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Design of a DWDM Demultiplexer Using a 2D Photonic Crystal Hybrid Cavity

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ABSTRACT: A high-performance Two-Dimensional Photonic Crystal (2DPC) demultiplexer is proposed for application in Dense Wavelength Division Multiplexing (DWDM). Simultaneous high-field confinement and higher modal coupling are achieved using a new hybrid cavity geometry design, which consists of a square cavity with an inner rod radius ($r = 110$ nm) and a circular cavity with an outer rod radius ($r = 100$ nm). It is an operating silicon platform featuring a square lattice, bus waveguide, and four drop ports. Plane Wave Expansion (PWE) and Finite Difference Time Domain (FDTD) simulation methods reveal a large photonic bandgap (0.27–0.37 a/λ) and excellent spectral performance, including a 98.75% average transmission efficiency, a high Q-factor of 7281, and precise 0.8 nm channel separation. System-level verification, Lumerical INTERCONNECT, and eye diagram and BER analyses were used to test signal integrity. The hybrid geometry also has a smaller footprint and improved integration, making it a suitable design for next-generation optical communication systems.

1. INTRODUCTION

Single Mode Fiber (SMF) is a type of fiber-optic cable that uses light pulses to transmit data over long distances. It offers lower attenuation and faster rates than coaxial transmission. Owing to the development of modern technologies, large volumes of data can now be sent across long distances at breakneck speeds. High-performance optical devices are required to transmit massive amounts of data over long distances at high rates using optical communication networks. Photonic crystal structures have recently been proposed as ideal candidates for the realization of all-optical devices [1, 2]. Radio-over-Free-Space Optical (Ro-FSO) and DWDM-based communication systems are also studied to improve data transmission capacity and reliability in varying channel conditions [3, 4]. Periodic dielectric structures, also known as photonic crystals, have gained popularity as a means of controlling light signals. Photonic Band Gap (PBG) phenomenon is the most exciting of PC architectures [5, 6].

For optical networking applications, photonic crystals (PCs) are a relatively new technology that has successfully generated high-quality photonic components due to their inherent characteristics, including nanometer-scale size, low power consumption, low loss, and improved performance. The dielectric components of PCs are arranged predictably to control the Transverse Electric (TE) and Transverse Magnetic (TM) waves within a crystal platform. Three types of PCs are distinguished based on their periodicity: One-Dimensional (1D), Two-Dimensional (2D), and Three-Dimensional (3D) [7]. Defects can be categorized into two types: line defects and point defects. A line defect is produced when the structural characteristics of the targeted structure are changed or when an entire row of rods is eliminated. Point defects are produced by either removing a single rod entirely or by changing its structural properties. In PC calculations, the defects of either or both forms are necessary in the design to allow light propagation to be controlled [8]. The capacity to modify PBG materials to regulate light propagation has garnered considerable interest in the past 10 years, and research in this area has produced several groundbreaking advancements in various optical domains [9].

Previously, a 2DPC device based on a Ring Resonator (RR) with a different shape was proposed and demonstrated. Several studies based on PCRRs have been reported in the literature for the realization of switches [10, 11], power splitters [12], and demultiplexers [13, 14]. Because they have several modes, ring resonators provide more flexibility in terms of mode design, size scaling, and structural design than point defect cavities. The literature suggests a few photonic crystal ring resonator (PCRR) designs that enhance the wavelength selectivity and transmission efficiency in optical demultiplexers. Other geometries of resonators have been explored to improve device properties, including the quality factor, channel separation, and crosstalk. As an example, resonator structures in a square shape have been reported where a wavelength filter is applied [15]. The coupling efficiency and spectral response were also investigated using hexagonal resonator configurations [16].

Circular photonic crystal ring resonators have also been widely researched because they are geometrically symmetrical and of high transmission efficiency [17]. Different designs have been suggested as alternative geometries that can be used to create compact demultiplexer designs like X-shaped [18] resonator structures. Moreover, elliptical resonator designs have also been studied to benefit the resonance properties and to per-

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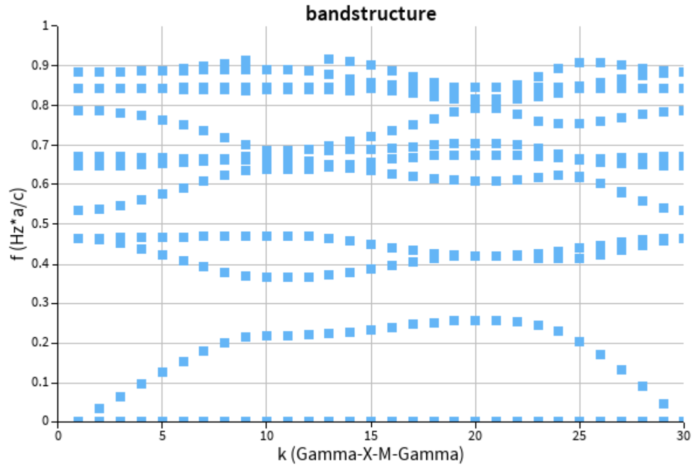

FIGURE 1. Photonic band gap structure for the proposed work.

fect the performance of the devices [19] and have all been used in the development of several types of 2DPCRR-based channel drop filters in recent years. Recent studies have been directed towards enhancing spectral properties and reducing the dimensions of the photonic crystal ring resonator-based demultiplexers for optical communication systems.

