



A new design of optical add/drop filters and multi-channel filters based on hexagonal PhCRR for WDM systems

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Abstract

In this research, using photonic crystal dielectric rods with a triangular lattice constant, a photonic crystal ring resonator (PhCRR) has been designed in order to be used in optical add/drop filters (ADF). Query Using the proposed hexagonal PhCRR with four different dropping waveguides, new ADFs have been designed and simulated. At a central wavelength of 1550.5 nm, the four proposed ADFs have an average transmission coefficient, a bandwidth, and a quality factor of 100%, 1.2 nm and 1330, respectively. The results obtained from these structures indicate the high flexibility of the proposed PhCRR and ADFs and their applicability in optical communication systems. Using the ADFs, two multi-channel drop filters have been designed in order to be used as optical MUX/DeMUX with a channel spacing of 4 nm which are suitable for wavelength division multiplexing systems. In this study, the plane wave expansion and finite difference time domain methods are, respectively, used, to characterize the photonic band gap and to investigate the optical behavior of the structures.

Keywords Photonic crystal · Ring resonator · Add/drop filter · Dropping waveguide · WDM · Photonic band gap

1 Introduction

In telecommunication systems such as plesiochronous digital hierarchy (PDH) and synchronous transport module (SDH), multiplexing and switching operations are carried out in electrical domain; therefore, the speed limitations of electrical processors restrict access to much higher transmission rates over optical fibers [1, 2]. Today, this problem has been solved with the introduction and use of wavelength division multiplexing (WDM) telecommunication systems, and this technique is considered as the main method of data transmission over optical fiber telecommunication systems [3, 4]. In this approach, multiple optical signals are merged at the same time and sent on an optical fiber line, resulting in the increased data transfer speed and increased network bandwidth. Given the importance of this issue, all-optical

signal processing techniques are highly considered and much research has been conducted on them [4]. In this regard, the use of photonic crystals (PhC) is one of the best options for manufacturing optical devices used in the above-mentioned systems [5]. PhCs are periodic optical structures in which the refractive index changes periodically [6]. Due to their photonic band gaps (PBG), PhCs are able to control and direct light within their structures. PhCs have been considered for realization of integrated optical devices on micro-nanometer scale because of their unique PBGs [7]. PhCs are used to design and manufacture various types of optical devices among which, optical waveguides and cavities [8], optical fibers [9], switches and optical gates [10], optical add/drop filters (ADF) [11, 12], optical demultiplexer [13, 14], optical converters [15] and photonic crystal lasers [16], can be mentioned. Among the aforementioned devices, photonic crystal ring resonator (PhCRR)-based ADFs have received considerable attention due to their interesting characteristics, such as the low loss of the incorporated optical waveguide when coupled with the resonator, low nonlinear effects and high quality factor and transmission coefficients. So far, different types of PhCRR for use in ADFs are designed and presented. The most recent types reported in the literature are plus-shaped PhCRR [17], x-shaped PhCRR [18], quasi-shaped PhCRR [19], egg-shaped PhCRR [20], hexagonal PhCRR [21], h-

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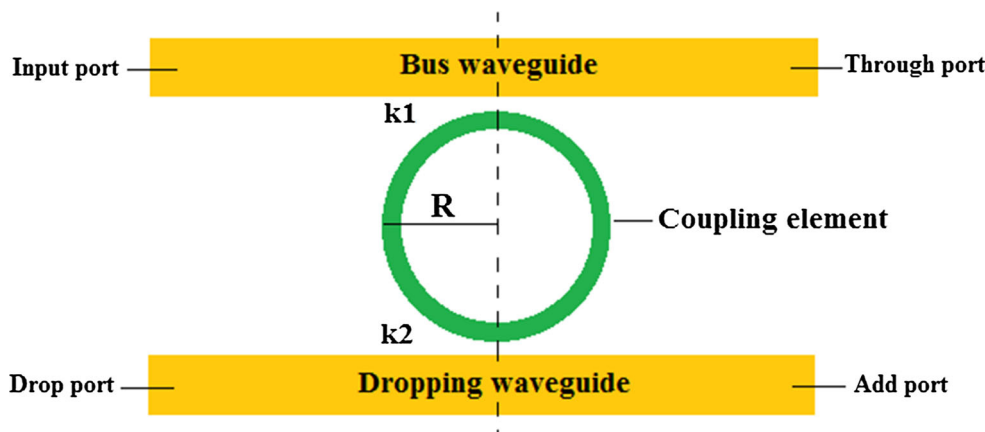


Fig. 1 Schematic of an add/drop filter

shaped PhCRR [22], circular PhCRR [23], diamond PhCRR [24], dual-curved PhCRR [25], flower-shaped PhCRR [26], rectangular PhCRR [27], and square-shaped PhCRR [28]. In this paper, using a hexagonal PhCRR, four new ADFs with different dropping waveguides are presented. The proposed structures have very good results. Low channel spacing along with a narrow bandwidth has made the structures very suitable to be used in WDM systems. To design the proposed structures, the plane wave expansion (PWE) method has been used to extract and analyze the limits of the PBGs of the structures, and to simulate and analyze the four proposed structures, the two-dimensional finite difference time domain (2D-FDTD) numerical method has been used. The rest of the paper is organized as follows: In Sect. 2, the analytical models for optical ring resonator-based ADF are presented. Section 3.1 focuses on the design of the proposed ADFs with different dropping waveguides. Design of an optical MUX/DMUX with indirect dropping waveguide for WDM systems is described in Sect. 3.2, and the design of MUX/DEMUX with diagonal dropping waveguide is described in Sect. 3.3. Finally, the conclusions are presented in Sect. 4.

