a very sharp transient filter with a passivity of 94.8% and a 2583 quality factor. According to the results of the simulations, it was observed that by changing design parameters, including radius of dielectric rods, we can adjust central wavelength of the filter output spectrum. The high transfer rates, high-performance coefficients, and low-bandwidth are among the important features of this proposed filter, which show remarkable improvement over previous reported work.

Abbreviations

Band Pass Filter	BPF
photonic crystal	PC
Wavelength-Division Multiplexing	WDM
Finite-difference time-domain	FDTD
plane-wave expansion	PWE
full width at half maximum	FWHM
Focal Plane Module	FPM

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*Conflicts of interest/Competing interests (include appropriate disclosures)

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*Availability of data and material (data transparency)

Not available

*Code availability (software application or custom code)

Not available

*Authors' contributions (optional: please review the submission guidelines from the journal whether statements are mandatory)

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Figures

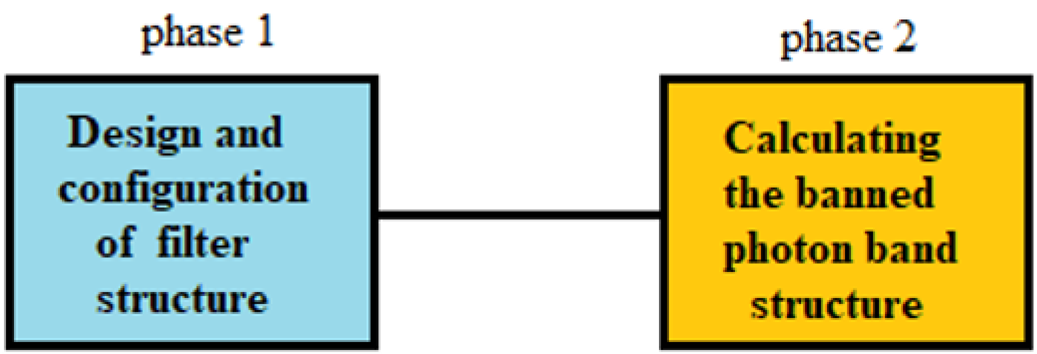

Figure 1

two general phases of proposed method for filter design

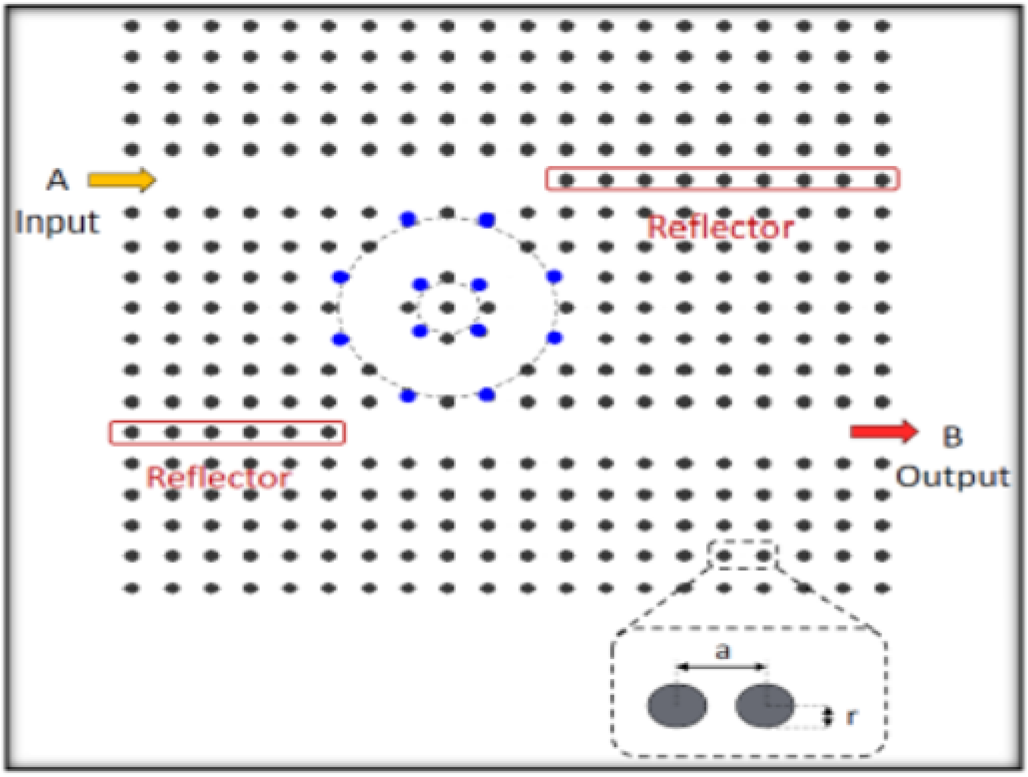

Figure 2

The proposed two-dimensional filter structure

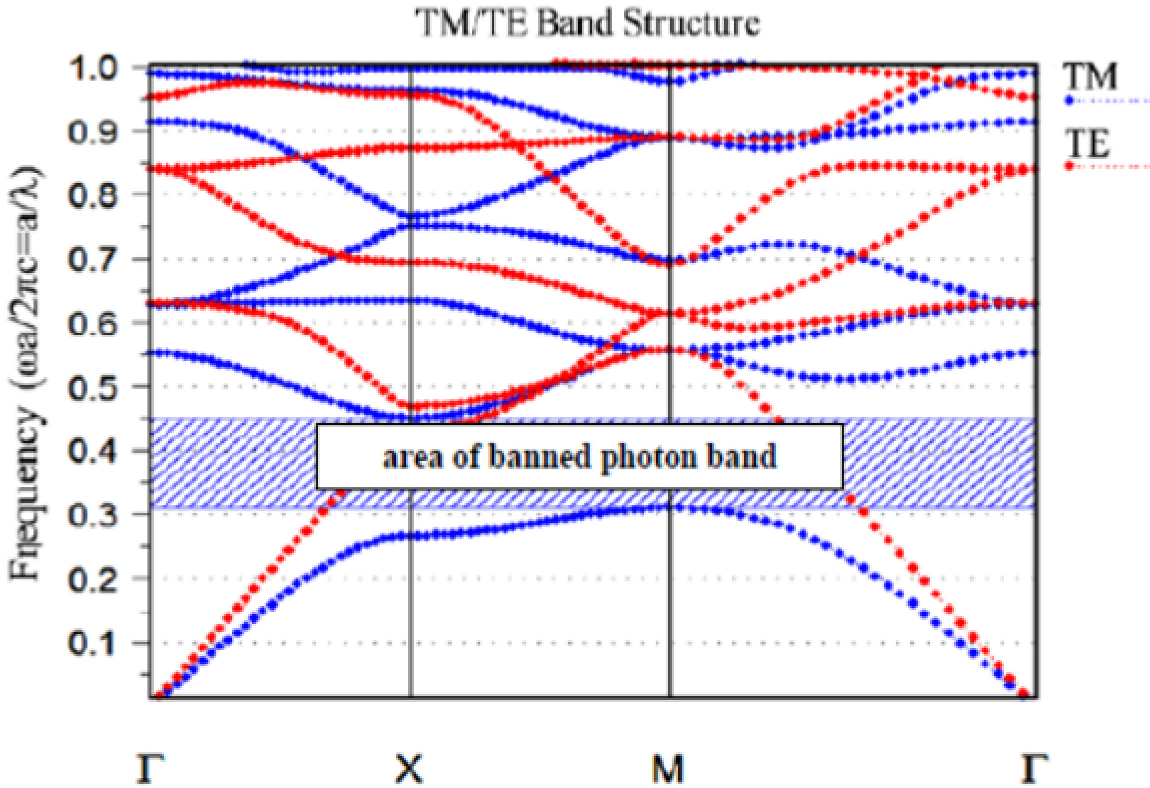

Figure 3

The photonic crystal band structure of proposed filter in the TM mode (blue) and TE mode (red)