It has provided a high-performance multichannel photonic crystal demultiplexer with improved wavelength selectivity and higher transmission efficiency [20]. A design suggested a small PCRR-based demultiplexer architecture that could have low crosstalk and a large quality factor in dense wavelength division multiplexing [21]. The review of the photonic crystal ring resonator arrangement has demonstrated it to be circular in nature; this design has been created to promote the inherent characteristics of resonance and to advance transmission capabilities [22]. Additional enhancements in the performance of the devices of demultiplexing did occur by an optimization of the resonator geometries and coupling strategies within photonic crystal structures [23]. Researchers have also explored the designs of multichannel demultiplexers based on modified ring resonator designs to achieve enhanced channel isolation and filtering characteristics [24].

Photonic crystal-based demultiplexers have also been designed with better structural parameters to achieve a better quality factor and lower insertion loss [25]. Smaller PCRR-based multifunctional demultiplexer systems that could be implemented in integrated photonic circuits are also investigated in the recent literature [26]. High-speed optical communication networks were reported to be supported by advanced photonic crystal demultiplexer designs with enhanced channel separation and wavelength selectivity [27]. Moreover, there have been a number of studies aimed at maximizing the photonic crystal lattice designs in order to attain high transmission efficiency in optical demultiplexers [28]. More recent PCRR configurations of demultiplexers have been suggested to enhance spectral response, and compactness of devices is needed for modern photonic integrated circuits [29]. Wavelength division multiplexers (MUX and DMUX) are essential components of optical communication networks. The behaviour of a DWDM optical transmission system in various operating situations was examined [30]. Recent advances in Optical and Nano-Optical technology have improved optical confinement and performance for all types of devices that can support the development of compact DWDM systems [31–33].

2. BAND GAP STRUCTURE FOR THE PROPOSED HYBRID CAVITY

The proposed PC structure is a series of dielectric rods in a square lattice structure. The resulting periodic structure forms a 2D photonic crystal that can regulate the propagation of electromagnetic waves by contrast of refractive indices. To establish an understanding of the presence of photonic band gaps, the photonic band structure of the lattice was calculated using the PWE methodology, which is illustrated in Figure 1. The band diagram was computed by sweeping the wavevector k over a high-symmetry path through the square lattice of the first Brillouin zone, the path being: Γ-X-M-Γ. The obtained band structure affirms the forbidden frequency band where electromagnetic waves are not allowed to propagate in the periodic structure. The electromagnetic fields are concentrated mostly within the high-index rods in the bands below the photonic bandgap, which are guided or dielectric modes. The above bands, on the other hand, indicate propagating modes that can pass through the crystal structure. The PBG is the absence of permitted modes in a particular frequency range, which is the most important mechanism that allows light to be confined in defect-based photonic crystal systems.

Based on the band diagram in Figure 1, two important photonic band gaps occur within the normalized frequency bands of $f = 0.27$–0.37 and $f = 0.55$–0.62. These PBG areas inhibit the spread of light and, hence, serve as optical barriers. This type of band gap is required in the design of waveguides, filters, and resonant cavities, where it enables localized defect states to be found in the forbidden frequency range. The photonic band gap in the proposed work provides the confinement mechanism in the proposal of the hybrid cavity resonator utilized in the DWDM demultiplexer. The defect cavity adds resonant modes within the PBG, which allows for filtering by wavelength and effective separation of channels. The normalized frequency re-

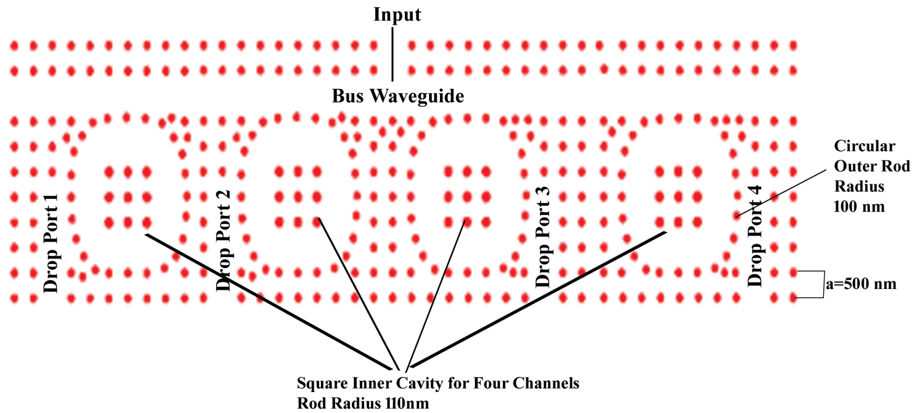

FIGURE 2. Diagram of the proposed 2D hybrid cavity demultiplexer employing a photonic crystal made of a bus waveguide and four drop ports. The lattice constant was $a = 500$ nm, the radius of the circular rod was 100 nm, and the radius of the square inner cavity rod was 110 nm. This building material consists of silicon, whose refractive index is $n = 3.477$ at a wavelength of 1550 nm.