2 Analytical models for optical ring resonator-based ADF

An optical ring resonator is an integrated optic traveling-wave resonator which is constructed by bending an optical waveguide to form a closed loop, typically with a circular shape. The light propagating in the ring waveguide interferes with itself after every trip around the ring. When the roundtrip length is exactly equal to an integer multiple of the guided wavelength, constructive interference of light occurs, giving rise to sharp resonances and large intensity buildup inside the ring. The high wavelength selectivity, strong dispersion, large field enhancement, and high quality factor are impor-

tant characteristics which make ring resonators extremely versatile and useful for a wide range of applications in the optical communications, signal processing, sensing, nonlinear optics, and quantum optics. One of the most important applications of the ring resonators is their application in the synthesis of ADFs. An ADF is a device that alters the amplitude, phase, or group delay characteristics of input signals in a desired fashion. A ring resonator-based ADF has four ports and a ring resonator with a radius of R to separate the wavelength sandwiched between the two optical waveguides. As can be seen in Fig. 1, this device has an input port, a through port, a drop port, and an add port [12, 29]. A ring resonator confines light in all special directions, and the light is transmitted by the optical waveguides through which the light is directed into or out of it. The reason for this is also the contrast between the coupling coefficient of the bus waveguide (k_1) and the dropping waveguide (k_2) to form the loop. If the signal entering into the ring resonator is coupled in the off mode, the light is transmitted to the through port without resonance and this occurs when the input signal has not the same characteristics as the ring resonator. However, if the input signal is coupled to the ring resonator in the on mode, the light is resonated by the ring resonator and is sent to the dropping waveguide where it is transmitted into either drop or add port, while the same function of the structure of the optical filters is used as a piece in WDM communication networks [29].

3 Design and simulation result

3.1 Design of ADFs with different dropping waveguides

To design the given ADF, a 2D-PhC structure with a triangular lattice constant (a) of 642 nm has been used. In the 2D-PhC structure, 27×21 dielectric rods (the number

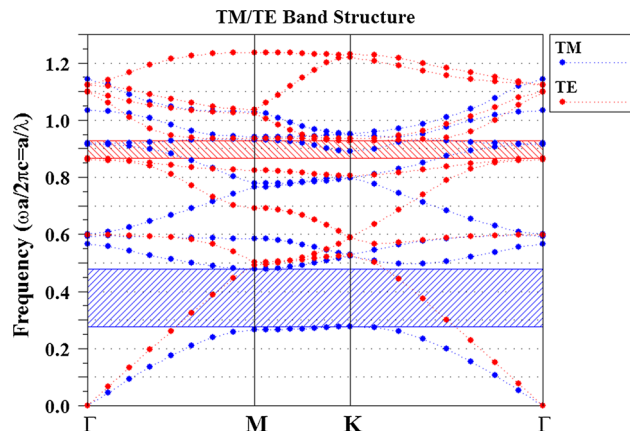


Fig. 2 Band structure of the proposed structure

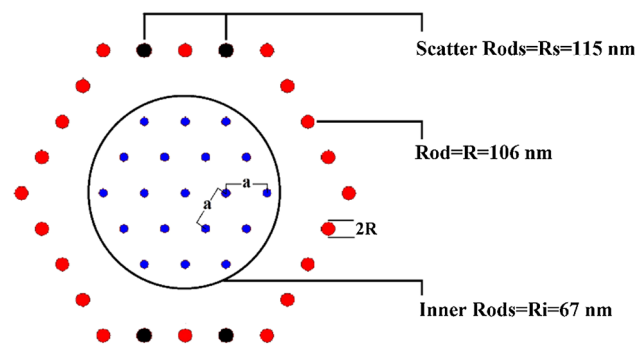


Fig. 3 Schematic of new hexagonal PhCRR

of rods in x and z directions have been 27 and 21, respectively) with a refractive index (nr) of 3.56 and a radius (R) of 106 nm have been placed in an air background. Prior to creating any defect in the PhC structure, the PBG has been extracted to examine the permissible and functional

ranges used in telecommunication areas. The plane wave expansion (PWE) method has been used to calculate PBG of the structure. As shown in Fig. 2, the structure has had 2 PBG frequency ranges in TE and TM modes. According to this figure, the frequency range has been equal to $0.867 \leq \frac{a}{\lambda} \leq 0.927$ in TE mode, which has been equal to the wavelength range of $692 \text{ nm} \leq \lambda \leq 740 \text{ nm}$. In addition, the frequency range has been equal to $0.275 \leq \frac{a}{\lambda} \leq 0.475$ in TM mode, which has been equal to the wavelength range of $1351 \text{ nm} \leq \lambda \leq 2334 \text{ nm}$. Among the PBG frequency ranges, TM mode has been considered suitable to be used for designing telecommunication devices because it covers a wide range of telecommunication wavelengths.

A new hexagonal PhCRR has been used to design the ADF structure, as shown in Fig. 3. To create the ring resonator, the removal of dielectric rods has been used in such a way that they form a full loop mode. To separate the wavelength, the size of the inner rods of the resonator has been reduced to $R_i = 67 \text{ nm}$. The scattering rods placed between the bus waveguides and ring resonator with a size of $R_s = 115 \text{ nm}$ are shown in Fig. 3. Power transfer from the bus waveguide to the ring resonator and add/drop waveguide can be changed by adjusting the radius of the scattering rods. According to the configuration shown in Fig. 4, by removing two rows of dielectric rods in the PhC structure, creating two optical waveguides on the top and down structure, and placing the ring resonator between them, the ADF structure has been designed. An input signal has been launched into the port A. The optical pulse spectra of the output ports (B, C and D) have been obtained.

After designing the proposed structure, a Gaussian light source with a TM polarization has been launched into the input and the output spectrum transmitted has been examined, as shown in Fig. 5. According to the output spectrum,

