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Optical Demultiplexer by Using In-Line Fiber Filter

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Abstract- The signal pulses will be broadened through the fiber and so we need a very sharp cutoff filters with demultiplexers. The in-line fiber filter becomes the appropriate filters. Most of these demultiplexers used after erbium-doped fiber amplifier (EDFA) which need a sharp wavelength bandpass filter (BPF) to filter out wavelengths other than the signal wavelength
Exact analysis of in-line fiber filter is occurred by derive a polynomial expression for the dopant ratios of GeO_2 and P_2O_5. The refractive index of silica doped either GeO_2 or P_2O_5 is defined as a function of both the wavelength and the dopant ratio. The calculations of the dopant ratios of the pair materials (GeO_2 and P_2O_5) are done at a specific filter cutoff wavelength (λ_c) for both high pass filter (HPF) and low pass filter (LPF). Two in-line fiber filters (HPF and LPF) are cascaded to make a sharp bandpass filter (BPF).
The length of in- line fiber filter must be very short to overcome the weak of the propagation constsnt throuh it.
The normalized frequency is discused. A theoritical 8-channels demultiplexer is done. The design of demultiplexer becomes very easy.

Keywords: *In-line fiber filter, Germanosilicate, Phosphosilicate, bandpass filter and demultiplexer.*

I. INTRODUCTION

Demultiplexer split the mixed light up into many mixed outputs (one per required output power) and then filter each port individually. There are several searches published about multiplexer/demultiplexers [1-6,7]. The signal pulses will be broadened [6] and so we need a very sharp cutoff filters with demultiplexers [8-10]. Light at a specific wavelength is filtered out of a single-mode fiber. The in-line fiber filter [8] becomes the appropriate filters. Most of these demultiplexers used after erbium-doped fiber amplifier (EDFA) which need a sharp wavelength bandpass filter (BPF) to filter out wavelengths other than the signal wavelength [11]. EDFA with operating wavelength ranged from 1540 nm to 1570 nm [11] or from 1525 nm to 1565 nm [12] or from 1570 to 1610 nm [12].

Therare several techniques for optical filters [13-21]. Fiber filters have been widely used to achieve dynamic wavelength filtering in the fields of optical communication [16]. Fiber-optic filter is an optical fiber instrument used for wavelength selection, which can select desired wavelengths to pass and reject the others. It is Widely used in DWDM systems dynamic wavelength selection[18]. An in-line fiber-optic bandpass wavelength filter has been demonstrated based on a single-mode fiber [19]. New types of in-line fiber filters whose core and cladding are composed of binary silica doped with either boron or fluorine are proposed. Utilizing dispersive characteristics of SiO2–B2O3 and SiO2–F systems [20]. The fabrication of narrowband highly reflecting filters in single-mode step-index fibers [21]

The idea of in-line fiber filter based upon that, the difference between the refractive indexs of the silica doped material of the core and the silaica doped material of the cladding. This difference is a function of both the wavelength and the dopant ratio of materials. The sign of this difference changes from negative to positive values and vice versa. The filter cutoff wavelength (λ_c) is the wavelength at which the difference equals zero.
The dopants of both the core and the cladding must be from materials which increasing the refractive index of the silica such as germania (GeO_2) and phosphorus pentoxide (P_2O_5). Also, from materials which decreasing the refractive index of the silica such as fluorine (F) and boria (B_2O_3). But in our study the GeO_2 and P_2O_5 are used.

The refractive index of the pure silica (n_s) , the refractive index of germanosilicate (n_{sg} , silica doped GeO_2) and the refractive index of phosphosilicate (n_{sp} , silaica doped P_2O_5) are functions upon the operating wavelength (λ) and the dopant ratios (x_1) of GeO_2 and (x_2) of P_2O_5. The rate of change of both n_{sg} and n_{sp} with wavelength are not equally. And so, the difference value between n_{sg} and n_{sp} ($\Delta n_{sg\,sp} = n_{sg} - n_{sp}$) can change from a positive value into a negative value (or vice versa) acoording to the operating wavelength (λ). The wavelength at which $n_{sg} = n_{sp}$ is called the cutoff wavelength of the fiber (λ_c). At $\lambda=\lambda_c$, the fiber propagation constant becomes zero ($\beta=0$), therefore , the optical fiber operates at wavelengths that make the difference $\Delta n_{sg\,sp}$ positive. And so, the fiber acts as a filter.

In-line fiber filter uses as an optical filter (either high pass filter, HPF, or low pass filter, LPF). And by using two cascaded filters, HPF and LPF, the final bandpass filter (BPF) is designed.

The filter becomes low pass filter (LPF) if the passband wavelengths smaller than λ_c (in this case λ_c is named λ_{cL}). While the filter becomes high pass filter (HPF) if the passband wavelengths greater than λ_c (in this case λ_c is named λ_{cH}). The bandpass filter (BPF) with bandpass limits (λ_{cL} to λ_{cH}) consists of HPF with cutoff λ_{cH} cascaded by LPF with cutoff λ_{cL}. The materials of in-line fiber filter are germanosilicate (core) and phosphosilicate (cladd) for LPF , and vice versa for HPF as shown in Fig.1.

