An 8-Channel C-Band Demux Based on Multicore Photonic Crystal Fiber

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ABSTRACT

A novel 8-channel demux device based on multicore photonic crystal fiber (PCF) structures that operate at C-band range (1530-1565nm) has been demonstrated. The PCF demux design is based on replacing some air-holes areas with lithium niobate and silicon nitride materials over the PCF axis alongside with the appropriate optimizations of the PCF structure. The beam propagation method (BPM) combined with Matlab codes were used to modeled the demux device and to optimized the geometrical parameters of the PCF structure. Simulation results show that 8-channel can be demultiplexing after light propagation of 5 cm with large bandwidth (4.03-4.69nm) and crosstalk ((-16.88)-(-15.93) dB). Thus, the proposed device has a great potential to be integrated in dense wavelength division multiplexing (DWDM) technology for increasing performances in networking systems.

Keywords: photonic crystal fiber, demultiplexer, dense wavelength division multiplexing

1. INTRODUCTION

Dense wavelength division multiplexing (DWDM) its a system [1-2] that used to integrated information from different sources over one fiber, while each source carried on its own divided light wavelength at the same time. DWDM has the ability to divided up to 80 ports and more of information that can be multiplexed into a light-stream transferred on a one fiber. Demux is an essential device in DWDM system and its main functionality is to divided signals from one input port into multiple ports. Demux device has several advantages such as low bit error rate [3-4], high data rate, large bandwidth, low crosstalk and less propagation delay. Therefore, researchers show the potential of designing demux based waveguide techniques such as silicon photonics [5], Y-branch [6], multimode interference (MMI) [7-9], machzehnder interferometers [10], MMI in slot-waveguide structures [11-13] and etc.

Photonic crystal fiber (PCF) is a powerful waveguide that based on a micro-structured arrangement of materials of different refractive index [14]. The background material is usually a pure silica and the low-index regions are air-holes which located along the fiber length. Several works has been demonstrated the great potential of using PCF structurer in comparison to conventional fiber [15-17]. The main benefit of design demux device based on PCF structure is the ability to integrate different materials that have a high difference in the refractive index value. This is because the light guiding machenizem in PCF is based on bandgap and not total internal reflection. Another advance is the ability to achieve a lower coupling length, especially in the case of closer coupled ports (cores) [18].

Several techniques have been demonstrated how its passible to couple light between closer coupled ports (cores) in PCF structure such as changing the PCF index-profile by replacing some air-holes regions with pure silica along the fiber length [18-19] and using different air-hole sizes in the PCF structure [20-23].

The C-band range is set from 1530 to 1565 nm wavelength and it is the most efficient and useful range in optical communication field [24] . The advance of the C-band is the ability to transmit data with a high bitrate over long distance due to the fact that C-band support DWDM and optical amplifier fiber technologies [25].

In this work, we demonstrated a 1x8 wavelength demux in PCF structure that split eight wavelengths in the C-band range. The operating wavelengths are between 1530-1565nm with a spacing of 5 nm between two wavelengths. The light coupling between closer coupled cores were obtain by replacing some air-holes areas with lithium niobate and silicon nitride materials along the fiber length.

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Numerical investigations were carried out on the locations of the lithium niobate and silicon nitride layers and the key geometrical parameters of the multicore PCF structure to obtain high efficiency demultiplexing between the operated wavelengths.

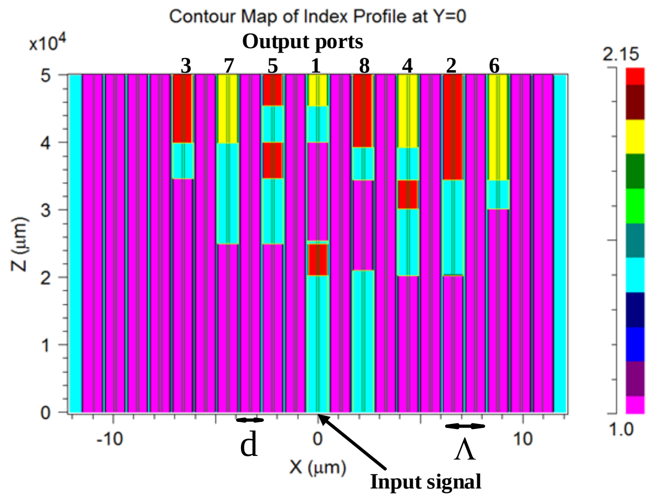
The demux PCF structure was analyzed and simulated using a BPM and matlab codes. This device can be useful to increase data bitrate in the C-band using DWDM system.