lation between the lattice constant and operating wavelength can be used to determine the wavelength of the photonic band gap.

$$\lambda = \frac{a}{f} \tag{1}$$

where 'a' is the lattice constant, λ the wavelength in nm, and f the frequency in Hz.

The operating wavelength range was obtained using the normalized photonic band gap frequency and lattice constant. The wavelengths of the first band gap were 1459 to 2000 nm, and those of the second band gap were 870 to 981 nm. In long-haul telecommunication applications, the range of wavelengths used is 1500 to 1600 nm (C band) because it is commonly applied in DWDM optical communication systems. A photonic crystal resonant structure is formed by creating point defects within the structure to create a hybrid cavity and line defects to create bus and drop waveguides. The photonic band gap is an important aspect in the functioning of photonic crystal devices, as it inhibits the transmission of certain wavelength ranges in the periodic structure. It is possible to create localized modes within the PBG by introducing structural defects to the periodic lattice.

In the proposed design, the circular outer cavity and square interior cavity of the resonator are the defects that allow the high confinement and wavelength filtering of light to occur. In this study, a hybrid cavity consisting of circular and square geometrical shapes is used to apply both geometrical shapes in the same resonant structure through the performance metrics of the Quality Factor (Q-factor), transmission efficiency, and crosstalk.

3. PROPOSED FOUR-CHANNEL HYBRID CAVITY DEMULTIPLEXER DESIGN

In DWDM applications, a four-channel demultiplexer on a 2D PC platform with a hybrid cavity is suggested. It is constructed on a rectangular silicon dioxide (SiO_2) substrate, and the photonic crystal lattice is made up of 42×11 high-index silicon rods, as shown in Figure 2. The dimensional characteristics and material features of the proposed photonic crystal hybrid cavity structure are discussed in this section. In the suggested design, silicon rods are applied to a silicon dioxide (SiO_2) background substrate to obtain a significant refractive index contrast needed to form a strong photonic band gap and provide efficient optical confinement. Silicon refractive index is $n = 3.477$, and silicon dioxide refractive index is $n = 1.44$ at the operating wavelength of 1550 nm. The photonic crystal lattice constant is defined as 'a' $= 500$ nm, which defines the scaling of the photonic band gap. The periodic lattice required to form the band gap is ensured by the outer circular rods with a radius of 100 nm ($0.2a$). A square rod of the dimension of 110 nm is inserted in the hybrid cavity area to form a defect and increase the light confinement to be able to tune light resonances accurately to separate channels in DWDM. The rod sizes were changed to examine their influence on resonant wavelength, transmission efficiency, and Q-factor. This was found to have an inner cavity size as the primary determinant of resonance and Q-factor and an outer rod radius as the determinant of coupling efficiency. The selected values are used to offer the best balance between the performance parameters. A performance analysis was performed over a range of values of the rod dimensions ranging from 90 to 120 nm to see how each rod dimension changed the resonant wavelength, throughput, and quality factor of the resonant cavity. The distance between the rods corresponds to the lattice periodicity. Together, these parameters allow for maximum optical confinement and efficient modal coupling within the C-band spectral region. A hybrid cavity, which is a combination of circular and square geometrical features in the PC lattice, is the main aspect of the design. This defect is a hybrid defect formed by the removal and repositioning of dielectric rods to disrupt the periodicity of the lattice, thereby producing localized resonant modes. The radius of the cavity contributes to the efficient optical circulation of reduced radiative loss, and the square area of the cavity facilitates mode confinement and encourages coupling with orthogonally aligned waveguides. The hybrid cavity has a more stable resonance and a more selective wavelength because of the combination of the two shapes compared to traditional single-geometry cavities.

TABLE 1. Proposed design output for the four-channel demultiplexer.