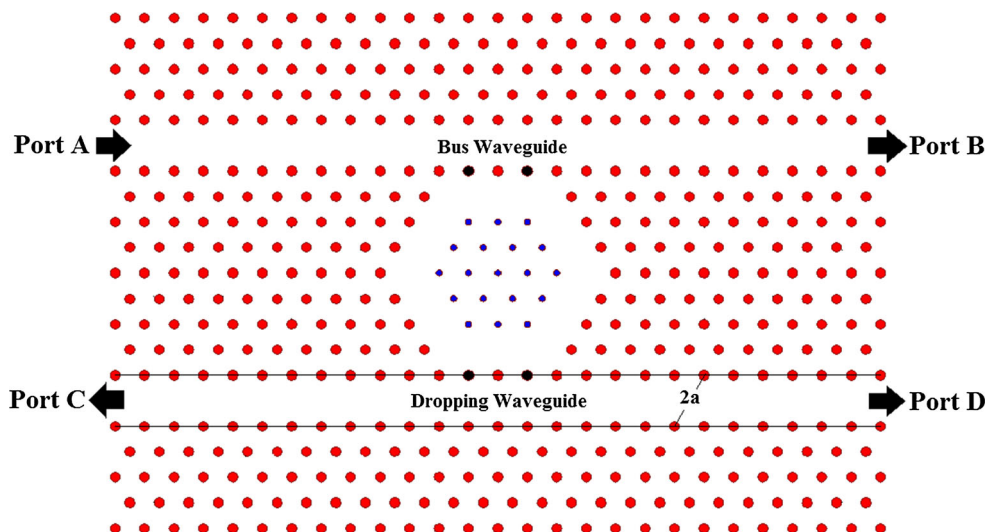


Fig. 4 Schematic of the proposed ADF with direct dropping waveguide

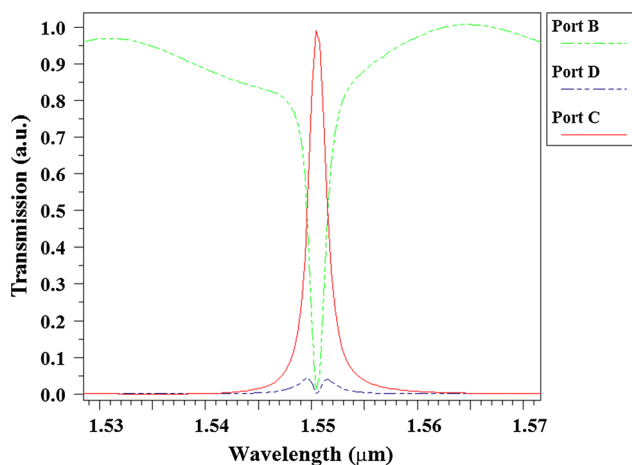


Fig. 5 Output spectrum of the proposed ADF with direct dropping waveguide

the ADF structure has been capable of the wavelength separation (λ) of 1550.5 nm with a transmission coefficient of 100%, a bandwidth ($\Delta\lambda$) of 1.3 nm, and a quality factor of 1192. When an optical pulse with such a wavelength is sent to the structure, it is received and separated by the proposed ring resonator and is transmitted to the output C. In these conditions, the normalized power level in the port C has been about 100% and it has been equal to 0 in other output ports as demonstrated in Fig. 6.

In the following, the changes created in the dropping waveguides have been discussed and their effects on the results of the output spectrum to make the structure more functional have been studied. In such a case, the dropping waveguide is in the indirect mode as shown in Fig. 7. In this mode, as in the previous mode, the structure has been capable of the wavelength separation (λ) of 1550.5 nm with a transmission coefficient of 92%, a bandwidth ($\Delta\lambda$) of 1.2 nm, and

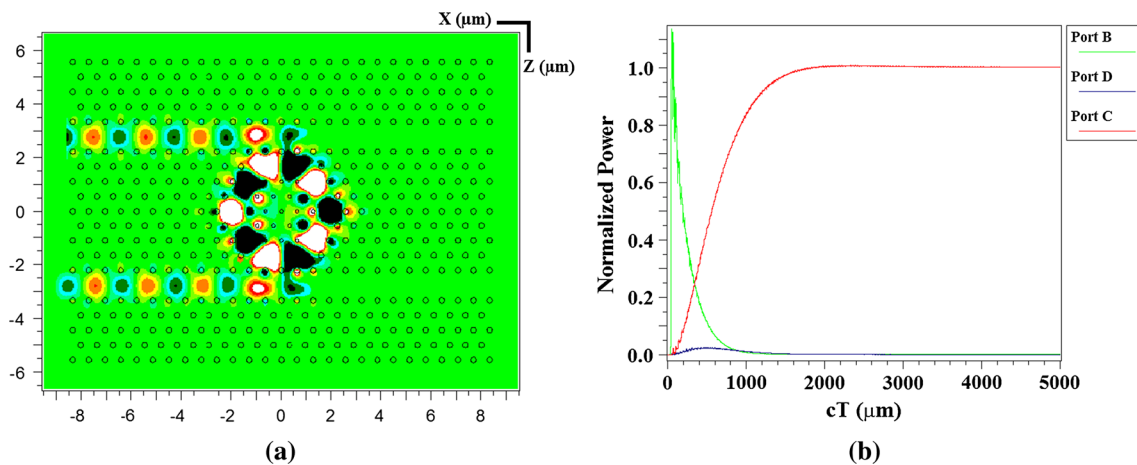


Fig. 6 Optical behavior of ADF with direct dropping waveguide in $\lambda = 1550.5$ nm, **a** electric field and **b** normalized output power

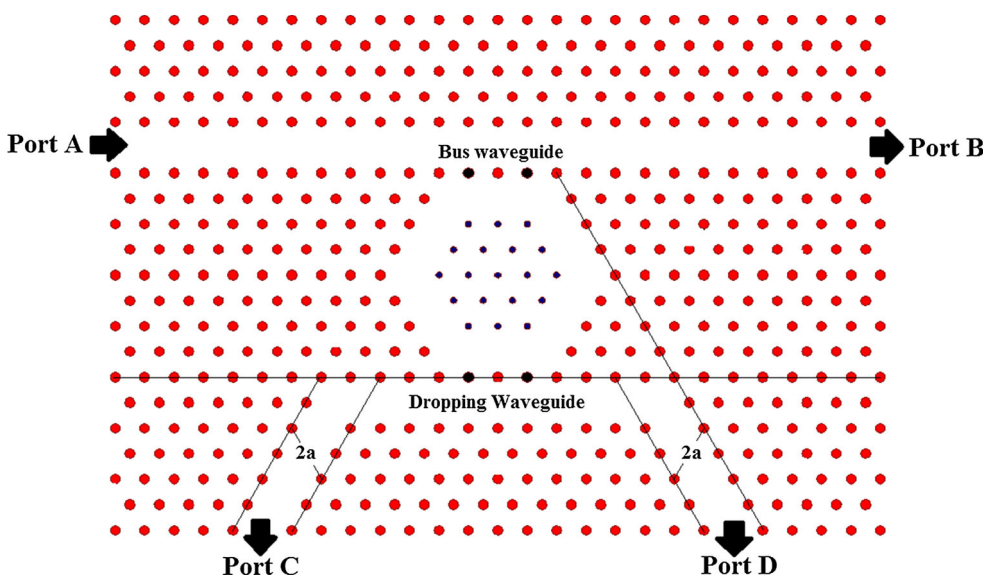


Fig. 7 Schematic of the proposed ADF with indirect dropping waveguide (dual-output)

