A STUDY ON MATERIAL DISPERSION AROUND ZERO MATERIAL DISPERSION WAVELENGTH

Under the supervision of

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Comprehensive Project Report has been submitted in Partial fulfillment of M.Sc Degree in Electronics under West Bengal State University

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CERTIFICATE

This is to certify that Sampurna Patra(University reg no.1011821401864 of 2018-2020,Roll no.22242009) , student of Electronic Science, Acharya Prafulla Chandra College under West Bengal State University has presented the project work entitled as “A STUDY OF MATERIAL DISPERSION AT ZERO MATERIAL DISPERSION WAVELENGTH” under my supervision. Comprehensive work of the report is submitted in partial fulfillment for M.Sc degree in Electronic Science to be conferred by West Bengal State University.

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DECLARATION

We certify that

1. The work contained in this report is original and has been done by us under the guidance of our supervisor(s).
2. We have followed the guidelines provided by the institutes in the preparing the report.
3. Whenever we used materials (data, theoretical analysis, plots and texts) from other sources, we have given due credit to them by citing them in the text of the report and giving their details in the references. Further, we have taken permission from the copyright owners of the sources, whenever necessary.

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Sampurna Patra [Reg. no: 1011821401864 of 2018-2020; Roll no: 22242009]

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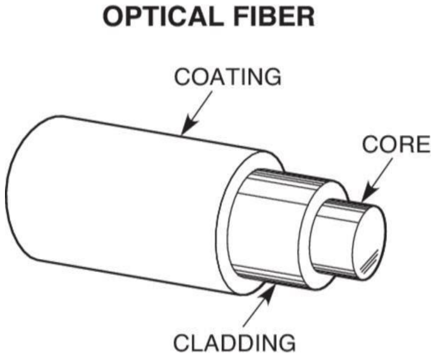
CHAPTER-1

1.1.Introduction:

Optical communication consists of a “transmitter” that converts electrical signals into optical signals, a “receiver” that converts optical signals into electrical signals, and “optical fibers” that transmit optics.

The fiber optical cable uses the application of total internal reflection of light. The fibers are designed such that they facilitate the propagation of light along the optical fiber depending on the requirement of power and distance of transmission. A single mode fiber is used for long-distance transmission while multimode fiber is used for shorter distances. The outer cladding of these fibers needs better protection than metal wires.



1.2 Importance Of Optical Fiber :

Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data transfer rates) than electrical cables.

Need Of Optical Fiber Communication System :

1. *Optical fiber communication has enormous bandwidth and hence show for greater transmission potential than the metallic cable system.*
2. *Optical fiber cables are of small size and weight as compared to metallic cables and hence occupy small space for its operation.*
3. *Optical fibers are insulators electrically. They do not show earth loop and interface problem like metallic cables.*
4. *Optical fiber form a dielectric wave guide and are therefore free from electromagnetic interference, or radio frequency interference*.

Types of Optical Fiber :

There are three types of fiber optic cable commonly used:

- **Single mode Fiber .**
- **Multimode Fiber .**
- **Plastic optical fiber (POF).**

- **Single mode Fiber :**In is an optical fiber designed to carry only a single mode of light - the transverse mode. It transmit the fundamental mode only.
- **Multimode Fiber :** Multimode optical fiber is a type of optical fiber mostly used for communication over short distances such as within a building or campus.
- **Plastic optical Fiber :** It is a optical fiber that is made of polymer, similar to glass optical fiber, POF transmit light through the core of the fiber. It is not suitable for data community.

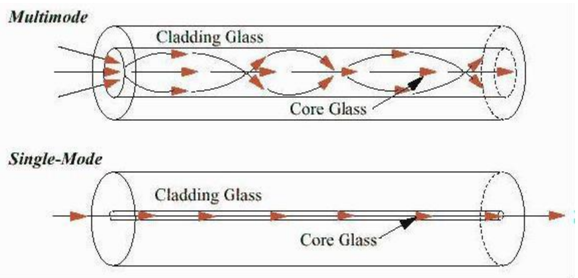


Figure : single and multimode fiber

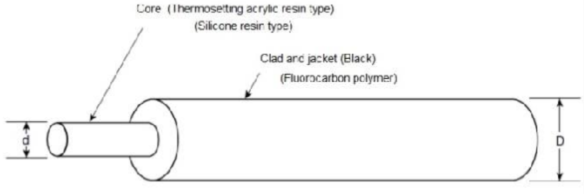


Figure : Plastic Optical Fiber

Optical Fiber Transmission Methodology :

- ✓ The light in the fiber optic travels through the core (hallway) by constantly bouncing from the Cladding by a principle called "**Total Internal Reflection".** Because, the Cladding does not absorb only light from Core, the light wave can travel great distances. However, Some of light signal degrades within the fiber by ---