2. 1X8 WAVELENGTH DEMULTIPLEXER DESIGN

Figs .1(a)-(c) show the full refractive index profile structure of the demux PCF design at xz plane (y=0 cm), xy plane (z=0 cm) and xy plane (z=5 cm), respectively. In these figures, the background material is pure silica and its marked in light blue color, air-hole areas are marked in purple color, lithium niobate ($LiNbO_3$) areas are marked in red color and silicon nitride areas are marked in yellow color. d, Λ (pitch) and z are the geometrical parameters of the PCF structure. In Fig 1(a) d represents the hole diameter of the air-holes, pitch represents the distance between two air-holes and z represents the light propagation axis.

The principle work of the PCF demux device is based on light confinement inside the channel (core) and controlling the light coupling length size between two closer channels (cores). These effects can be obtained by replacing some air-holes regions with a high-index material along the fiber length. Furthermore, the coupling length value can be shifted by changing the operated wavelength. Thus, the suitable coupling length value between two closer channels can be found by optimized the PCF geometrical parameters (z, Λ , d) and the materials layer locations over the light propagation axis (z).

It can be noticed from Fig. 2(a) that the areas which light can be coupled between closer ports are located as follows: port 1 and port 8 at z=0cm, port 4 and port 2 at z=2.15cm, port 5 and port 7 at z=2.6cm, port 2 and port 6 at z=3cm, port 7 and port 3 at z=3.6cm, port 4 and port 8 at z=3.65cm, port 1 and port 4 at z=4.2cm. Also, it can be noticed that each port has a light confinement area as shown in Fig. 2(a). Figs. 2(b)-(c) show the input port at z=0 (port 1) and eight output ports at z=5cm (red and yellow colors).



(a)

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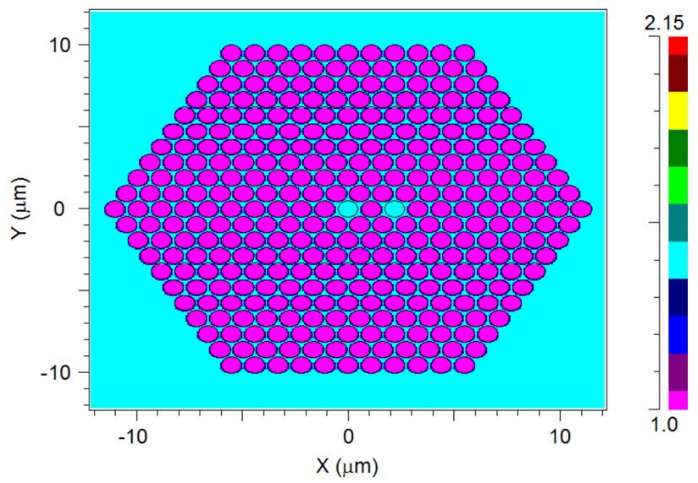
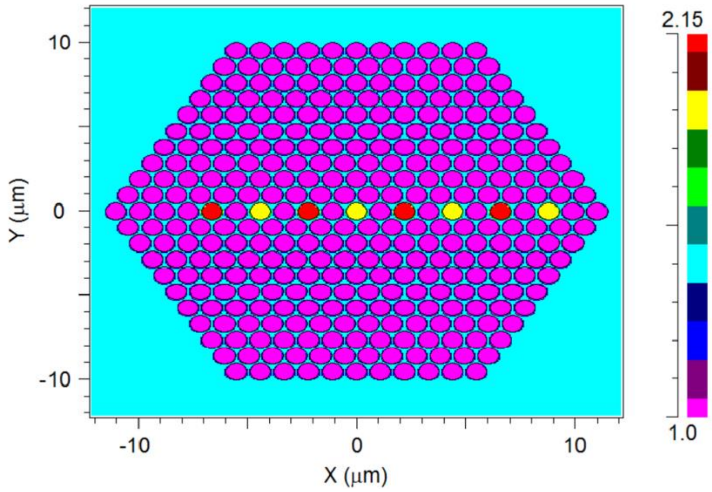


(b)



(c)

Figure 1. Refractive index profile of the 1x8 wavelength demux: (a) xz plane at y=0cm. (b) xy plane at z=0cm. (c) xy plane at z=5cm.