Channel	Resonance Wavelength (λ) (nm)	$\Delta\lambda$ (nanometre)	Quality Factor	Transmission (%)
Channel 1	1554.7	0.22	7066	98.7
Channel 2	1555.5	0.21	7407	98.8
Channel 3	1556.3	0.21	7410	99.1
Channel 4	1557.2	0.215	7242	98.4

The third row of the lattice was eliminated to form a bus waveguide, which allowed the input optical signal to pass through the structure. The drop waveguides were made by removing the columns of the selected rods to select the various wavelength channels. In particular, the 3rd, 12th, 29th, and 40th columns are cleared to create Drop Ports 1, 2, 3, and 4, respectively. The spacing and location of the drop ports were decided on both theoretical coupling considerations and FDTD simulations. The ports have been spaced properly for efficient energy transfer from the cavity to each drop port while minimizing field overlap and crosstalk with adjacent channels. This arrangement improves the isolation of each channel and the total transmission performance. This location will optimize the bus waveguide to hybrid cavity coupling while still allowing for sufficient distance between drop waveguides so that crosstalk is kept to a minimum. The coupling efficiency between the waveguide and the cavity is affected when the position of the bus waveguide is changed. By moving the bus waveguide further away from the cavity, there is less field overlap, which gives a lower efficiency of energy transfer. This results in a lower transmission efficiency and increased crosstalk. Such spatially separated waveguides maintain a useful separation of channels and minimize inter-channel interaction. It is also necessary to launch the optical source at the middle of the hybrid cavity to effectively excite the localized resonant modes and investigate the characteristics of field confinement within the structure. This input light is excited into the bus waveguide, and only those wavelengths for which the resonance condition of the hybrid cavity is met couple into the respective drop waveguides. The non-resonant wavelengths continue to propagate along the bus waveguide. The arrangement of the rods surrounding the hybrid cavity was optimized to reduce radiation loss and inhibit backward reflections in the arrangement to achieve improved field confinement in the defect region.

The proposed demultiplexer is a hybrid cavity design to achieve a better resonance stability as well as optical confinement by applying a square inner cavity and a circular outer cavity. The outer and inner parts use various radii of the rods to enhance wavelength and spectral selectivity. Hybrid cavity designs provide a small, compact design, thus leading to a smaller demultiplexing device than conventional demultiplexers made from PCRR. In addition, the device performance simulation within the FDTD is verified with the examination of the system-level DWDM within Lumerical INTERCONNECT, and the suitability of the device to optical communication systems is demonstrated.

4. SIMULATION RESULTS AND ANALYSIS

The designed demultiplexer is based on a hybrid cavity integrated into a 2D PC and is simulated using the FDTD method in the Lumerical simulation environment. Compared to 3D models, 2D simulations have a good trade-off between efficiency and physical precision, which is why they are appropriate for the design of compact integrated optical devices. Ansys Lumerical FDTD simulations with a spatial mesh of 10–20 nm were used to resolve the photonic crystal structure. The computational runtime for each simulation was approximately 15 to 20 minutes, depending on the system configuration. Outgoing waves were absorbed by using Perfectly Matched Layer (PML) boundary conditions with 8–12 layers. The solver automatically adjusted the time step (Δt) based upon the Courant stability condition and was in the range 3×10^{-17} s to achieve numerical stability and correct field propagation. The device was analyzed with a Gaussian broadband source with a center wavelength of 1550 nm in the C-band. Monitors for transmission were placed at different ports to assess the performance of the device.

It has a square-lattice photonics crystal with a hybrid cavity consisting of circular and square geometrical patterns that further increase the stability of the resonances and the selectivity of wavelengths. A significant parameter of DWDM systems is crosstalk, which is calculated, and the proposed design results in an average crosstalk of -45 dB, which is a good indication of good channel isolation. In addition, the hybrid cavity demultiplexer has a large Q-factor, high transmission efficiency, small footprint, and small channel separation and is applicable to both dense DWDM and on-chip photonic applications. The important parameters analyzed to validate the device performance include bandwidth, resonance wavelength, channel spacing, Q-factor, transmission efficiency, and lattice constant optimization.

Table 1 lists each channel's transmission efficiency, Q factor, and the width of the resonance for the suggested design. With a first channel resonance wavelength of 1554.7 nm and a bandwidth of 0.22 nm, the Q factor is 7066. The second channel resonance wavelength is 1555.5 nm, with a bandwidth of 0.21 nm, and the Q factor was determined to be 7407. The wavelength of the third channel is 1556.3 nm, and its bandwidth is 0.21 nm, with a Q factor of 7410.

The fourth channel's wavelength is 1557.2 nm, and its bandwidth, using the Q factor value of 7242, is 0.215 nm. The suggested work's Q-factor in Equation (2) is shown below.