Snell's Law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

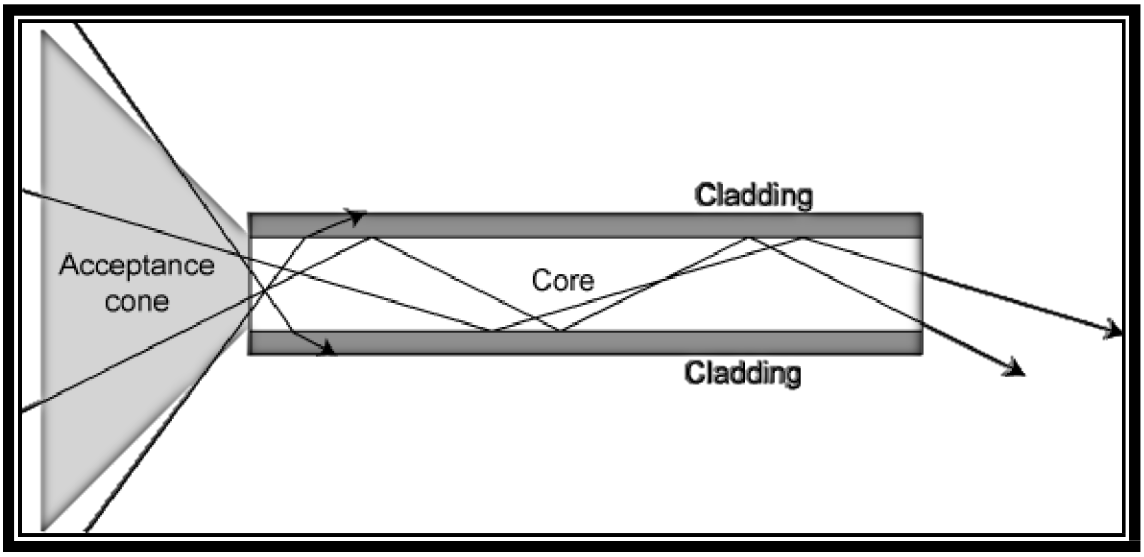


Figure : Fiber Works by "Total Internal Reflection"

Material Dispersion :

- ✓ Material dispersion is a phenomenon in which different optical wavelengths propagate at different velocities, depending on the refractive index of the material usedin the fiber core. The above figure shows the variation of refractive index n with wavelength λ for fused silica used in current glass fibers. Material dispersion is caused by the velocity of light (or refractive index) being a function of wavelength as shown above.

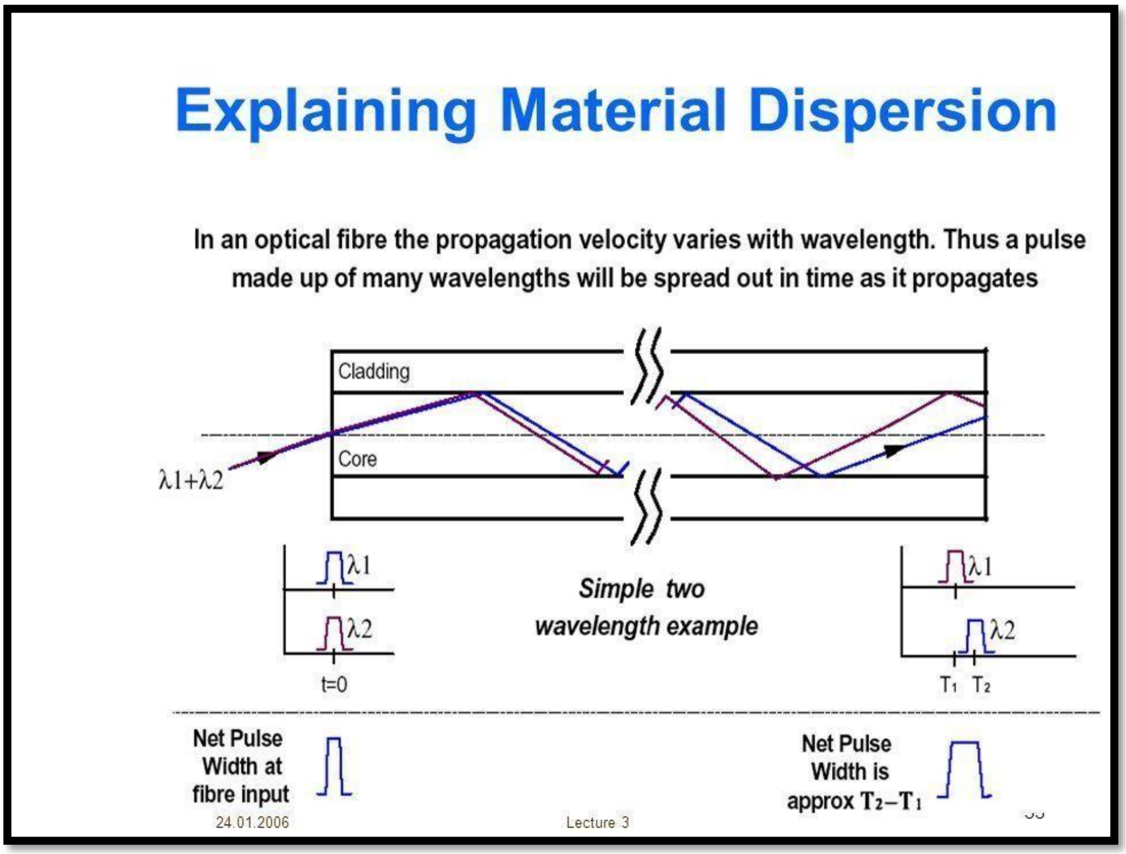
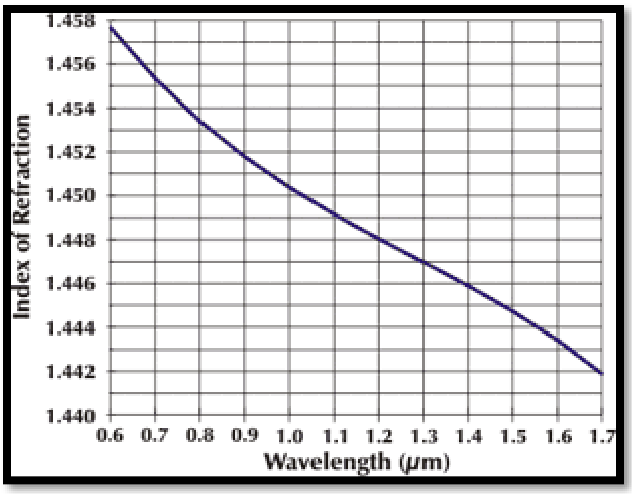