3. SIMULATION RESULTS

The 1x8 PCF wavelength demultiplexer structure was simulated using an Rsoft-Photonics cad suite software which is based on the beam propagation method.

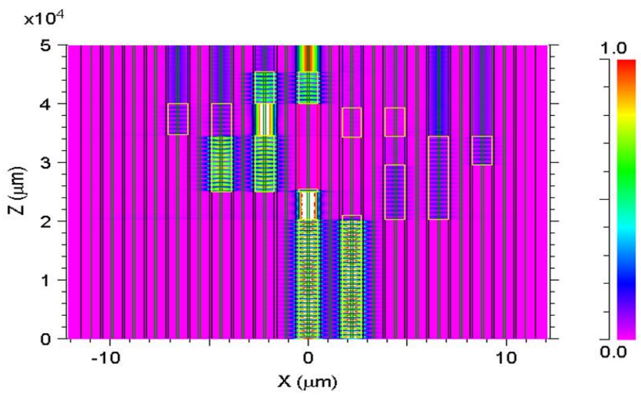
The optimal values of the PCF structure are: $\Lambda = 1.14\mu m$, $d = 0.97\mu m$, $z = 5cm$

Fig. 2(a) shows the light propagation of 1530nm wavelength in the PCF structure and its optical path can be described as follows: z=0-1.9cm, light coupled between port 1 and port 8; z=1.9-2.5cm, light confined in port 1; z=2.5-2.6cm light coupled from port 1 to port 5; z=2.6-3.5cm, light coupled between port 5 and port 7; z=3.5-4cm, light confined in port 5; z=4-4.7cm, light coupled between port 5 and port 1; z=4.7-5cm, light confined in port 1. Fig. 2(b) shows the light propagation of 1535nm wavelength in the PCF structure and its optical path can be described as follows: z=0-2cm, light coupled between port 1 and port 8; z=2-2.15cm, light coupled from port 8 to port 4; z=2.15-3cm light coupled between port 4 and port 2; z=3-3.5cm, light coupled between port 2 and port 6; z=3.5-5cm, light confined in port 2. Fig. 2(c)

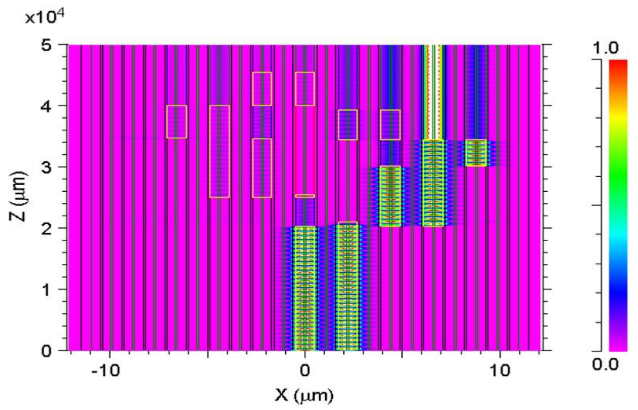
doi:10.20944/preprints201808.0498.v1

Peer-reviewed version available at *Nanomaterials* **2018**, *8*, 845; doi:10.3390/nano8100845