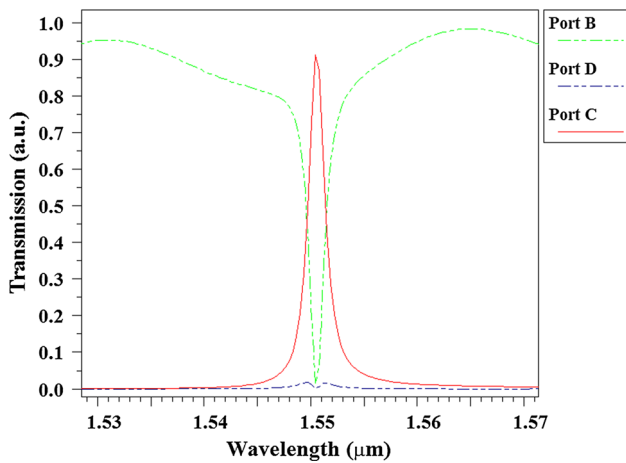


Fig. 8 Output spectrum of the proposed ADF with indirect dropping waveguide (dual output)

the quality factor of 1292, as demonstrated in Fig. 8. How the given wavelength is separated by the proposed ring resonator and its behavior are presented in Fig. 9. In this case, according to the figure, the normalized power level in the output port has been 92% and it has been equal to 0 in other output ports.

3.2 Design of an optical MUX/DMUX for using in WDM system with indirect dropping waveguide

ADFs are always used in the design of other optical devices, such as optical MAX/DMAXs. The structure of the proposed ADFs has not been recognized suitable for this work. Accordingly, a third structure has been presented for this purpose. In this structure, the indirect output waveguide has been used again, except when the waveguide has

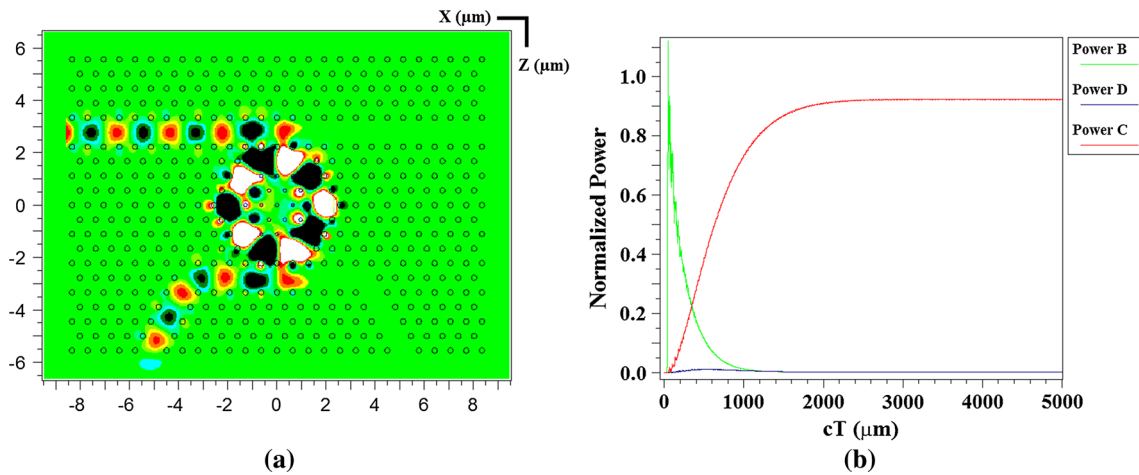


Fig. 9 Optical behavior of ADF with indirect dropping waveguide in $\lambda = 1550.5$ nm, a electric field and b normalized output power

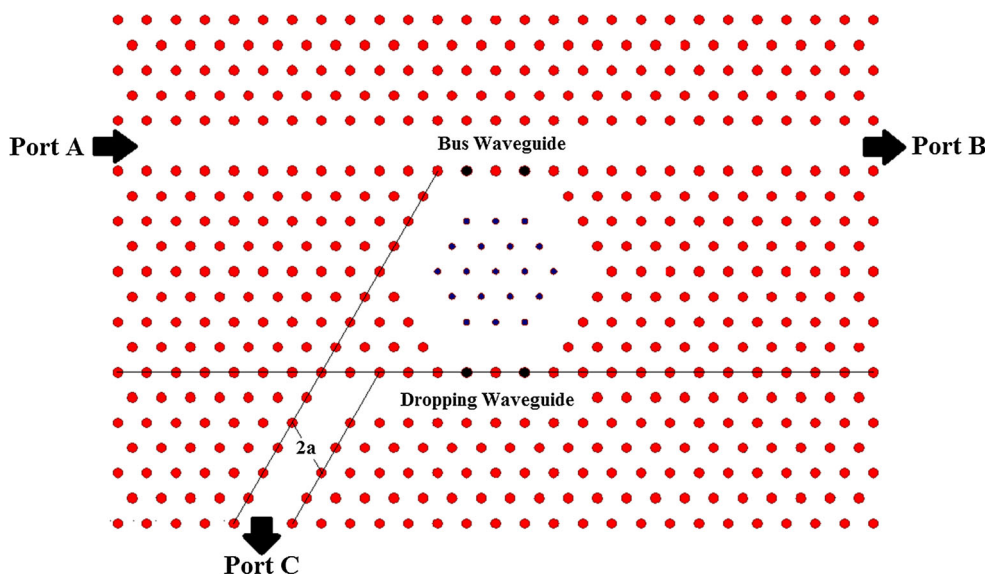


Fig. 10 Schematic of the proposed ADF with indirect dropping waveguide (single output)