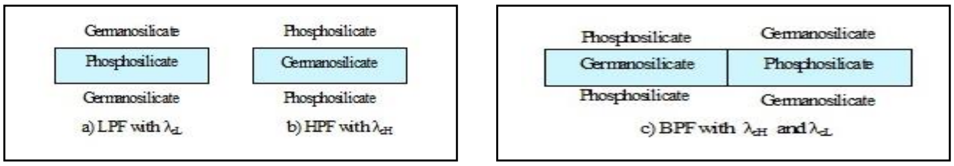


Fig.1 Structure of LPF, HPF and BPF

In this work : the pair of dopant materials (GeO_2 and P_2O_5) is studied. The values of these dopant ratios are calculated for LPF, HPL and BPF with different specific filter cutoff wavelengths. The normalized frequency is discused. Theoritically design example of BPF and demultiplexer are done for 8-channels.

II. Mathimatical Analysis and Numerical Results With Discussions

II.1. Refractive index

Due to the importance of the refractive index in this work, the different formulas which used to find the refractive index are disscused.

Germanosilicate {x_1 GeO_2 + ($1-x_1$) SiO_2} has refractive index (n_{sg}) with dopant ratio x_1. Where Germania (GeO_2) is an optional, but very effective component for forming a network structure and increasing the refractive index of the silica. The preferred range of GeO_2 is 0 to 12.0 %. [22].

Phosphosilicate {x_2 P_2O_5 + ($1-x_2$) SiO_2} has refractive index (n_{sp}) with dopant ratio x_2. Where Phosphorus pentoxide (P_2O_5) is an essential component for the optical glass according to the present invention and a main component for forming a network structure of the glass, and increasing the refractive index of the silica. The preferred range of P_2O_5 is 15.0 to 30.0 %. [22].

The above preferred ranges of the dopant ratios are as indicative values for the fiber as a filter but it becomes necessary for material dispersion.

Silica (SiO_2) is a material of considerable technological important, with broad application devices contaning optical fiber [23].

There are different published formulas for the index dispersion (n) at main values of the dopant ratio [24-28]. But we need a formula which gives the index dispersion as a function of dopant ratio (i.e. refractive index as a function of both wavelength, λ, and the dopant ratio, x,).

II.1.1 For Germanosilicate : x_1 GeO_2 + ($1-x_1$) SiO_2

The refractive index of Germanosilicate (n_{sg}) is determined from the following two equations.

The first equation is [29]; (Sellimere formula 1)

$$n^2 = 1 + \frac{a_1\,\lambda^2}{\lambda^2 - b_1^2} + \frac{a_2\,\lambda^2}{\lambda^2 - b_2^2} + \frac{a_3\,\lambda^2}{\lambda^2 - b_3^2} \quad (1)$$

Where; [30]

$a_1 = a_{10} + u_1 x_1$, $b_1 = b_{10} + v_1 x_1$, $a_2 = a_{20} + u_2 x_1$, $b_2 = b_{20} + v_2 x_1$,
$a_3 = a_{30} + u_3 x_1$, $b_3 = b_{30} + v_3 x_1$, $a_{10} = 0.6961663$, $b_{10} = 0.0684043$
$a_{20} = 0.4079426$, $b_{20} = 0.1162414$,
$a_{30} = 0.8974794$, $b_{30} = 9.89616087$, $u_1 = 0.110700$, $v_1 = 0.000568306$,
$u_2 = 0.31021588$, $v_2 = 0.03772465$, $u_3 = -0.04331091$, $v_3 = 1.94577$

The second equation is [27, 28]; (Sellimere formula 2)

$$n^2 = 1 + \frac{a_1\,\lambda^2}{\lambda^2 - b_1^2} + \frac{a_2\,\lambda^2}{\lambda^2 - b_2^2} \qquad (2)$$

Where the values of a_1, a_2, b_1 and b_2 are derived from [28] as;

$$a_1 = \frac{14.71+0.78\,x_1}{13.38-3.58\,x_1} \quad , \quad b_1 = \frac{c_1}{13.38-3.58\,x_1} \quad , \quad a_2 = \frac{0.11251 - 0.14x_1}{0.12536 - 0.01236\,x_1} \quad , \quad b_2 = \frac{c_1}{0.12536 - 0.01236\,x_1}$$

$$c_1 = \frac{\mathrm{h\,c}}{\mathrm{e}} = \frac{6.625 * 10^{-34} * 3 * 10^{8}}{1.602 * 10^{-19}} = 1.24082397\ (ev\ \mu m) \qquad (3)$$

The values of a_1, a_2, b_1 and b_2 for SiO_2 are defined by putting $x_1 = 0$ into Eq.(2.b).