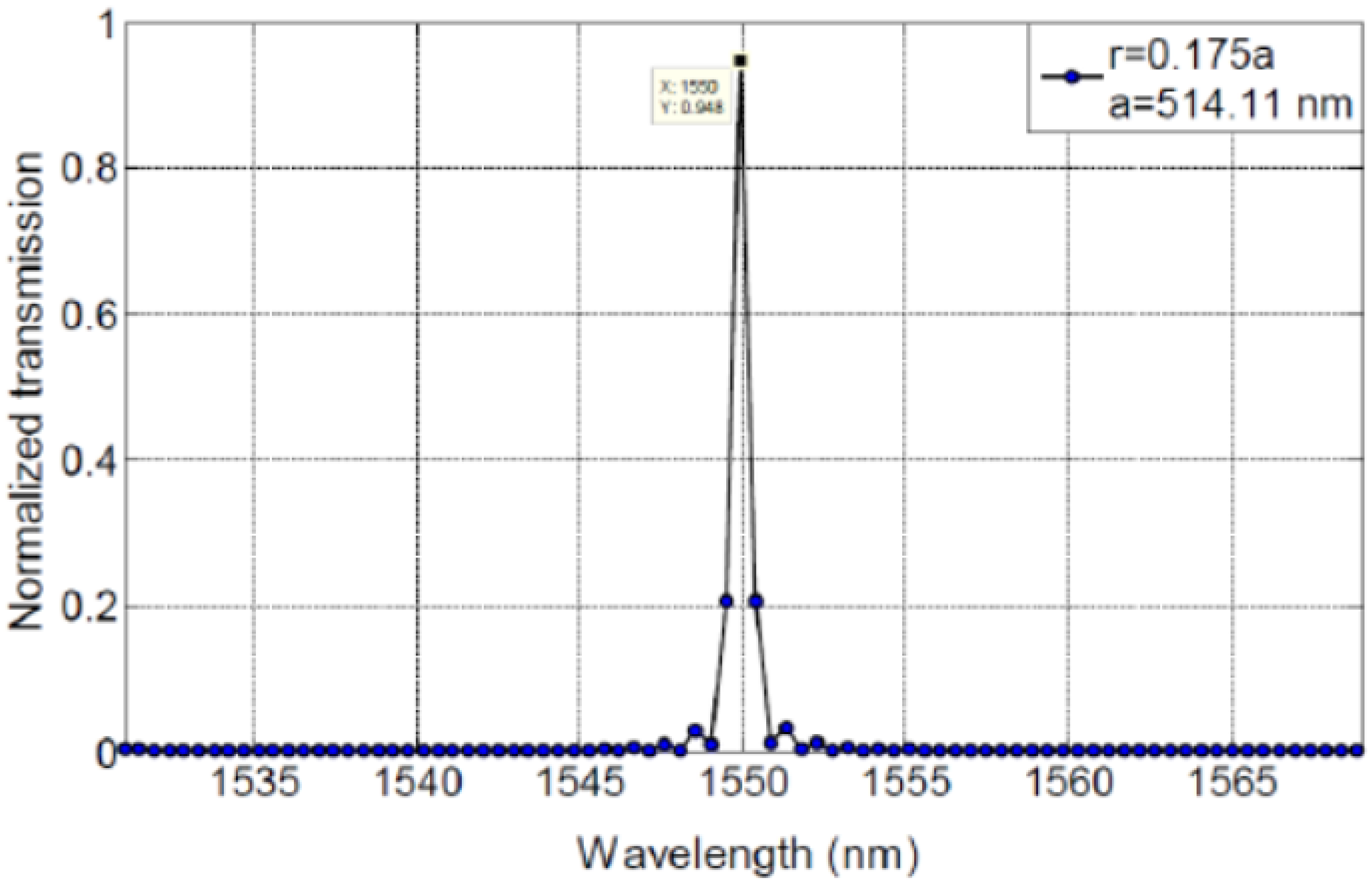

Figure 4

Proposed Normalized Output Filter

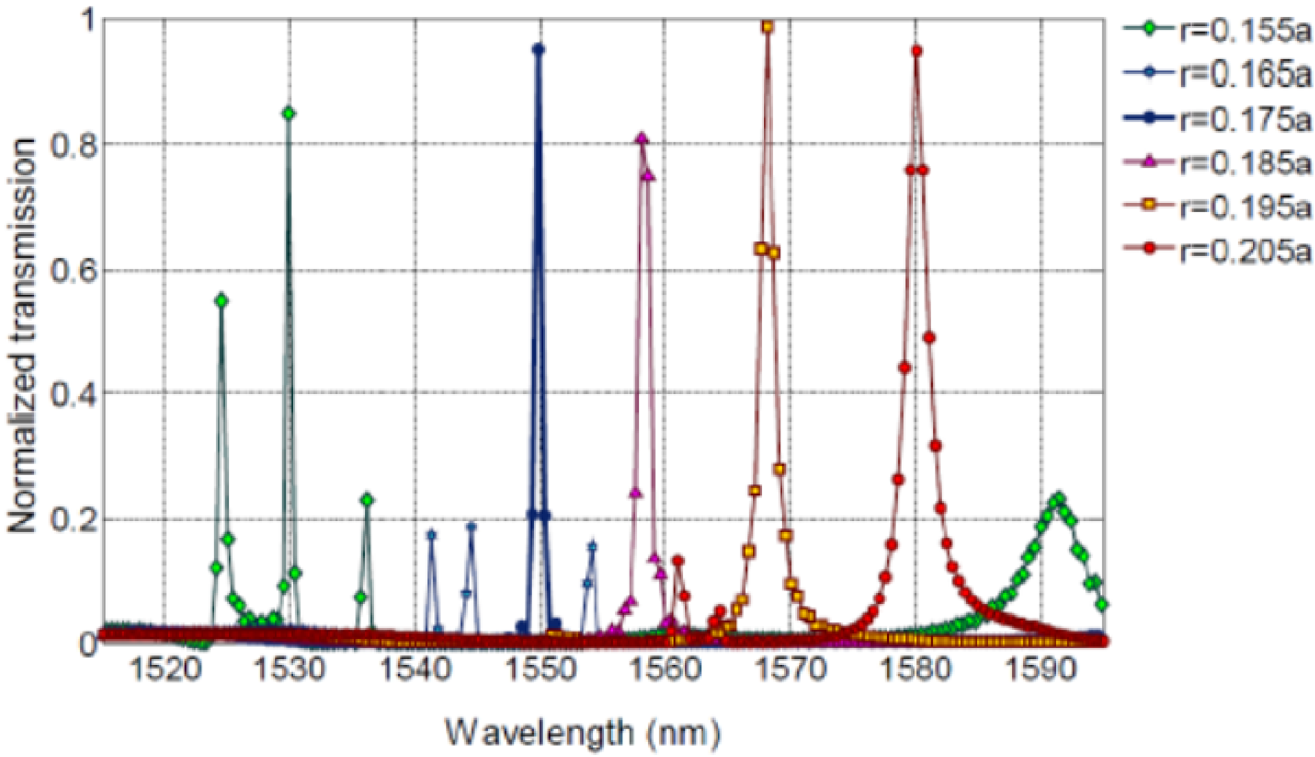

Figure 5

shows the filter output spectrum for different dielectric bar radii