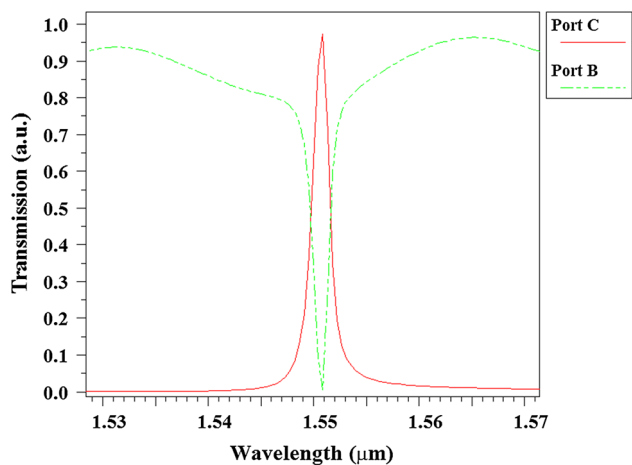


Fig. 11 Output spectrum of the proposed ADF with indirect dropping waveguide (single-output)

an output due to making the structure smaller by placing them together, as shown in Fig. 10. This structure has been capable of the wavelength separation (λ) of 1550.5 nm with a transmission coefficient of 98%, a bandwidth ($\Delta\lambda$) of 1.2 nm

and a quality factor of 1292, as demonstrated in Fig. 11. How the wavelength is separated is represented in Fig. 12. In the given ADF structure, the normalized power level in the port C has been 98%, while it has been equal to 0 in other outputs.

Using the given ADF structure, a multi-channel drop filter which is capable of separating different wavelengths and can play the role of an optical demultiplexer has been designed. In the design of this multi-channel drop filter, three proposed hexagonal PhCRRs together with an input waveguide for transmitting input light to ring resonators have been used. To transmit the separated wavelengths, indirect waveguides have been used for each of the ring resonators, as can be seen in Fig. 13. Inner rods with different radii have been used to separate different wavelengths. The radius of the inner rods (R_{iC}) has been equal to 65 nm for the channel C which has been capable of the wavelength separation (λ_C) of 1546.8 nm. It has been equal to $R_{iD} = 67$ nm for the channel D with a wavelength separation (λ_D) of 1550.7 nm, and it has been equal to $R_{iE} = 69$ nm for the channel E with a wavelength separation (λ_E) of 1554.7 nm, and the results of its output spectrum can be seen in Fig. 14. The channel spacing of the

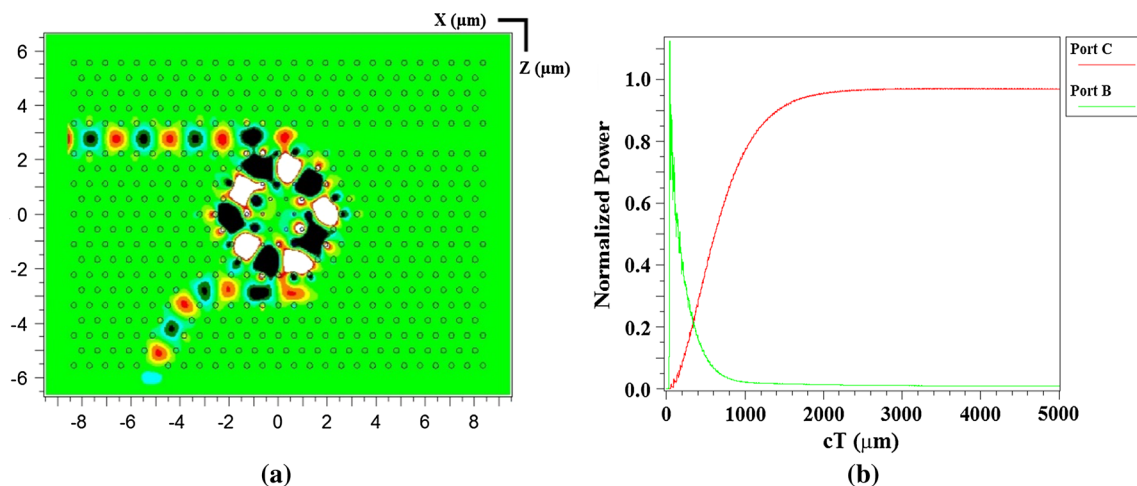


Fig. 12 Optical behavior of ADF with indirect dropping waveguide in $\lambda = 1550.5$ nm, **a** electric field and **b** normalized output power

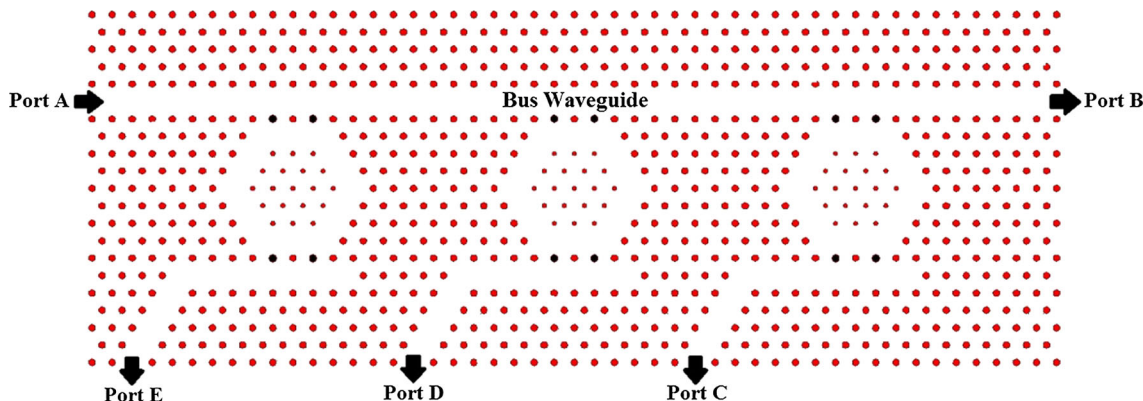


Fig. 13 The proposed structure of multi-channel drop filter with three hexagonal PhCRRs

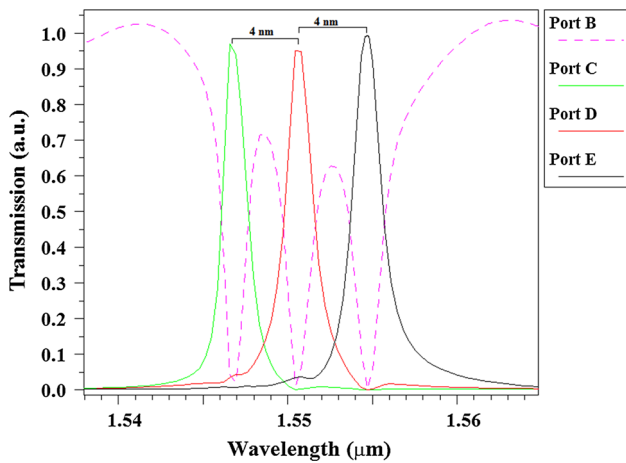


Fig. 14 Output spectrum of the proposed multi-channel drop filter with three hexagonal PhCRRs

given multi-channel drop filter structure has been about 4 nm. Its average bandwidth has been 1.2 nm, and the quality factor and the transmission coefficient of the structure have been about 1283 and 97.5%, respectively, as the detailed data are presented in Table 1. According to the results obtained, the designed multi-channel drop filter structure has an appropriate quality factor and a high transmission coefficient with low channel spacing, which make its application in WDM

systems highly justifiable. On the other hand, using a larger number of proposed hexagonal PhCRRs together, we will be able to design a structure with more telecommunication channels.