II.1.2. For Phosphosilicate: $x_2\ P_2O_5 + (1-x_2)\ SiO_2$

The refractive index of Phosphosilicate (n_{sp}) is evaluated from Eq.(2). Where the values of a_1, a_2, b_1 and b_2 are derived from [28] as;

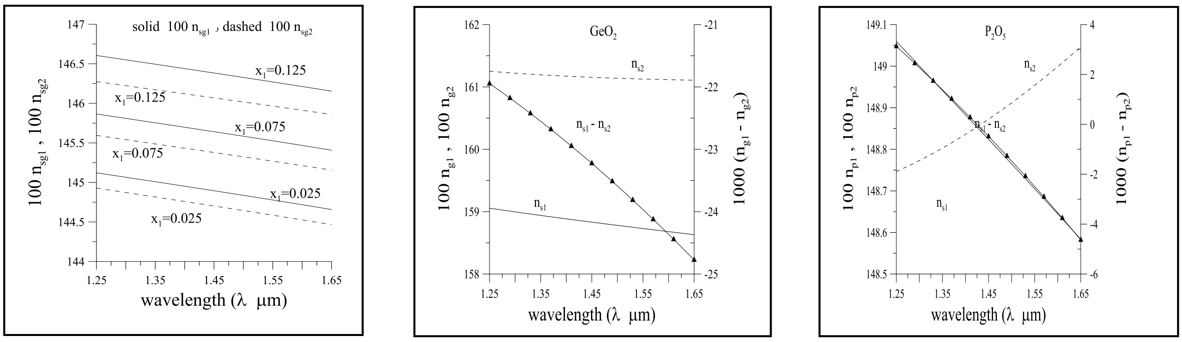
$$a_1 = \frac{14.71+18.27\,x_2}{13.38+14.3\,x_2} \quad , \quad b_1 = \frac{c_1\,(1+x_2)}{13.38-3.58\,x_2}$$

$$a_2 = \frac{0.11251 + 0.09251x_2 - 0.02\,x_2^2}{0.12536+0.18464\,x_2} \quad , \quad b_2 = \frac{c_1\,(1+x_2)}{0.12536+0.18464\,x_2} \qquad (4)$$

II.2. Comparison between refractive index which evaluated by Eq.(1) and by Eq.(2)

II.2.1. Refractive indexs of SiO_2, GeO_2 and P_2O_5,

Which are calculated by Eq.(1), n_{s1}, n_{g1} and n_{p1}, and by Eq.(2), n_{s2}, n_{g2} and n_{p2}, are shown in Fig.(2). Refractive index From Eq.(1) either greater or less than that by Eq.(2).



a) n_{s1} ,n_{s2} and $\Delta n_{s12} = n_{s1}-n_{s2}$ b) n_{g1} ,n_{g2} and $\Delta n_{g12} = n_{g1}-n_{g2}$ c) n_{p1} ,n_{p2} and $\Delta n_{p12} = n_{p1}-n_{p2}$

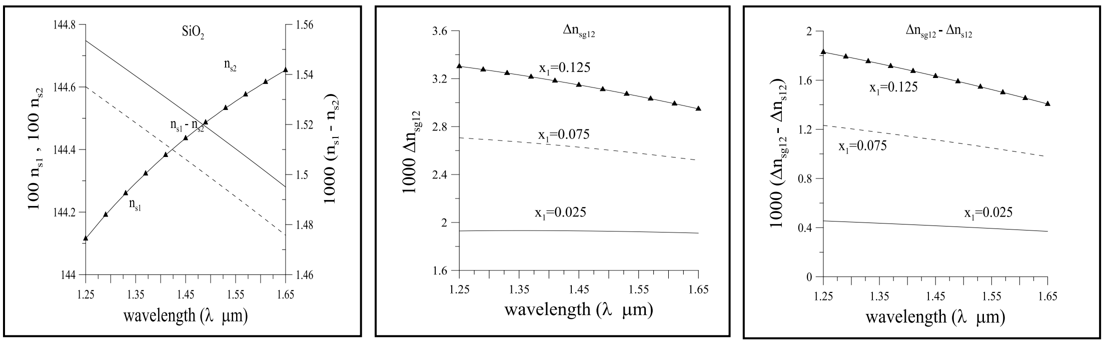
Fig.2 Comparison between Eq.(1) and Eq.(2) for SiO_2 , GeO_2 and P_2O_5

Coefficients of Eq.(1.a), $a_1 \rightarrow a_3$ and $b_1 \rightarrow b_3$, for SiO_2, GeO_2 and P_2O_5 are indicated in Table (A.1)

II.2.2 *Refractive index of Germanosilicate*

Which calculates by Eq.(1), $n_{sg\,1}$, and from Eq.(2), $n_{sg\,2}$, with λ=1.25μm to 1.65μm and x_1 = 0.025 , 0.075, and 0.125 is shown in Fig.(3.a).