Figure : Explaining Material Dispersion



All light sources (even a laser source) have some degree of spectral width. This means that even in a single mode fiber (since laser source also has some spectral linewidth), longer wavelengths travel faster and arrive earlier than shorter wavelengths at the receiver, and this causes pulse spreading.

Zero Material Dispersion :

- ✓ In a single-mode optical fiber, the zero-dispersion wavelength is the wavelength or wavelengths at which material dispersion and waveguide dispersion cancel one another. The zero dispersion wavelength, e.g. of an optical fiber, is the wavelength where the group delay dispersion (second-order dispersion) is zero. For standard telecom fibers , this wavelength is ≈ 1.3 μm, but by employing designs with modified waveguide dispersion it is possible to shift the zero dispersion wavelength to the 1.5-μm region (→ *dispersion-shifted fibers*). The dispersion is anomalous for wavelengths longer than the zero dispersion wavelength, and normal for shorter wavelengths.

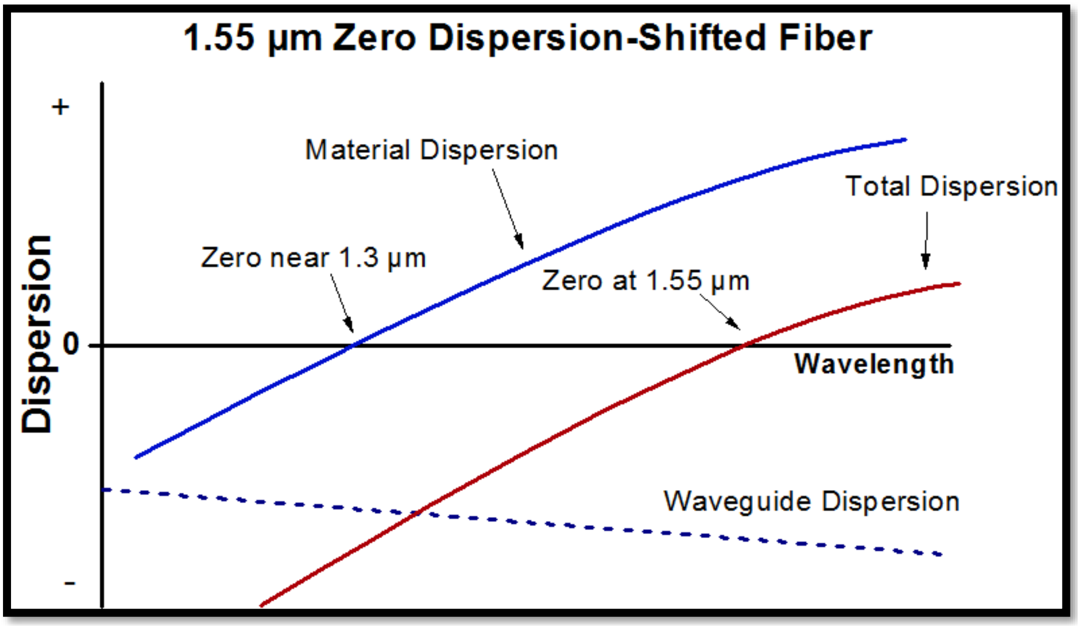


Figure: Zero Material dispersion at different wavelength

CHAPTER – 2

Review On Our Study(Material dispersion around Zero material wavelength):

- At the present age when the Optical Fiber based communication system is the base of best quality communication, huge research is going on to improve the still prevailing constraints of the optical fiber based communication. Considering all the issues the best wavelength for communication is settled at 1.55 µm. But for conventional pure silica based Single Mode Fiber has Zero material dispersion wavelength at 1.27 µm.