$$Q = \frac{\lambda}{\Delta\lambda} \tag{2}$$

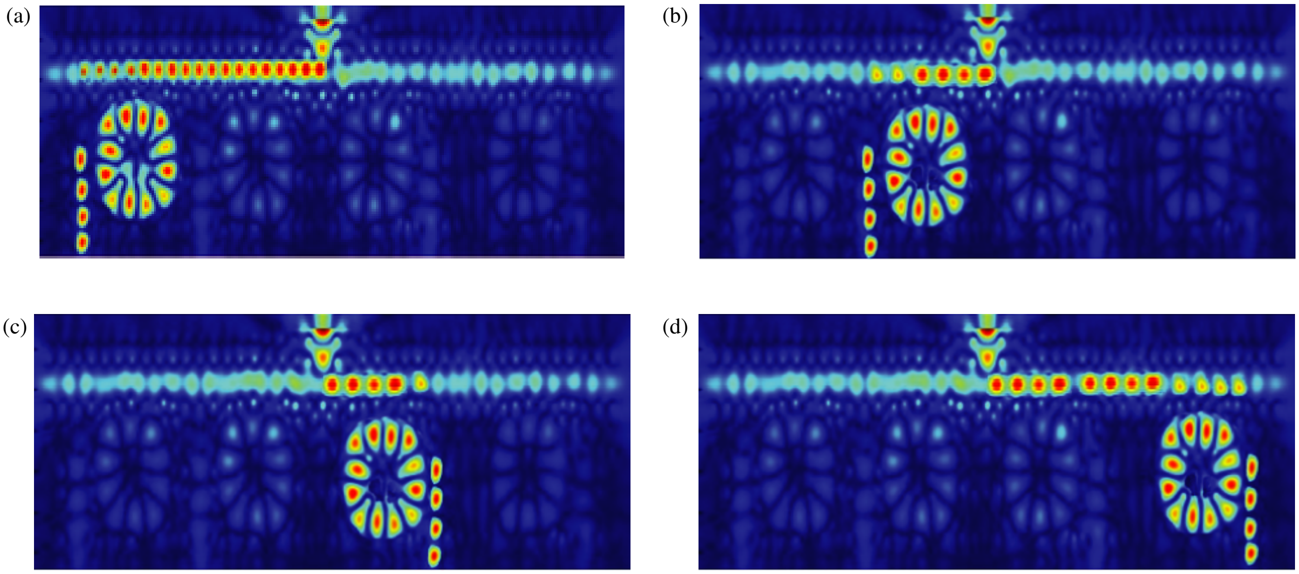

FIGURE 3. Electric field distribution at different resonance wavelengths. (a) $\lambda_1 = 1554.7\,\text{nm}$, (b) $\lambda_2 = 1555.5\,\text{nm}$, (c) $\lambda_1 = 1556.3\,\text{nm}$, (d) $\lambda_2 = 1557.2\,\text{nm}$.

TABLE 2. Proposed work parameter value with existing work.

References	Number of Channels	Material	Quality Factor	Transmission Efficiency (%)	Cross-talk (dB)	Foot-print (μm^2)
Proposed work	4	Silicon rods	7281	98.75	−45	197
[35]	4	Graphene-based PC	1944	90	−60	400
[36]	4	Silicon rods	3805	98	−41	-
[37]	4	Silicon photonic crystal slab	6000	97	−11	475
[38]	4	High-index dielectric rods	2567	97	−25	374

where λ is teh resonance wavelength, and $\Delta\lambda$ is the bandwidth.

The ratio between the wavelength of resonance and the bandwidth of each channel is used to calculate the Q-factor. The wavelength in Equations (1) and (2) is the ideal wavelength of a perfect periodic bandgap of the photonic crystal. Nevertheless, defects are created to shape the hybrid cavity and waveguides by the proposed structure, which disturbs the periodic lattice to some extent. Since these structural changes exist, there will be minor variations between the actual and the analytical resonances' wavelengths. To precisely calculate the resonance properties of the proposed demultiplexer, the FDTD technique is employed. Figure 3 demonstrates the interaction of light in the waveguide with the cavity using drop waveguides at certain wavelengths.

Table 2 presents a comparison between the proposed demultiplexer and previously reported photonic crystal-based DWDM demultiplexer designs. Most of the referenced works operate in the optical communication C-band around 1550 nm and are analyzed using the FDTD simulation method. Although the structural configurations are different, the comparison focuses on key performance parameters, such as the number of channels, channel spacing, quality factor, transmission efficiency, and crosstalk. The primary difference among these designs lies in the material used in the photonic crystal structure, which has been included as an additional column to provide a clearer basis for comparison. Nevertheless, the excellent confinement of light within the hybrid cavity provides a high Q and effective selection of the wavelength with minimum energy loss. The optimized structure exhibited low light leakage and scattering, thus making it suitable for DWDM optical communication.