shows the light propagation of 1540nm wavelength in the PCF structure and its optical path can be described as follows: z=0-1.9cm, light coupled between port 1 and port 8; z=1.9-2.5cm, light confined in port 1; z=2.5-2.6cm light coupled from port 1 to port 5; z=2.6-3.5cm, light coupled between port 5 and port 7; z=3.6-4cm, light coupled between port 3 and port 7; z=4-5cm, light confined in port 3. Fig. 2(d) shows the light propagation of 1545nm wavelength in the PCF structure and its optical path can be described as follows: z=0-2cm, light coupled between port 1 and port 8; z=2-2.15cm, light coupled from port 8 to port 4; z=2.15-3cm light coupled between port 4 and port 2; z=3-3.5cm, light confined in port 4; z=3.5-4cm light coupled between port 4 and port 8; z=4-5cm, light confined in port 4. Fig. 2(e) shows the light propagation of 1550nm wavelength in the PCF structure and its optical path can be described as follows: z=0-1.9cm, light coupled between port 1 and port 8; z=1.9-2.5cm, light confined in port 1; z=2.5-2.6cm light coupled from port 1 to port 5; z=2.6-3.5cm, light coupled between port 5 and port 7; z=3.5-4cm, light confined in port 5; z=4-4.7cm, light coupled between port 5 and port 1; z=4.7-5cm, light confined in port 5. Fig. 2(f) shows the light propagation of 1555nm wavelength in the PCF structure and its optical path can be described as follows: z=0-2cm, light coupled between port 1 and port 8; z=2-2.15cm, light coupled from port 8 to port 4; z=2.15-3cm light coupled between port 4 and port 2; z=3-3.5cm, light coupled between port 2 and port 6; z=3.5-5cm, light confined in port 6. Fig. 2(g) shows the light propagation of 1560nm wavelength in the PCF structure and its optical path can be described as follows: z=0-1.9cm, light coupled between port 1 and port 8; z=1.9-2.5cm, light confined in port 1; z=2.5-2.6cm light coupled from port 1 to port 5; z=2.6-3.5cm, light coupled between port 5 and port 7; z=3.6-4cm, light coupled between port 3 and port 7; z=4-5cm, light confined in port 7. Fig. 2(h) shows the light propagation of 1565nm wavelength in the PCF structure and its optical path can be described as follows: z=0-2cm, light coupled between port 1 and port 8; z=2-2.15cm, light coupled from port 8 to port 4; z=2.15-3cm light coupled between port 4 and port 2; z=3-3.5cm, light confined in port 4; z=3.5-4cm light coupled between port 4 and port 8; z=4-5cm, light confined in port 8.



(a)



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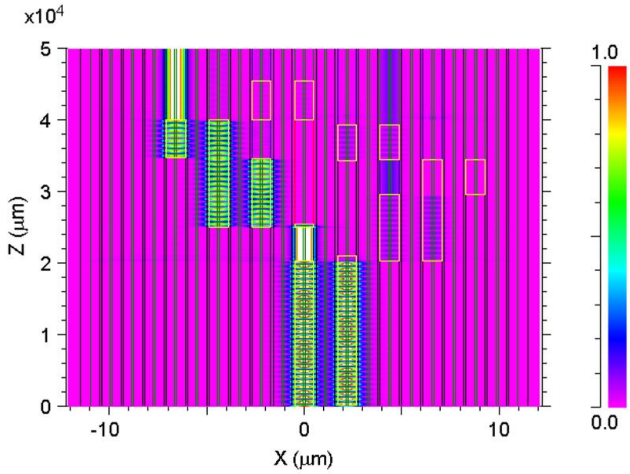

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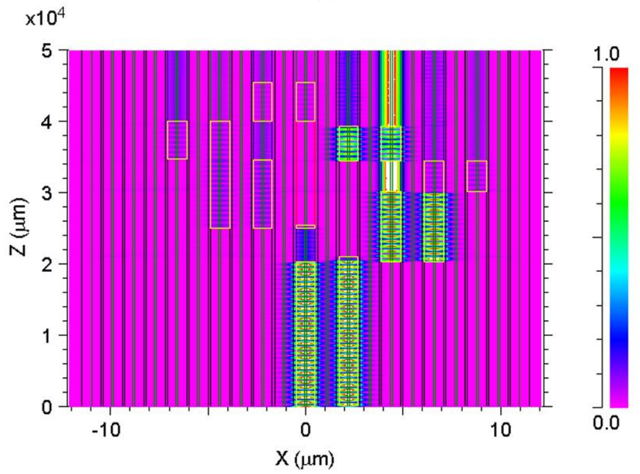

(d)