- Our study on 'data available material' based optical fiber has produced both the types of results. Some fibers are producing better response and some are not. Here we have studied some doped fibers to find a fresh and effective alternative. We have taken samples of Doped glass Fiber and different fluoride glass fibers. In this study we have determined the ZMDW of different fibers, and find the flatness of material dispersion.

Review On Materials :

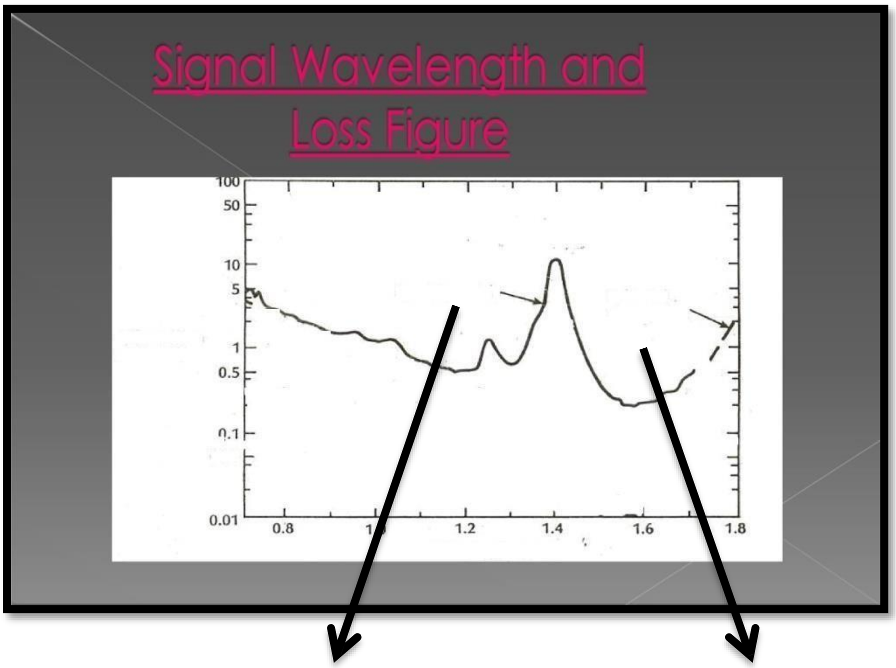
- ✓ Here we have worked with Conventional Doped Fiber, Fluoride glass fiber and also we found the Zero material dispersion wavelength among the materials of above mentioned category. Here the conventional doped fibers are – doped Silica fiber (SiO_2), Boron doped fiber (B_2O_3) and germanium doped fiber (GeO_2) and also phosphorus pentoxide (P_2O_5).

  And also the Fluoride glass fibers are – ABCY, ZBLAN, ZBG, ZBLAa and HBLa etc.

In the optical fiber based communication system there is a number of challenges to have a smooth and sustained effective communication system. Among the different dispersion mechanism the material dispersion is the most inherent property and has less impact of variable parameters.

Silica (SiO_2) based fiber glasses were the initial effective option of Optical Fiber material. The SiO_2 based fiber has a specific loss and dispersion criterion. In search of a better alternative we have studied with some more Optical fibers doped with some other dopant. We have studied Pure SiO_2 along with GeO_2 and B_2O_3 , and P2O5 also studied the fluoride based glass materials.

In optical fiber the low loss region is about 1.2 μm to 1.8 μm. It results a wide bandwidth and wide variety of doping materials for optical fiber. So, the challenge becomes to determine the best doping or fluorination to have the ZMDW at or near the minimum loss point for the optical fiber.



"**Experimental**" "**Infrared absorption**"

Here we will see the graph which is signal wavelength vs loss figure. In this curve we will see that the different attenuation at different wavelength at 1.55μm, it is minimum.

CHAPTER - 3

Mathematical formulation:

For Matrerial dispersion in pure and doped Silica -

The refractive index of doped Silica can be represented by the following empirical formula ::-

$$n^2(\lambda)-1= \frac{b1(\lambda^2)}{\lambda^2-a_1} + \frac{b_2(\lambda^2)}{\lambda^2-a_2} + \frac{b_3(\lambda^2)}{\lambda^2-a_3} \text{ ---------(1)}$$

Where λ is expressed in micrometers . The values of the co-efficients are $a1$, $a2$,$a3$, $b1$, $b2$ *and* $b3$ for pure and some doped Silica .

Material dispersion in fluoride glasses :

The Equation of refractive index of Fluoride glasses ------

$$n(\lambda) = A\lambda^{-4} + B\lambda^{-2} + C + D\lambda^2 + E\lambda^4 \text{ ---------------- (2)}$$

Where λ is expressed in micrometers. The values of A, B, C, D, E can be determined from here.