The difference Δn_{sg12} ($\Delta n_{sg12} = n_{sg1}-n_{sg2}$) increases with x_1 but it decreases with λ (Fig.3.b). We also can show that, the defference ($\Delta n_{sg12} - \Delta n_{s12}$) not constant with λ (Fig.3.c).



a) n_{sg1} and n_{sg2} b) $\Delta n_{sg12} = n_{sg1} - n_{sg2}$ c) $\Delta n_{sg12} - \Delta n_{s12}$

Fig.3: Comparison between Eq.(1) and Eq.(2) for Germanosilicate with x_1= 0.025, 0.75 and 0.125.

II.2.3 Accuracy of Eq.1 for Germanosilicate

The differtence between refractive index of Germanosilicate by Eq.(1), $n_{sg\ eq1}$, and from published coefficients, $a_1 \rightarrow a_3$ and $b_1 \rightarrow b_3$ (Table A.2),
at special values of x_1 ($n_{sg\ pb}$) is denoted by $\Delta n_{sg\ pb\ eq} = n_{sg\ pb} - n_{sg\ eq1}$.
This difference ($\Delta n_{sg\ pb\ eq}$) is indicated in Table (A.3) which gives that Eq.(1) with some values of x_1 does not accurate. But there isn't any other option which can be used as a general equation for Germanosilicate.

II.2.4 Accuracy of published data for Phosphosilicate at x_2=9.1% and x_2 = 10.5 %

Published coefficients of Eq.(1) for Phosphosilicate (Table A.4) at x_2= 9.1% [31] are not corecte. Where n_{sp1} (with x_2= 9.1%) greater than n_{sp1} (with x_2 = 10.5 %) (Fig.A.1), and so, these coefficients are rejected.

III In-line Fiber Filter With the Pair of Germanosilicate and Phosphosilicate

Due to the difference between the rate of changes of n_{sg} and n_{sp} with respect to λ, there is a specific wavelength (filter cutoff wavelength, λ_c) at which $n_{sg} = n_{sp}$ with main dopant values x_1 and x_2 .r are equals at λ_c.

III.1 Claculation of x_1 corresponding to x_2 from Eq.(2),

For Germanosilicate , Eq.(2) is converted into the following polynomial equation;

$$A_o + A_1x_1 + A_2x_1^2 + A_3x_1^3 + A_4x_1^4 = 0 \quad (5)$$

Where; the coefficients $A_0 \rightarrow A_4$ depend upon the parameters λ_c, n_{sg}, and a_1, a_2, b_1 and b_2 from Eq.(3). Therefore with main values of λ_c and x_2 the value of n_{sp} is evaluated from Eq.(2) and by putting $n_{sg} = n_{sp}$, the corresponding value of x_1 is the root of Eq.(5), where $0 < x_1 < 1$.

III.2 Claculation of x_2 corresponding to x_1 from Eq.(2)

For Phosphosilicate, Eq.(2) converted into the following polynomial equation;

$$B_o + B_1x_2 + B_2x_2^2 + B_3x_3^3 + B_4x_2^4 + B_5x_2^5 = 0 \quad (6)$$

Where; the coefficients $B_0 \rightarrow B_5$ depend upon the constants inside the parameters λ_c and n_{sp}, and a_1 , a_2 , b_1 and b_2 from Eq.(4). Therefore with main values of λ_c and x_1 the value of n_{sg} is evaluated from Eq.(2) and by putting $n_{sp} = n_{sg}$, the value of x_2 is the root of Eq.(6), where $0 < x_2 < 1$.

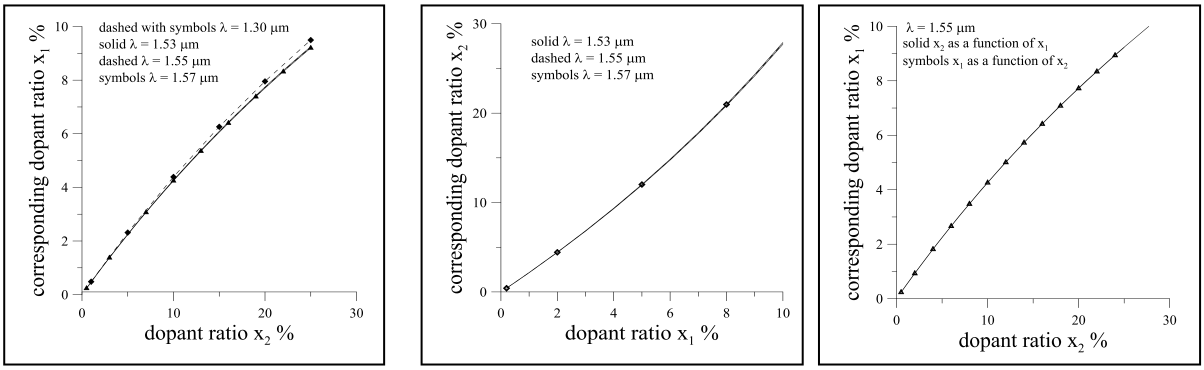
III.3 *Claculation of x_1 corresponding to x_2 from Eq.(1),*