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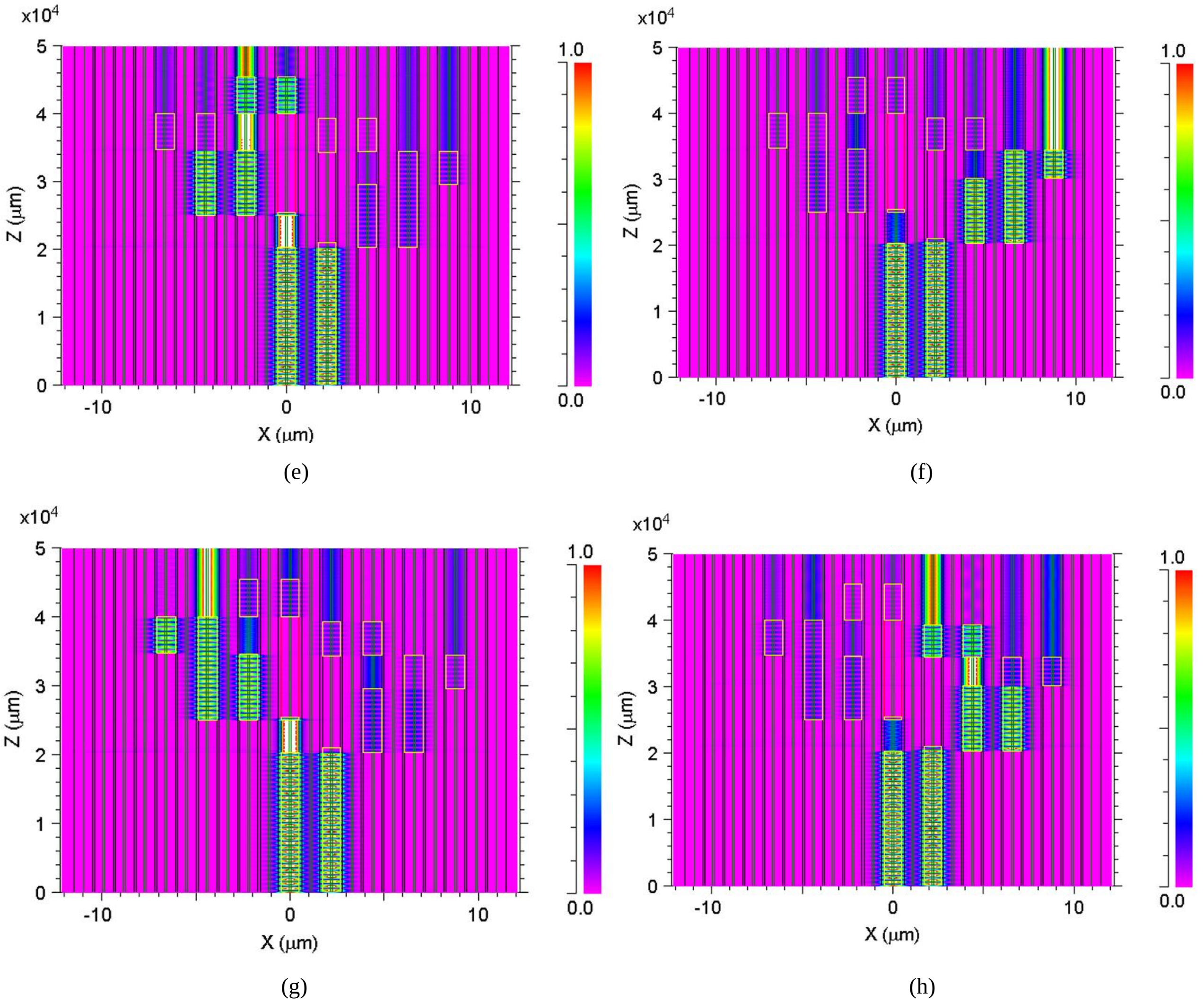

Figure 2. Intensity profile of the 1x8 MMI wavelength demultiplexer: (a). λ1 =1530nm (port 1); (b). λ2 =1535nm (port 2); (c). λ3 =1540nm (port 3); (d). λ4 =1545nm (port 4); (e). λ5 =1550nm (port 5); (f). λ6 =1555nm (port 6); (g). λ7 =1560nm (port 7); (h). λ8 =1565nm (port 8).

BPM simulations combined with the Matlab script code was performed to determine the 1x8 wavelength PCF demultiplexer properties. Fig. 3 shows the optical bandwidth transmission results for wavelengths around the C-band range (1530-1565nm).