→ For 1st Order derivative of various fluoride glasses is----

$$\frac{dn}{d\lambda} = -4A\lambda^{-5} - 2B\lambda^{-3} + 2D\lambda + 4E\lambda^3 \text{ -----------(3)}$$

→ For 2nd Order derivative of various fluoride glasses is----

$$\frac{d^2n}{d\lambda^2} = 20A\lambda^{-6} + 6B\lambda^{-4} + 2D + 12E\lambda^2 \text{ ------------- (4)}$$

Simulation Work :

Algorithm of Matlab code for Pure Doped fibers :

1st Step: We take the range of wavelength (λ)

2nd Step: Take the value of co-efficient $a_1, a_2, a_3, b_1, b_2, b_3$ for doped silica materials

3rd Step: Apply the formula for refractive index

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

4th step: first order derivative of refractive index for doped silica materials

$$nf=\frac{dn}{d\lambda}=-\frac{\lambda}{n}\left[\frac{a_1b_1}{(\lambda^2-a_1)^2}+\frac{a_2b_2}{(\lambda^2-a_2)^2}+\frac{a_3b_3}{(\lambda^2-a_3)^2}\right]$$

5th Step: Second order derivative of refractive index for doped silica materials

$$ns=\frac{d^2n}{d\lambda^2}=\frac{4\lambda^2}{n}\left[\frac{a_1b_1}{(\lambda^2-a_1)^3}+\frac{a_2b_2}{(\lambda^2-a_2)^3}+\frac{a_3b_3}{(\lambda^2-a_3)^3}\right]-\frac{1}{n}\left[\frac{a_1b_1}{(\lambda^2-a_1)^2}+\frac{a_2b_2}{(\lambda^2-a_2)^2}+\frac{a_3b_3}{(\lambda^2-a_3)^2}\right]-\frac{\lambda^2}{n^3}\left[\frac{a_1b_1}{(\lambda^2-a_1)^2}+\frac{a_2b_2}{(\lambda^2-a_2)^2}+\frac{a_3b_3}{(\lambda^2-a_3)^2}\right]^2$$

6th Step: Print the value of refractive index(n),wavelength(λ),first order derivative of refractive index(nf), second order derivative of refractive index(ns) and make table from these values.

7th Step: Plot the wavelength (λ) vs first order derivative of refractive index(nf) and Plot the Wavelength(λ) vs second order derivative of refractive index(ns) graph from these values.

Algorithm of Matlab code for fluoride glass fibers :

1st Step: We take the range of wavelength (λ)

2nd Step: Take the value of co-efficient A, B, C, D, E for fluoride glass fibers

3rd Step: Apply the formula for refractive index of Fluoride glasses

$$n(\lambda)=A\lambda^{-4}+B\lambda^{-2}+C+D\lambda^{2}+E\lambda^{4}$$

4th step: first order derivative of refractive index for Fluoride glass fibers

$$nf=\frac{dn}{d\lambda}=-4A\lambda^{-5}-2B\lambda^{-3}+2D\lambda+4E\lambda^{3}$$

5th Step: Second order derivative of refractive index for Fluoride glass fibers

$$ns=\frac{d^2n}{d\lambda^2}=20A\lambda^{-6}+6B\lambda^{-4}+2D+12E\lambda^{2}$$

6th Step: Print the value of refractive index(n),wavelength(λ),first order derivative of refractive index(nf), second order derivative of refractive index(ns) and make table from these values.

7th Step: Plot the wavelength (λ) vs first order derivative of refractive index(nf) and Plot the Wavelength(λ) vs second order derivative of refractive index(ns) graph from these values.

CHAPTER- 4

Result and analysis- I:

4.1 Computation of Pure Doped Fiber Materials:

Silica (SiO_2) based fiber glasses were the initial effective option of Optical Fiber material. The SiO_2 based fiber has a specific loss and dispersion criterion. In search of a better alternative we have studied with some more Optical fibers doped with some other dopant. We have studied Pure SiO_2 along with GeO_2 and B_2O_3, P_2O_5.

We worked with ten materials some of them are conventional doped silica fiber and GeO_2,B_2O_3,P_2O_5 and another is fluoride glass fiber(ABCY, HBLa, ZBG, ZBLAa, ZBLAN).

Among this material the response of B_2O_3 is very similar with conventional SiO_2 fibers has zero material dispersion at 1.27 μm and 1.26 μm and also P_2O_5 has a wavelength at 1.29 μm respectively But conventional minimum loss is at 1.55 μm.

We observed the zmdw of GeO_2 at 1.38 μm , which is closer to 1.55 μm wave length. It is the positive sign and also it has a flatness at 1.55 μm.