The specific values of the resonant wavelength, whereby light is perfectly coupled and routed to the relevant output channel at each peak, are observed in the transmission spectrum. Sharp, well-separated peaks indicate that high-quality resonators are used, ensuring the accurate selection of the wavelength with low losses, as shown in Figure 6. The graph shows how well this photonic crystal-based demultiplexer separates four different wavelengths, a feature that makes it suitable for applications that involve optical communication. The small widths of the resonance peaks reduce the crosstalk and spectral overlap between neighbouring channels, and only the desired wavelength can be transmitted through each drop port. This enables the device to be used in high-density DWDM optical net-

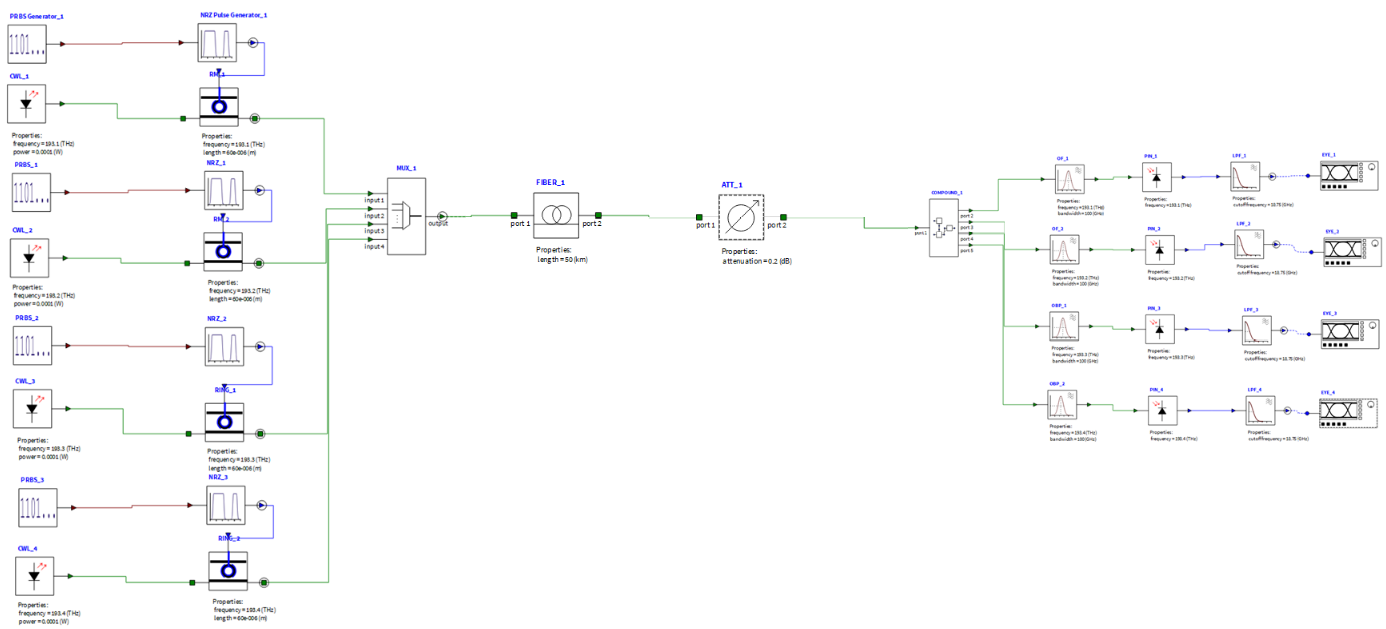

FIGURE 4. Four-channel DWDM system.

works, where several channels are near one another. The transmission spectrum demonstrated low loss and high efficiency, which proves the efficiency of the proposed hybrid cavity demultiplexer.

It contains optimized bandwidth that enables it to filter accurately at various wavelengths; therefore, it will be a significant element in the next-generation optical communication system with high capacity. The proposed design has a mean Q-factor of 7281, 98% transmission efficiency, crosstalk of -45 dB, and a small area of 197 μm^2 compared to previous designs. Crosstalk is calculated using Equation (3) and is defined as the ratio of the unwanted signal power from adjacent channels to the desired signal power at the corresponding drop port.

$$CT = 10\log_{10}\left(\frac{P_{\text{unwanted}}}{P_{\text{desired}}}\right) \tag{3}$$

Crosstalk is shown in dB (decibels), and it is given a negative value since the power of undesired signals is less than that of the desired signals. System-level implementation also validates the demultiplexer with reference to DWDM applications [34].

5. SYSTEM-LEVEL IMPLEMENTATION OF THE HYBRID CAVITY PROPOSED DWDM DEMULTIPLEXER

The four-channel hybrid cavity demultiplexer was designed at the device level in FDTD, and its essential performance parameters of resonance wavelengths, bandwidth, efficiency of transmission, and Q-factor were input into a system-level model implemented in Lumerical INTERCONNECT, as shown in Figure 4. For a simulation of the system level, an attenuation coefficient of 0.2 dB/km and a transmission distance of 10 km were chosen to reflect the normal characteristics of single-mode fiber in the C-band. The study focuses mainly on evaluating how well the proposed demultiplexer performs; therefore, the effect of attenuation will be considered the primary performance-limiting factor. Typical values of chromatic dispersion ($\sim 16\,\text{ps/nm/km}$) and nonlinearity ($\sim 1.3\,\text{W}^{-1}\text{km}^{-1}$) are considered in a qualitative manner in this work. Four optical signals at various wavelengths (DWDM channels) were created, and the data were modulated and bundled together into one fiber connection in this system. The proposed demultiplexer model was then connected to the input (bus waveguide) using a multiplexed signal. According to the spectral properties obtained by designing the device, each wavelength was distinguished and sent to the corresponding drop port. Photodetectors and filters were utilized at the receiver end to retrieve the transmitted data, and the quality of the signal was checked using an eye diagram and output spectra. The findings also demonstrate that the hybrid cavity demultiplexer separates closely spaced DWDM channels with low crosstalk and good transmission characteristics, which substantiates the fact that the device can be useful in real-world optical communication systems.