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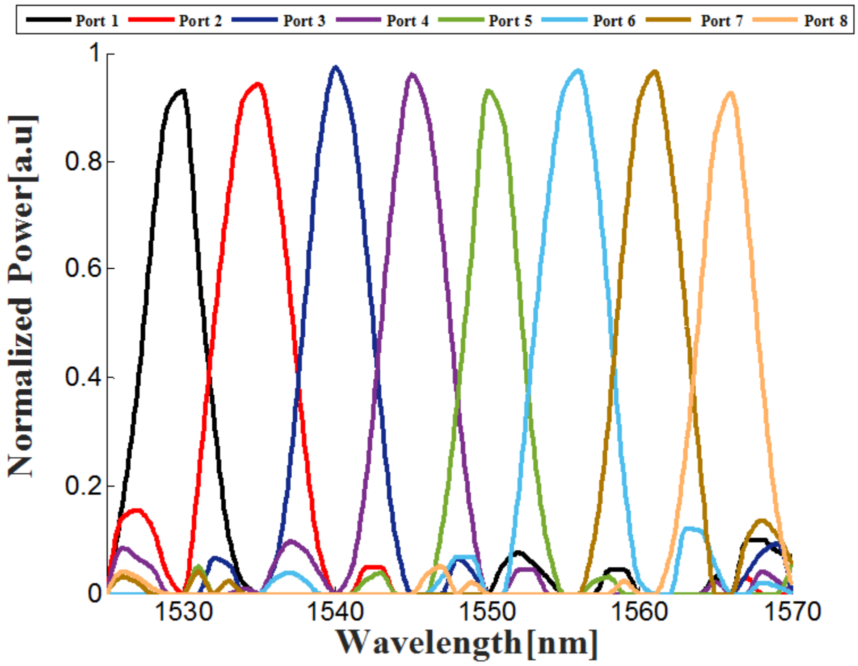

Figure 3. Normalized power as function of the optical signals.

From Fig. 3 the values of the crosstalk, insertion losses and full width maximum (FWHM) can be found. Table. 1 shows the values of the crosstalk, bandwidth (FWHM) and loss for each port.

Table 1. Values of the crosstalk, FWHM and losses for the operated wavelengths.

λ_m(nm)	1530	1535	1540	1545	1550	1555	1560	1565
Port number	1	2	3	4	5	6	7	8
Crosstalk (dB)	-16.65	-16.73	-16.88	-16.81	-16.6	-16.32	-16.08	-15.93
FWHM (nm)	4.23	4.38	4.67	4.69	4.03	4.1	4.62	4.15
Losses (dB)	0.31	0.26	0.2	0.18	0.55	0.31	0.45	0.69

4. CONCLUSIONS

To conclude, in this work, we have shown that a 1x8 wavelength demultiplexer can be implemented in the PCF structure with integrated $LiNbO_3$ and silicon nitride materials.

Simulation results show that operated wavelengths 1530nm, 1535nm, 1540nm, 1545nm, 1550nm,1555nm ,1560nm ,1565mm with a short spacing of 5nm and support the whole C-band range can be separated after a propagation length of 5cm with a bandwidth range of 4.02-4.69nm.

The proposed device has a low crosstalk ((-16.88)-(-15.93) dB) with an insertion loss of 0.18-0.69dB. Thus, this device has the potential to increase data bitrate in optical communications system that work on DWDM technology.