For Germanosilicate Eq.(1) can be converted into the following polynomial equation

$$C_o + C_1x_1 + C_2x_1^2 + C_3x_1^3 + C_4x_1^4 + C_5x_1^5 + C_6x_1^6 = 0 \quad (7)$$

Where; the coefficients $C_0 \rightarrow C_6$ depend upon the values of λ_c and n_{sg}, and $a_{10} \rightarrow a_{30}$, $b_{10} \rightarrow b_{30}$, $u_1 \rightarrow u_3$ and $v_1 \rightarrow v_3$ from Eq.(1). Therefore with main values of λ_c and x_2 the value of n_{sp} is evaluated from Eq.(1) with coefficients from Table (A.3) and by putting $n_{sg} = n_{sp}$, the value of x_1 is the root of Eq.(7), where $0 < x_1 < 1$.

As expected the value of x_1 increases with the value of x_2 (Fig.4.a) also x_2 increases with x_1 (Fig.4.b). Also, the required values of x_2 usually greater than the corresponding values of x_1 (i.e. GeO_2 increases the index of SiO_2 more than P_2O_5) and the ratio of x_2 to x_1 increases with x_2. The pair of x_2 and x_1 is coinside with the pair x_1 and x_2 (Fig.4.c).



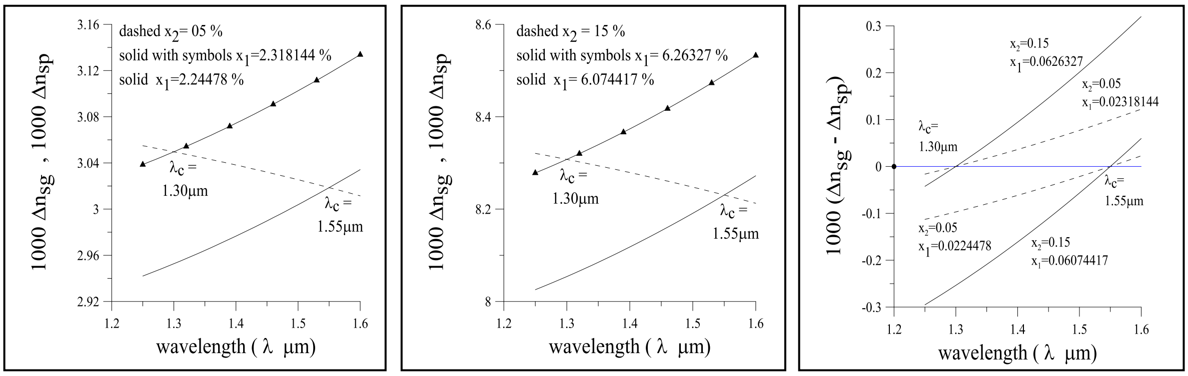
a) x_1 as a function of x_2 b) x_2 as a function of x_1 c) check of x1 with x2

Fig.4 Values of x_2 (corresponding to x_1) and the value x_1 (correspondind to x_2) by Eq.2

The values of both x_2 and the corresponding values of x_1 are in invers relationship with filter cutoff wavelength, λ_c, (Fig.4). Also, the dependence of x_1 or x_2 on wavelength is very little.

As a numerical example of in-line fiber filter with cutoff wavelength (λ_c = 1.30μm) the values of pairs x_1 and x_2 can be are (x_2 = 0.05 and x_1= 0.02318144) or (x_2 = 0.15 and x_1= 6.263270). But with λ_c = 1.55μm, the values of these pairs become (x_2 = 0.05 and x_1= 0.0 224478) or (x_2= 0.15 and x_1= 0.06064417) (Fig.4).

The in-line fiber filter becomes high pass filter (HPF) with fiber core (Germanosilicate) and fiber cladding (Phosphosilicate) and vice versa for low pass filter (LPF) (Fig.5). The bandpass filter (BPF) is structured from cascaded highpass filetr by lowpass filter



a) x_2=5 % b) x_2=15 % c) Δn_{sg} - Δn_{sp}

Fig.5 The cutoff wavelength (λ_c) and the corresponding pair values of x_2 and x_1 ($\Delta n_{sg} = n_{sg} - n_s$ and $\Delta n_{sp} = n_{sp} - n_s$)

IV Theoritical Application : In-Line Fiber BPF (after EDFA) and Demultiplexer

BPF is a micro optics device [32] and it is used with DWDM system and after EDFA. It is consists of HPF cascaded by LPF.

Number of chaneels, bandwidth of each channel and the guard between the channels of the demuliplexers depend upon the applied system. Such as 8-channels (200 GHz bandwidth, λ=1471→1611 nm, 1.6 nm band, 0.4 nm guard) [33], ITU-T currently recommends 81-channels (25 GHz bandwidth, λ = 1528.77 →1560.17 nm, 0.2 nm band, 0.19 nm guard) [34], and 8-channels (200 GHz bandwidth, with band =1.6nm, spacing =1.61 nm, and guard= 0.01nm) [2] Table (1).