3.3 Design of optical MUX/DMUX for using in WDM system with diagonal dropping waveguide

Additionally, by making changes in the type of the dropping waveguide, another ADF has been designed to be used in WDM systems. This structure which has been designed by inserting diagonally the dropping waveguide is shown in Fig. 15. According to the output spectrum shown in Fig. 16, the given structure has been capable of the wavelength separation (λ) of 1550.5 nm with a transmission coefficient of 100%, a bandwidth ($\Delta\lambda$) of 1 nm, and a quality factor of 1550.5. How the wavelength is separated by the proposed ring resonator is presented in Fig. 17, according to which the normalized power level in the port C has been 100% and it has been equal to 0 in the rest of the outputs, indicating good results.

Using this structure, a multi-channel drop filter which can play the role of an optical MUX/DeMUX has been designed. The final structure of the optical MUX/DeMUX has been designed by putting three proposed hexagonal

Table 1 Simulation results of the proposed multi-channel drop filter

Transmission (%)	Quality factor	Spectral width (nm)	Central wavelength (nm)	Resonant rod (nm)	Output port
97.5	1406	1.1	1546.8	65	Port C
95.3	1292	1.2	1550.7	67	Port D
100	1151	1.35	1554.7	69	Port E

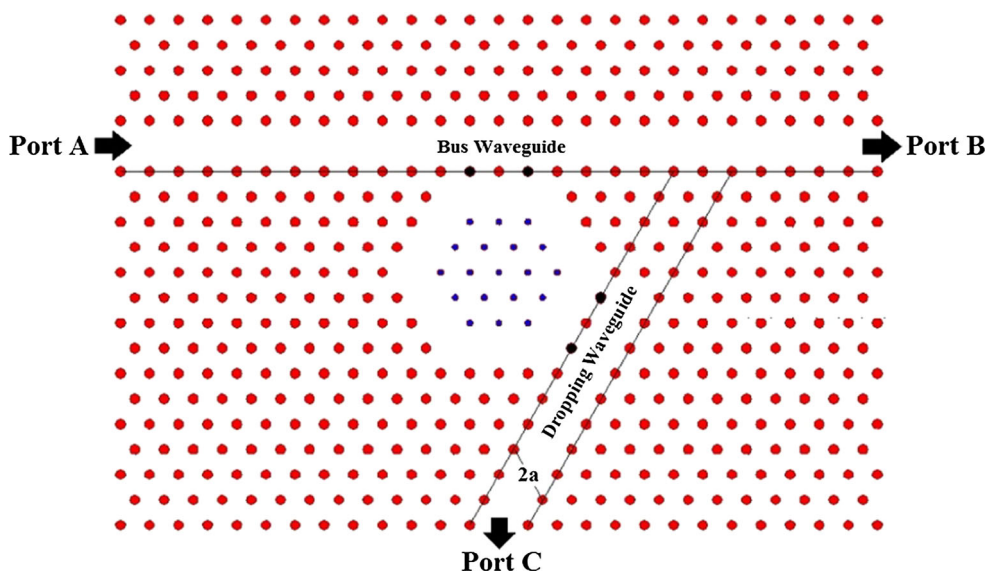


Fig. 15 Schematic of the proposed ADF with diagonally dropping waveguide

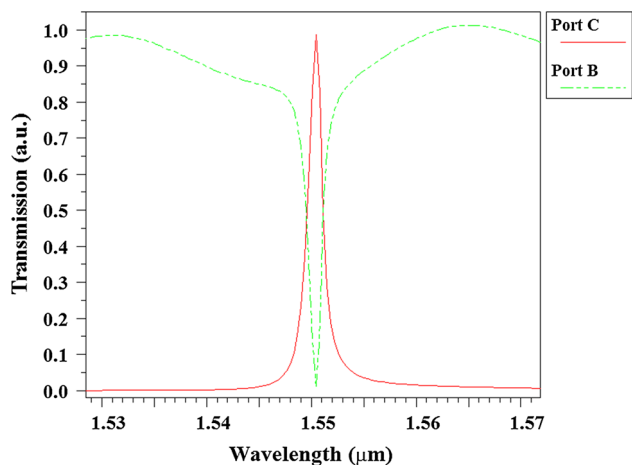


Fig. 16 Output spectrum of the proposed ADF with diagonally dropping waveguide

PhCRRs together and using an input waveguide and three diagonal dropping waveguides for each of the channels, as shown in Fig. 18. To separate different wavelengths, inner

rods with different radii have been used in the hexagonal PhCRRs. In the channel C, $RiC = 65$ nm and it has been capable of the wavelength separation (λ_C) of 1546.6 nm. The channel D includes $RiD = 67$ and has been capable of the wavelength separation (λ_D) of 1550.6, and eventually, the channel E includes $RiE = 69$ nm and the wavelength separated by this ring resonator has been $\lambda_E = 1554.7$ nm. The output spectrum of the structure is shown in Fig. 19. The transmission coefficient, bandwidth, quality factor and the channel spacing have been, respectively, 95.8%, 1.08 nm, 1435 and 4 nm in this structure, more details of which are given in Table 2. According to the table, the given structure enjoys very good results, which justifies highly the application of the structure in WDM systems. On the other hand, due to the high flexibility of this structure, the number of channels can be increased in it to separate more wavelengths.