Values of coefficient in Sellemeier's formula for pure and doped Silica :

Dopant (mole%)	a_1	a_2	a_3	b_1	b_2	b_3
Pure SiO2	0.004679148	0.01351206	97.93400	0.6961663	0.4079426	0.8974794
GeO2 (6.3)	0.007290464	0.01050294	97.93428	0.7083952	0.4203993	0.8663412
GeO2 (19.3)	0.005847345	0.01552717	97.93484	0.7347008	0.4461191	0.8081698
B2O3 (5.2)	0.004981838	0.01375664	97.93353	0.6910021	0.4022430	0.9439644
P2O5 (10.5)	0.005202431	0.01287730	97.93401	0.7058489	0.4176021	0.8952753

Here, from the table we have collected the values of coefficient of pure silica and put it in the above equation –

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

and simulate this equation through matlab and got the curve of different optical fibers .

For Pure SiO_2 the Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/d\lambda^2$
0.65	1.456535	-0.027158	0.102907
0.7	1.455292	-0.022783	0.073971
0.75	1.454237	-0.019612	0.054019
0.8	1.453317	-0.017284	0.039884
0.85	1.452498	-0.01556	0.029635
0.9	1.451754	-0.014277	0.022048
0.95	1.451065	-0.013324	0.01633
1	1.450417	-0.012622	0.011948
1.05	1.4498	-0.012113	0.00854
1.1	1.449204	-0.011756	0.005854
1.15	1.448622	-0.011518	0.003709
1.2	1.44805	-0.011378	0.001976
1.25	1.447483	-0.011316	0.000559
1.3	1.446918	-0.011318	-0.00061
1.35	1.44635	-0.011373	-0.001587
1.4	1.445779	-0.011474	-0.00241
1.45	1.445202	-0.011612	-0.003111
1.5	1.444618	-0.011783	-0.003714
1.55	1.444024	-0.011982	-0.004238
1.6	1.443419	-0.012206	-0.004698
1.65	1.442803	-0.012451	-0.005105