Table 1: The limits of 8-channels demultiplexer
(λ = 1540.5 → 1553.37 nm, with band =1.6 nm and spacing = 1.61 nm) [2]

Ch.	1	2	3	4	5	6	7	8
λ_s	1540.50	1542.11	1543.72	1545.33	1546.94	1548.55	1550.16	1551.77
λ_e	1542.10	1543.71	1545.32	1546.93	1548.54	1550.15	1551.76	1553.37

The special avaliable value of x_2 = 10.5 % (Table A.4) is used to apply both Eq.(1) and Eq.(2).

1) *In-Line Fiber BPF after EDFA*, to pass 8-channels, from Table (1);
   λ_{cHPF} = 1540.50 nm so x_1= 4.491799 with Eq.(1), but x_1 = 4.453913 with Eq.(2)
   λ_{cLPF} = 1553.37 nm so, x_1=4.490390 with Eq.(1), but x_1= 4.445769 with Eq.(2).
2) *In-Line Fiber BPFs to demultiplex 8- channels*,(Fig.6) and Table (1); the values of x_1 for 8 LPF and 8 HPF (i.e. 8 BBF) are calculated from Eq.(1) (Table 2) and from Eq.(2) and (Table 3) with x_2 = 10.5%.

Figure 7 obveuses Δn_{sg} and Δn_{sp} for 8 BPFs with Eq.(1) and Eq.(2).

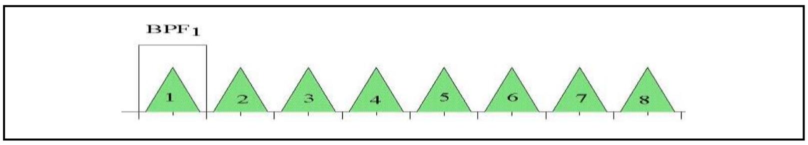


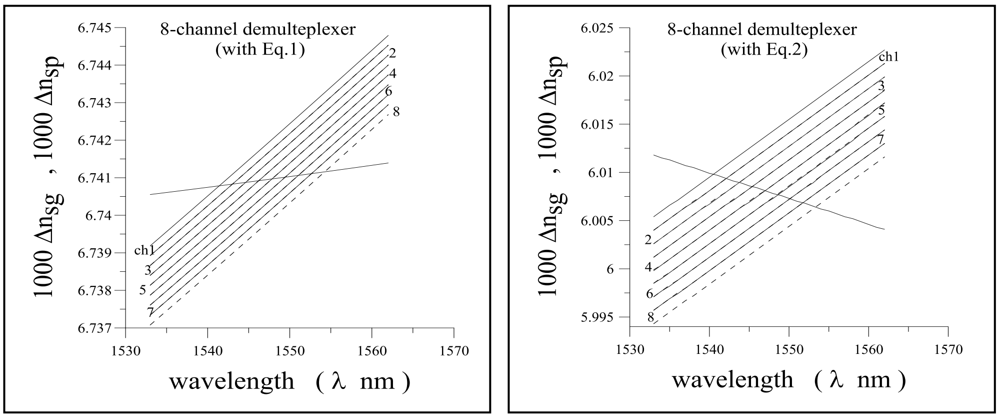
Fig.6 A 8-channels demultiplexer

Table 2: The ratios of GeO_2 % for the 8-channels demultiplexer
with P_2O_5 =10.5% either core or cladding (* clad and ** core) Eq.(1)

Ch.	1	2	3	4	5	6	7	8
HPF *	4.491799	4.491624	4.491448	4.491272	4.491096	4.490920	4.490743	4.490566
LPF **	4.491625	4.491449	4.491274	4.491097	4.490921	4.490744	4.490567	4.490390

Table 3: The ratios of GeO_2 % for the 8-channels demultiplexer
with P_2O_5 =10.5% either core or cladding (* clad and ** core) Eq.(2)

Ch.	1	2	3	4	5	6	7	8
HPF *	4.453913	4.452899	4.451883	4.450867	4.449848	4.448829	4.447808	4.446786
LPF **	4.452905	4.451890	4.450873	4.449855	4.448835	4.447814	4.446792	4.445769



a) by using Eq.(1) b) by using Eq.(2)

Fig.7 8-channels demultiplexer by applied both Eq.(1) and Eq.(2)

We must be noticed that, with any value of x_2 , the corresponding value of x_1 by Eq.(1) differes with that calculated from Eq.(2) because the value of $n_{s1} > n_{s2}$ and $n_{sp1} \neq n_{sp2}$.