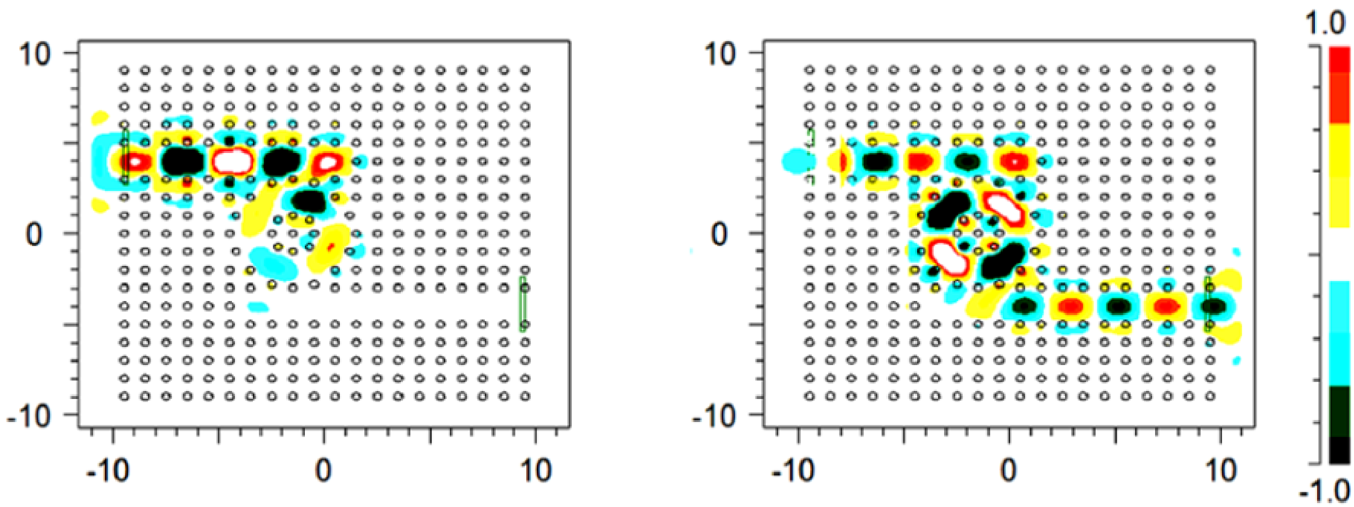

Figure 6

Light distribution of the proposed filter structure at a wavelength

(A: right) of 1550 nm and (B: left) 1545 nm