In this paper, a new ring resonator has been presented that is of the type of hexagonal. Using this ring resonator, an ADF with four different types of dropping waveguide has been designed. The results obtained from this structure indicate its suitability and applicability in comparison with other

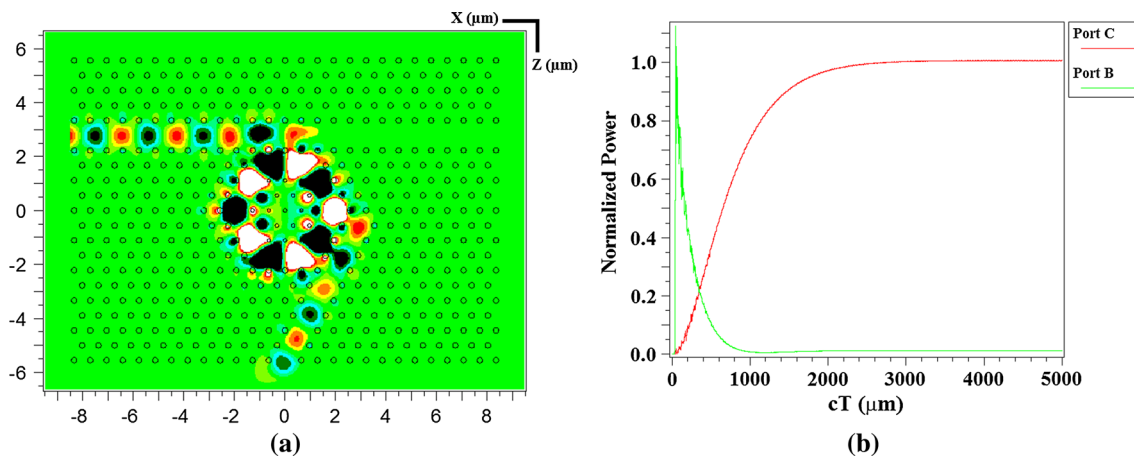


Fig. 17 Optical behavior of ADF with diagonally dropping waveguide in $\lambda = 1550.5$ nm, **a** electric field and **b** normalized output power

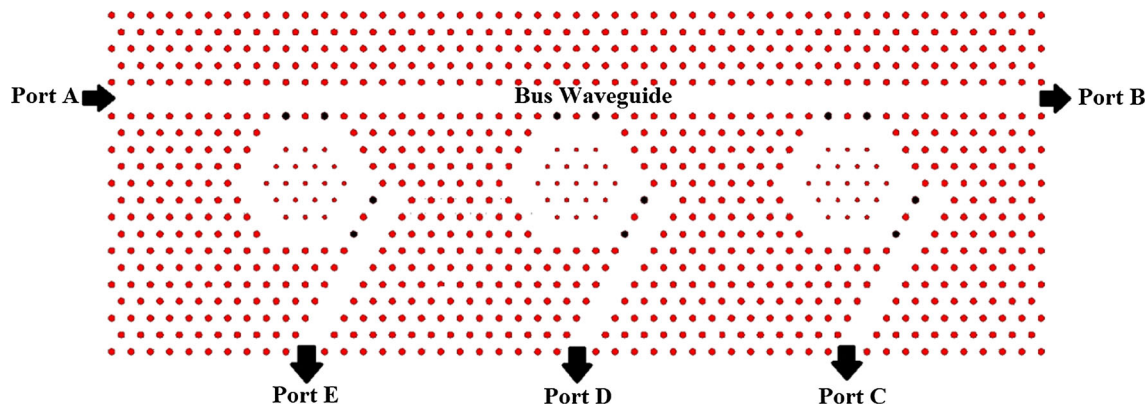


Fig. 18 The proposed structure of multi-channel drop filter with three hexagonal PhCRRs

structures introduced in this field. These results are presented in Table 3. The given structure has a high transmission coefficient with an appropriate quality factor, which makes the use of it in designing other optical devices justifiable.

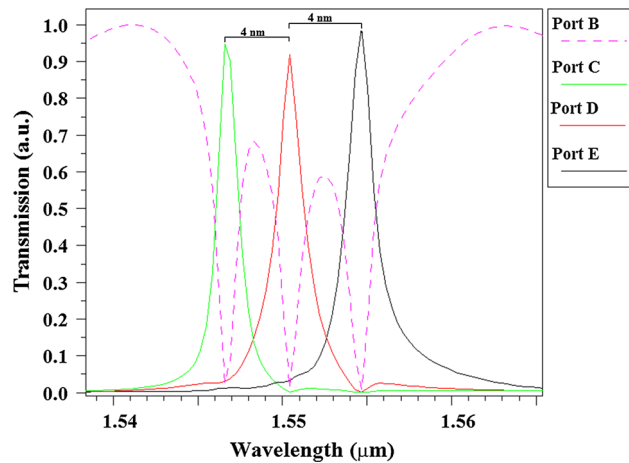


Fig. 19 Output spectrum of the proposed multi-channel drop filter with three hexagonal PhCRRs

Table 2 Simulation results of the proposed multi-channel drop filter

Transmission (%)	Quality factor	Spectral width (nm)	Central wavelength (nm)	Resonant rod (nm)	Output port
95.2	1546	1	1546.6	65	Port C
92	1409	1.1	1550.6	67	Port D
100	1351	1.15	1554.7	69	Port E

Table 3 Comparison of the proposed ADFs with reported one

Transmission (%)	Quality factor	Bandwidths (nm)	PhCRR type	References
100	1192	1.3	Hexagonal (direct dropping waveguide)	This paper
92	1292	1.2	Hexagonal (indirect dropping waveguide with dual-output)	This paper
98	1292	1.2	Hexagonal (indirect dropping waveguide with single-output)	This paper
100	1550	1	Hexagonal (diagonal dropping waveguide)	This paper
99	1011	–	Plus-shaped	[17]
100	1000	–	X-shaped	[18]
100	344	4.5	Quasi-shaped	[19]
100	647	–	Egg-shaped	[20]
95	1290	1.2	Hexagonal	[21]
100	221	–	H-shaped	[22]
100	114	13	Circular	[23]
95	775	–	Diamond	[24]
68	153	–	Dual-curved	[25]
100	205	–	Flower-shaped	[26]
100	842	–	Rectangular-shaped	[27]

4 Conclusion

Using a new hexagonal 2-D PhCRR with a triangular lattice constant, four types of ADFs have been designed in the present paper. ADFs differ in how the dropping waveguides, including the direct waveguide, indirect waveguide, dual-output waveguide, single-output waveguide, and diagonal waveguide, are arranged. The given ADFs have an average transmission coefficient of 97%, a bandwidth of $\Delta\lambda = 1.2$ nm and a quality factor of 1330 at a central wavelength of $\lambda = 1550.5$ nm, which has been recognized well suited for use in other optical devices. On the other hand, using this hexagonal PhCRR and the given ADFs, two types of the multi-channel drop filters have been designed that can be used as an optical MUX/DeMUX. They have a channel spacing of 4, which makes them very suitable for use in WDM systems.