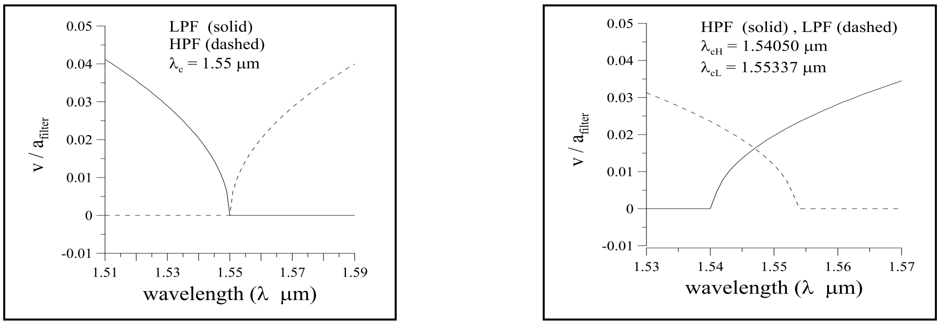
To indicate that, with the avilable value of $x_2 = 0.105$, the corresponing value of $x_1 = 0.04514289$ from Eq.(1) and $x_1= 0.04589308$ from Eq.(2) with $\lambda = 1.30\mu m$. Also, $x_1= 0.04490761$ from Eq.(1) and $x_1 = 0.04447910$ from Eq.(2) with $\lambda = 1.55\mu m$. Where $n_{sp1} = 1.453656$ and $n_{sp2} = 1.451497$ (λ=1.30μm), and $n_{sp1} = 1.450765$ and $n_{sp2} = 1.448502$ ($\lambda = 1.55\mu m$).

If we take in account of x_1 the difference between n_{s1} and n_{s2} ($\Delta n_{s12} = n_{s1}-n_{s2}$) the values of x_1 become;
$x_1 = 0.03516976$ at $\lambda = 1.30\mu m$ (where, $\Delta n_{s12} = 0.00148610$), and $x_1= 0.03470022$ at $\lambda = 1.55\mu m$ (where, $\Delta n_{s12} = 0.0015293$). Then, the results from Eq.(2) not equal with that from Eq.(1).

Also, if we take in account of x_1 the difference between n_{sp1} and n_{sp2} ($\Delta n_{sp12} = n_{sp1}-n_{sp2}$), the values of x_1 become;
$x_1 = 0.03065721$ at $\lambda = 1.30\mu m$ (where $\Delta n_{sp12} = 0.002159$), and $x_1= 0.02980713$ at λ=1.55μm (where, $\Delta n_{sp12} = 0.002263$). Then, the results from Eq.(2) not equal with that from Eq.(1).

V Normalized Frequency (v) of In-Line Fiber Filter

At cut-off wavelength, the corresponding normalized frequency (v) equals zero and the value of v increases with wavelengths apart from λ_c toward the active region of the filter (Fig.6). But, v stills very low, and so, the propagation constant is very weak. To increase the value of v, we need a large core radius of filter within single mode ($v < 2.4$). In this case, the splicing between the filter and the fiber link becomes difficult because the core radius of filter (a_{filter}) very large than the core radius of fiber link (a_{link}).



a) LPF and HPF b) BPF after E

Fig.6 Normalized frequency (v) as a function of wavelength (λ). Where a_{filter} is the core radius

As example for BPF with bandwidth from λ = 1540.50nm to λ = 1553.37nm (Fig.6.b), the maximum value of v = 0.0163a_{filter} and it occurs at λ = 1547.1 nm. So, with single mode, a_{filter} can be reach 147μm and so, the radius a_{filter} can be 30 times a_{link} (a_{link} , approximately 5μm). Therefore the maximum additional splicing losses due to the ratio a_{filter} / a_{link} becomes 14.77dB (where, splicing losses = 10log (a_{filter} / a_{link})).

Finally, the length of the in-line fiber filter must be very short to overcome the very small propagation constant through it.

VI. CONCLUSION

Exact analysis of in-line fiber filter is occurred by derive a polynomial expression for the dopant ratio of GeO_2 or P_2O_5. The in-line fiber high pass filter (HPF) consists of Phosphosilicate (core) and Germanosilicate (cladding) and vice versa for the in-line low pass filter (LPF).

For each specific filter cutoff wavelength (λ_c) there is one value of daopant ratio of the core corolated with that of the cladding. The in-line fiber BPF is constructed by cascaded the in-line fiber HPF and the in-line LPF.

The length of in-line fiber filter must be very short to overcome the weak of the propagation constsnt throuh it. The design of the demultiplexer becomes very easy. The refractive indices of BPFs which are used for 8-channels demultiplexer are evaluated.

The dopants of both the core and the cladding must be from materials which increasing the refractive index of the silica such as germania (GeO_2) and phosphorus pentoxide (P_2O_5). Also, from materials which decreasing the refractive index of the silica such as fluorine (F) and boria (B_2O_3).

The normalized frequency (v) of the in-line fiber filter is very small so, the corresponding propagation constant becomes very weak.