The Q-factor is very high to provide sharp resonance peaks and narrow linewidths to achieve very specific wavelength selectivity, and cavity coupling is optimized to reduce insertion loss and inter-channel interference. To determine the effect of these device characteristics on communication performance, the extracted parameters were made available in a system-level simulation. In this design, four data streams of Pseudo-Random Binary Sequence (PRBS) were produced and modulated to four different optical carriers with Mach-Zehnder modulators, which represent a typical transmitter section of a DWDM. These channels are multiplexed and sent via an optical channel, and realistic propagation effects, such as attenuation, are added. The proposed hybrid cavity demultiplexer, at the receiver side, will carry out wavelength separation depending on its resonance properties acquired using the design of the device.

Every demultiplexed channel is then translated into the electrical domain using photodetectors, and the signal can be recov-

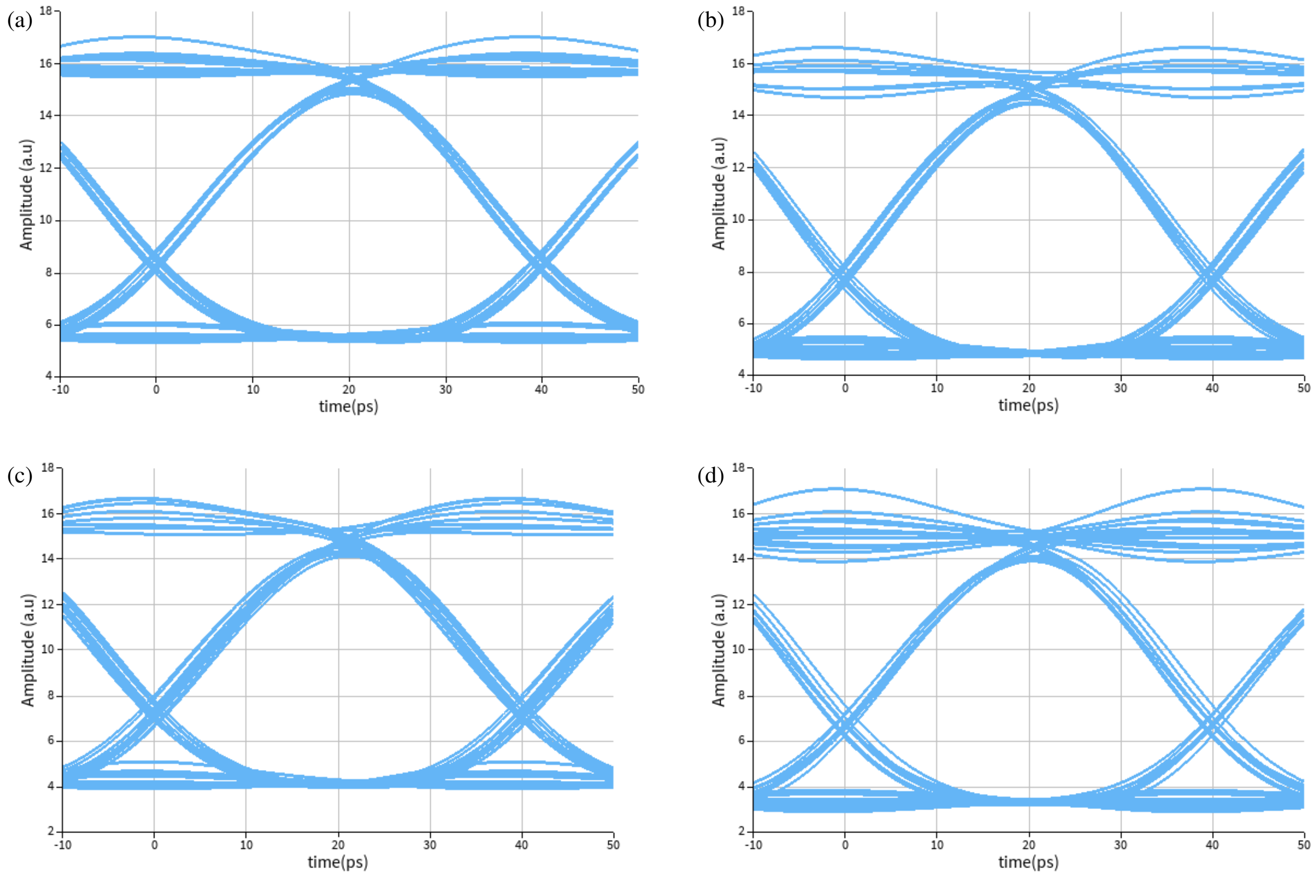

FIGURE 5. Eye diagram analysis for the four-channel DWDM system. (a) First channel eye diagram. (b) Second channel eye diagram. (c) Third channel eye diagram. (d) Fourth channel eye diagram.