References

[1] Ash, J., Ferguson, S.: The evolution of the telecommunications transport architecture: from megabit/s to terabit/s. *Electron. Commun. Eng. J.* **13**(1), 33–42 (2001)

[2] Angrisani, L.: Optimisation and performance assessment of a digital signal-processing method for jitter measurement in PDH/SDH-based digital telecommunication networks. *Measurement* **34**(4), 313–323 (2003)

[3] Mukherjee, B.: WDM optical communication networks: progress and challenges. *IEEE J. Sel. Areas Commun.* **18**(10), 1810–1824 (2000)

[4] Gunn, S.: Optical fibre wavelength division multiplexing. In: *Proceedings, Southern African Conference on Communications and Signal Processing COMSIG 88, 1988.* IEEE. (1988)

[5] Song, B.-S., Noda, S., Asano, T.: Photonic devices based on in-plane hetero photonic crystals. *Science* **300**(5625), 1537 (2003)

[6] Sukhoivanov, I.A., Guryev, I.V.: Introduction to Photonic Crystals, in *Photonic Crystals*, pp. 1–12. Springer, Berlin (2009)

[7] Yablonovitch, E., Gmitter, T.: Photonic band structure: the face-centered-cubic case. *Phys. Rev. Lett.* **63**(18), 1950 (1989)

[8] Foresi, J., et al.: Photonic-bandgap microcavities in optical waveguides. *Nature* **390**(6656), 143 (1997)

[9] Russell, P.S.J.: Photonic crystal fibers: basics and applications. In: *Optical Fiber Telecommunications VA: Components and Subsystems*, p. 485 (2010)

[10] Isfahani, B.M., et al.: All-optical NOR gate based on nonlinear photonic crystal microring resonators. *JOSA B* **26**(5), 1097–1102 (2009)

[11] Fan, S., et al.: Channel drop filters in photonic crystals. *Opt. Express* **3**(1), 4–11 (1998)

[12] Robinson, S., Nakkeeran, R.: Photonic crystal ring resonator-based add drop filters: a review. *Opt. Eng.* **52**(6), 060901 (2013)

[13] Fallahi, V., et al.: Four-channel optical demultiplexer based on hexagonal photonic crystal ring resonators. *Opt. Rev.* **24**(4), 605–610 (2017)

[14] Zavvari, M.: Design of photonic crystal-based demultiplexer with high-quality factor for DWDM applications. *J. Opt. Commun.* (2017). <https://doi.org/10.1515/joc-2017-0058>

[15] Mehdizadeh, F., et al.: A novel proposal for all optical analog-to-digital converter based on photonic crystal structures. *IEEE Photon. J.* **9**(2), 1–11 (2017)

[16] Stomeo, T., et al.: Design of two-dimensional photonic-crystal mirrors for InGaAs QW laser applications. *Microelectron. Eng.* **73**, 377–382 (2004)

[17] Bendjelloul, R., Bouchemat, T., Bouchemat, M.: An optical channel drop filter based on 2D photonic crystal ring resonator. *J. Electromagn. Waves Appl.* **30**(18), 2402–2410 (2016)

[18] Mahmoud, M.Y., Bassou, G., Metehri, F.: Channel drop filter using photonic crystal ring resonators for CWDM communication systems. *Opt. Int. J. Light Electron Opt.* **125**(17), 4718–4721 (2014)

[19] Mehdizadeh, F., Alipour-Banaei, H., Serajmohammadi, S.: Channel-drop filter based on a photonic crystal ring resonator. *J. Opt.* **15**(7), 075401 (2013)

[20] Alipour-Banaei, H., Mehdizadeh, F., Hassangholizadeh-Kashitaban, M.: A new proposal for PCRR-based channel drop filter using elliptical rings. *Phys. E Low-dimens. Syst. Nanostruct.* **56**, 211–215 (2014)

[21] Seifouri, M., Fallahi, V., Olyae, S.: Ultra-high-Q optical filter based on photonic crystal ring resonator. *Photon Netw. Commun.* **35**(2), 225–230 (2018)

[22] Rezaee, S., Zavvari, M., Alipour-Banaei, H.: A novel optical filter based on H-shape photonic crystal ring resonators. *Opt. Int. J. Light Electron Opt.* **126**(20), 2535–2538 (2015)

[23] Robinson, S., Nakkeeran, R.: Coupled mode theory analysis for circular photonic crystal ring resonator-based add-drop filter. *Opt. Eng.* **51**(11), 114001 (2012)

[24] Ma, Z., Ogusu, K.: Channel drop filters using photonic crystal Fabry–Perot resonators. *Opt. Commun.* **284**(5), 1192–1196 (2011)

[25] Andalib, P., Granpayeh, N.: Optical add/drop filter based on dual curved photonic crystal resonator. In: *IEEE/LEOS International Conference on Optical MEMs and Nanophotonics 2008.* IEEE (2008)

[26] Rashki, Z., Chabok, S.J.S.M.: Novel design of optical channel drop filters based on two-dimensional photonic crystal ring resonators. *Opt. Commun.* **395**, 231–235 (2017)

[27] Rakhshani, M.R., Mansouri-Birjandi, M.A.: Realization of tunable optical filter by photonic crystal ring resonators. *Opt. Int. J. Light Electron Opt.* **124**(22), 5377–5380 (2013)

[28] Djavid, M., Abrishamian, M.: Multi-channel drop filters using photonic crystal ring resonators. *Opt. Int. J. Light Electron Opt.* **123**(2), 167–170 (2012)

[29] Van, V.: *Optical Microring Resonators: Theory, Techniques, and Applications.* CRC Press, Boca Raton (2016)



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