The output plot of SiO_2 ---

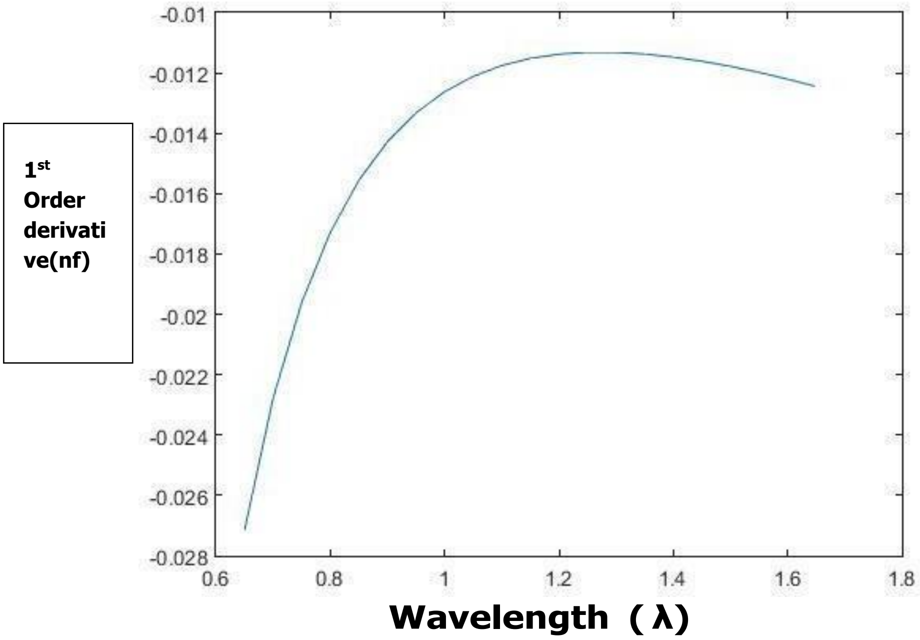


Figure: Wavelength Vs 1st order derivative

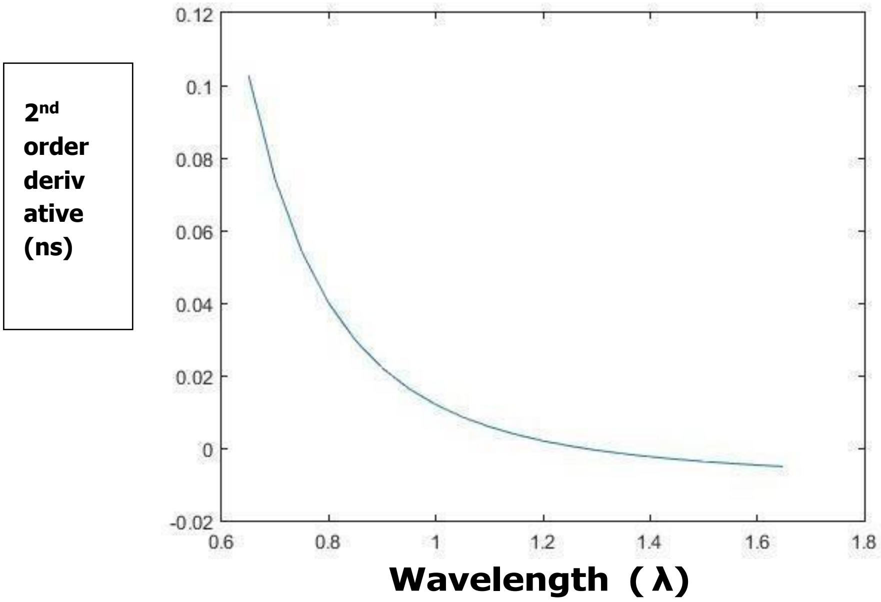


Figure: Wavelength Vs 2nd order derivative

For GeO_2(6.3) the Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/dλ^2$
0.65	1.465673	-0.028779	0.111047
0.7	1.464358	-0.024047	0.080196
0.75	1.463247	-0.020602	0.058868
0.8	1.462283	-0.018057	0.043729
0.85	1.46143	-0.01616	0.032734
0.9	1.460659	-0.014737	0.024586
0.95	1.459951	-0.013668	0.018438
1	1.459288	-0.012869	0.013725
1.05	1.45866	-0.012278	0.010058
1.1	1.458058	-0.011851	0.007166
1.15	1.457473	-0.011552	0.004857
1.2	1.456901	-0.011357	0.002993
1.25	1.456336	-0.011247	0.00147
1.3	1.455775	-0.011206	0.000213
1.35	1.455214	-0.011222	-0.000835
1.4	1.454652	-0.011287	-0.001717
1.45	1.454085	-0.011392	-0.002466
1.5	1.453512	-0.011532	-0.00311
1.55	1.452931	-0.011701	-0.003667
1.6	1.452341	-0.011897	-0.004155
1.65	1.451741	-0.012116	-0.004586