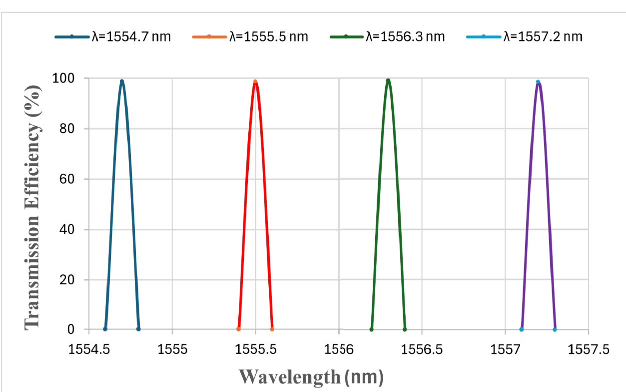

FIGURE 6. Wavelength vs transmission efficiency graph.

ered using low-pass filters. The Bit Error Rate (BER), Q-factor, eye opening, and signal distortion were measured using eye diagram analyzers. These findings indicate that the high spectral selectivity and strong optical confinement at the device level are directly converted to low crosstalk, low insertion loss, and the ability to observe eye diagrams at the system level. This investigation proves that the proposed demultiplexer is not only structurally small and spectrally efficient but can also support high-speed, low-error DWDM transmission.

Figure 5 presents the eye diagram of all four channels of the DWDM that were transmitted through the proposed hybrid cavity photonic crystal demultiplexer and system-level link. The eye pattern is very broad, and the levels of logical 1 and 0 are well defined, which means that there is low noise, less intersymbol interference, and timing stability is well observed. The results show that all channels exhibit clear and well-opened eye patterns, indicating good signal quality and minimal signal distortion. The similarity among the four eye diagrams confirms the uniform transmission performance of the proposed demultiplexer across all channels.

Table 3 presents the quantitative performance of each of the four channels in terms of the BER and Q-factor values. The results obtained indicate that the Q-factor of Channel 1 is 9.40 with the BER of 1.403×10^{-19}, Channel 2 has a Q-factor of 9.31 and a BER of 4.3×10^{-20}, Channel 3 has a Q-factor of 8.70 and a BER of 1.777×10^{-15} and Channel 4 has the best Q-factor of 11.85 and a BER of 1.302×10^{-31}. All the channels have similarly low values of BER and high values of Q-

TABLE 3. Output for proposed DWDM system.

S.No	BER	Q Factor
1	1.403×10^{-19}	9.40
2	4.3×10^{-20}	9.31
3	1.777×10^{-15}	8.70
4	1.302×10^{-33}	11.85

factor, indicating that the proposed hybrid cavity demultiplexer has identical performance at all wavelengths. The close correspondence in the open-eye diagram and the very small BER attest that the high spectral selectivity and low level of insertion loss at the device level can be successfully transferred to the system-level DWDM functionality. In the proposed design, the channel spacing is approximately 0.8 nm, which corresponds to about 100 GHz frequency spacing in the 1550 nm telecommunication band according to the (International Telecommunication Union) ITU DWDM grid standard. This spacing is widely used in practical DWDM optical communication systems for wavelength multiplexing. A fabrication tolerance investigation was performed by adding ± 5 to 10 nm to the rod radius and cavity dimensions within the model. The variation in the resonance wavelength in the range between 0.1 and 0.5 nm, with the transmission efficiency and Q-factor, also slightly changes with this measurement. However, overall device performance remains stable.

6. CONCLUSION

In this study, a 2DPC demultiplexer based on a hybrid circular-square cavity architecture has been modelled and simulated to be used in DWDM applications. With a lattice constant of $a = 500$ nm, mode confinement and stable resonant properties are realized by the incorporation of square inner rods with a radius of $r = 110$ nm and a circular outer rod with a radius of $r = 100$ nm. The simulated output of FDTD indicates that the channel spacing of 0.8 nm gives the device an average transmission efficiency of 98.75% with an average quality factor of 7281, which is within the ITU standards. In addition, the work on system-level verification was conducted with Lumerical INTERCONNECT, where eye diagrams and BER analysis were used to verify that the proposed demultiplexer does not degrade signal quality when transmitting multiple channels simultaneously. The findings indicate that the hybrid cavity structure is more spectrally selective and has a reduced footprint, which would be useful in dense photonic integration. The proposed design has a high tolerance for fabrication variation.

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