REFERENCES

[1] Bogdan. H., "DWDM Fundamentals, Components, and Applications," J. Opt. Netw, 1, 184-185 (2002).
[2] Gong. J.M., Zuo. X., Zhao. Y., "The steady SRS analysis theory of DWDM transmission system in single-mode silica fiber," Optics Communications, 350, 257–262 (2015).
[3] Charlier. J., Laurent. B., Berlioz. P., Perbos J.L., "Multi/demultiplexer and spectral isolator for optical inter-satellites communications," Proc. SPIE Opt. Space Commun. 54, 1131 (1989).
[4] Debashis, De Basic Electronics, Dorling Kindersley, 557 (2010).
[5] Dalai. P.K., Sarkar. P., "Analysis of silicon waveguide structure for realization of optical MUX/DEMUX circuit: An application of silicon photonics," Optik -Int. J. Light Electron Opt. 127, 10569–10574 (2016).
[6] Xiang. F., Lam Y. G., "A TM Y-branch wavelength multi/demultiplexer by K/sup +/ and Ag/sup +/ ion-exchange for /spl lambda/=1.31 and 1.55 /spl mu/m," Jouranl of Lightwave Technology, 14, 1690-1694 (1996).
[7] Lin. K. C., Lee. W. Y., "Guided-wave 1.30/1.55μm wavelength division multiplexer based on multimode interference, "Electron. Lett. 32, 1259-1261 (1996).
[8] Li. B., Li. G., Liu. E., Jiang Z., Qin. J., Wang. X., "Low-loss 1×2 multimode interference wavelength demultiplexer in silicon-germanium alloy," IEEE Photon. Technol. Lett. 11, 575-577 (1999).
[9] Tsao.S. L., Guo. H. C., Tsai. C. W., "A novel 1×2 single-mode 1300/1550nm wavelength division multiplexer with output facet-tilted MMI waveguide," Opt. Commun. 232, 371-379 (2004).
[10] Goto. N, Yip. G. L., "Y-branch wavelength multi-demultiplexer for λ=1.30μm and 1.55μm," Electron.Lett. 26, 102-103 (1990).
[11] Tervonen. A, Poyhonen. P, Honkanen. S, Tahkokorpi. M, "A guided-wave Mach-Zehnderinterferometer structure for wavelength multiplexing," IEEE Photon. Technol. Lett. **3**, 516-518 (1991).
[12] Xiao, J., Liu. X., Sun. X., "Design of an ultracompact MMI wavelength demultiplexer in slot waveguide structures, "Optics Express. 2007, 15, 8300-8308 (2007).
[13] Malka. D., Sintov. Y., Zalevsky. Z., "Design of a 1 × 4 silicon-alumina wavelength demultiplexer based on multimode interference in slot waveguide structures," Journal of Optics. 2015, 17, 1-9.
[14] Zaken, B. B. B., Zanzury. T, Malka. D., "An 8-Channel Wavelength MMI Demultiplexer in Slot Waveguide Structures," Materials, 9(11), 881 (2016).
[15] Russell. P. St. J., "Photonic-crystal fibers," J. Lightwave Technol. 24, 4729-4749 (2006).
[16] Birks. T. A., Knight J. C., Russel P. St. J., "Endlessly single-mode photonic crystal fiber," Opt. Lett. 22, 961-963 (1997).
[17] Knight. J. C., Broeng. J., Birks. T. A., Russel P. St. J., "Photonic band gap guidance in optical fiber," Science 282, 1476-1478 (1998).
[18] Broeng. J., Mogilevstev. D., Barkou. S. E., Bjarklev. A., "Photonic crystal fibers: A new class of optical waveguides," Opt. Fiber Technol. 5, 305-330 (1999).
[19] Elbaz. D., Malka. D, Zalevsky. Z., "Photonic crystal fiber based 1xN intensity and wavelength splitters/couplers ,"Electromagnetics 32, 209–220 (2013).
[20] Malka. D, Sintov. Y, Zalevsky. Z, "Fiber-laser monolithic coherent beam combiner based on multicore photonic crystal fiber," Opt. Eng. 54(1), 011007-1-011007-5 (2014).
[21] Koshiba. M, "Coupling Characteristics of Multicore Photonic Crystal Fiber-Based 1 x 4 Power Splitters," J. Lightwave Technol. 27, 2062-2068 (2009).
[22] Malka. D., Zalevsky. Z., "Multicore Photonic Crystal Fiber Based 1x8 Two-Dimensional Intensity Splitters/Couplers," Electromagnetics 33, 413–420 (2013).
[23] Malka. D., Peled. A., "Power Splitting of 1 × 16 in Multicore Photonic Crystal Fibers," Appl. Surf. Sci., no. , 417, (34-39 pages), (2017).
[24] Malka. D, Cohen. E, Zalevsky. Z, "Design of 4 x 1 power beam combined based on multicore photonic crystal fiber,"Applied Sciences, 7(7), (695 – 9 pages), (2017)