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Appendix A

Table A.1: Sellmeier's Coefficients of Eq.(1), $a_1 \rightarrow a_3$ and $b_1 \rightarrow b_3$ for SiO_2 , GeO_2 and P_2O_5

	$a_{1\ sg\ pb}$	$a_{2\ sg\ pb}$	$a_{3\ sg\ pb}$	$b_{1sg\ pb}$	$b_{2\ sg\ pb}$	$b_{3\ sg\ pb}$	references
SiO_2	0.6961663	0.4079426	0.8974794	0.0684043	0.1162414	9.89616087	[8,24,35]
GeO_2	0.80686642	0.71815848	0.85416831	0.069972606	0.15996605	11.841931	[27]
P_2O_5	0.78838154	0.43993784	0.87648797	0.103867	0.08992564	9.89616572	[24]

Table A.2: Sellmeier's Coefficients of Eq.(1), $a_1 \rightarrow a_3$ and $b_1 \rightarrow b_3$ for Germanosilicate at special values of x_1

x_1	$a_{1\ sg\ pb}$	$a_{2\ sg\ pb}$	$a_{3\ sg\ pb}$	$b_{1sg\ pb}$	$b_{2\ sg\ pb}$	$b_{3\ sg\ pb}$	
0.030	0.7052977	0.4111432	0.8717021	0.0780876	0.1256396	9.896154	[27]
0.031	0.7028554	0.4146307	0.8974540	0.0727723	0.1143085	9.896161	[35]
0.035	0.7042038	0.4160032	0.9074049	0.0514415	0.12916	9.896156	[31]
0.041	0.68671749	0.43481505	0.89656582	0.072675189	0.11514351	10.002398	[31]
0.058	0.7088876	0.4206803	0.8956551	0.0609053	0.1254514	9.896162	[35]
0.063	0.7083952	0.4203993	0.8663412	0.08538421	0.10248385	9.89617501	[24]
0.070	0.6869829	0.44479505	0.79073512	0.078087582	0.1155184	10.436628	[35]
0.079	0.7136824	0.4254807	0.8964226	0.0617167	0.1270814	9.896161	[35]
0.135	0.711040	0.451885	0.704048	0.064270	0.129408	9.425478	[27]
0.193	0.7347008	0.4461191	0.8081698	0.07646793	0.1246087	9.8962033	[24]

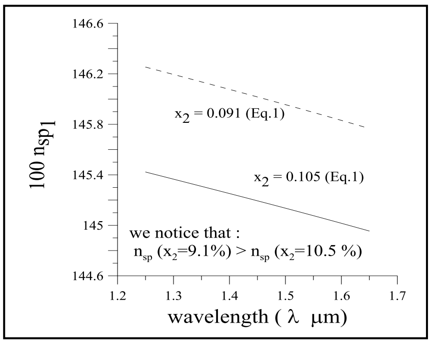
Table A.3: Difference between index of Germanosilicate by Eq.(1) and by published data Table (A.2)

x_1		0.030	0.031	0.035	0.041	0.058
λ=1.25 µm	$10^3 \Delta n_{sg\ pb\ eq}$	0.3699	0.0678	0.1391	0.2407	0.2830
	error %	0.0255	0.0047	0.0096	0.0165	0.0195
λ=1.65 µm	$10^3 \Delta n_{sg\ pb\ eq}$	0.2592	0.0042	0.1311	0.1492	0.2403
	error %	0.0179	0.0003	0.0090	0.0103	0.0140
x_1		0.063	0.070	0.079	0.135	0.193
λ=1.25 µm	$10^3 \Delta n_{sg\ pb\ eq}$	-0.5364	0.4409	1.1771	-1.2882	0.4844
	error %	-0.0368	0.0302	0.0801	-0.0874	0.0323
λ=1.65 µm	$10^3 \Delta n_{sg\ pb\ eq}$	-0.5378	1.0589	1.3999	1.2984	0.3405
	error %	-0.0370	0.0728	0.0956	-0.0883	0.0234

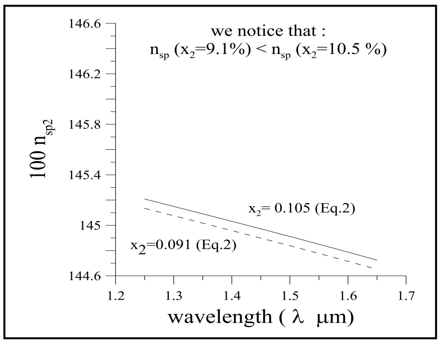
Note 1; Coefficients which calculated by Eq.(1) not satisfied with that from published data, Table (A.2)

Table A.4: Sellmeier's coefficients of Eq.(1), $a_1 \rightarrow a_3$ and $b_1 \rightarrow b_3$ for Phosphosilicate at special values of x_2

x_2	a_1	a_2	a_3	b_1	b_2	b_3	
0.091	0.6957900	0.4524970	0.7125130	0.0615680	0.1199210	8.6566410	[31]
0.105	0.7058489	0.4176021	0.8952753	0.07212788	0.1134782	9.8961614	[24]



a) With Eq.(1)



b) with Eq.(2)

Fig.A.1 Check for published coefficients of Phosphosilicate with x_2=9.1% and 10.5%