The Output Plot of GeO2(6.3)---

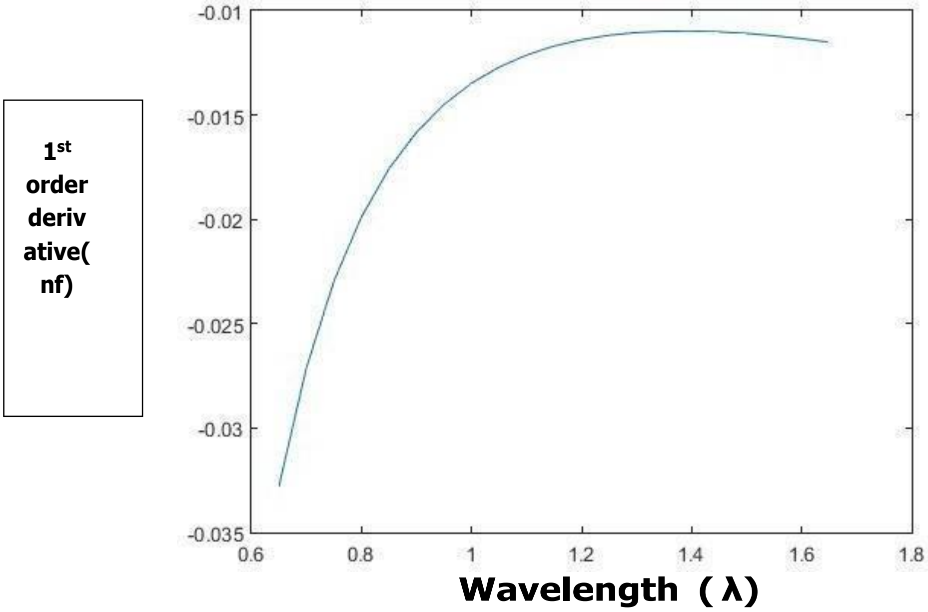


Figure: Wavelength Vs 1st order derivative

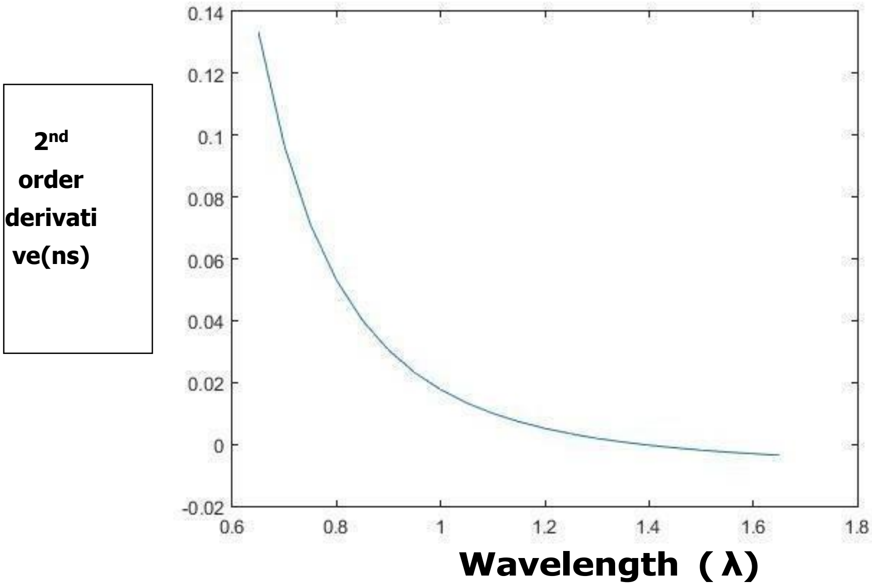


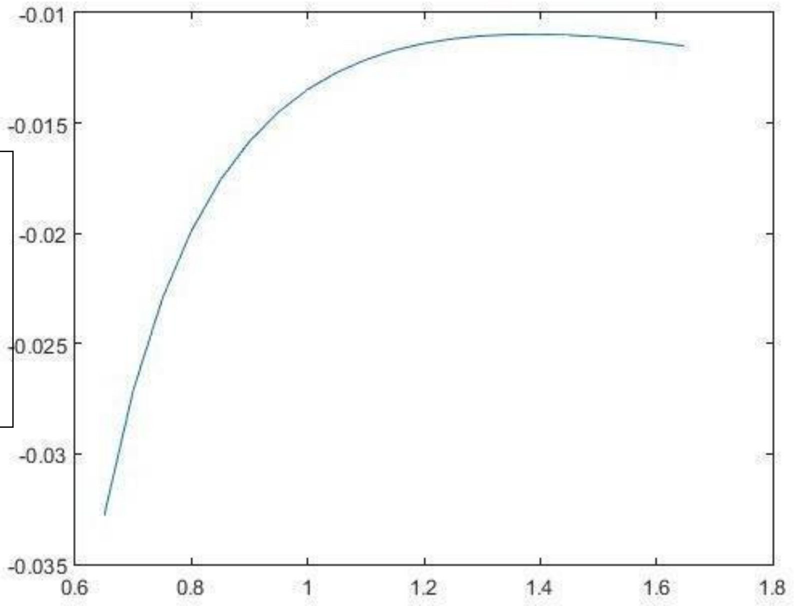
Figure: Wavelength Vs 2nd order derivative

For GeO2(19.3) the Output data table:

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/d\lambda^2$
0.65	1.484806	-0.032786	0.133309
0.7	1.483317	-0.027103	0.096383
0.75	1.482071	-0.022957	0.07098
0.8	1.481003	-0.019882	0.053019
0.85	1.48007	-0.017573	0.040018
0.9	1.479237	-0.015824	0.030411
0.95	1.47848	-0.014493	0.02318
1	1.477782	-0.013478	0.01765
1.05	1.477128	-0.012707	0.013356
1.1	1.476508	-0.012127	0.009978
1.15	1.475913	-0.011698	0.007288
1.2	1.475337	-0.011389	0.00512
1.25	1.474773	-0.011179	0.003353
1.3	1.474217	-0.011049	0.0019
1.35	1.473667	-0.010985	0.000693
1.4	1.473118	-0.010976	-0.00032
1.45	1.472568	-0.011014	-0.001178
1.5	1.472016	-0.011092	-0.00191
1.55	1.471458	-0.011204	-0.002542
1.6	1.470895	-0.011345	-0.003091
1.65	1.470324	-0.011512	-0.003573

The Output Plot of GeO2(19.3)---

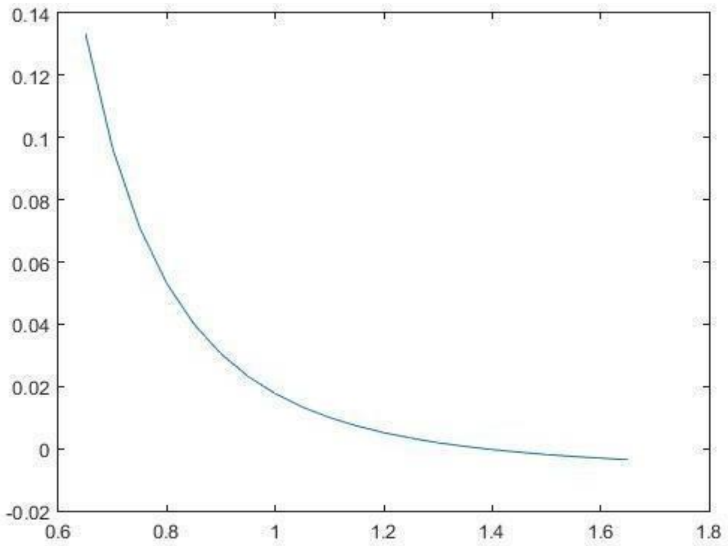
1st order derivative(nf)



Wavelength (λ)

Figure: Wavelength Vs 1st order derivative

2nd order derivative (ns)



Wavelength (λ)

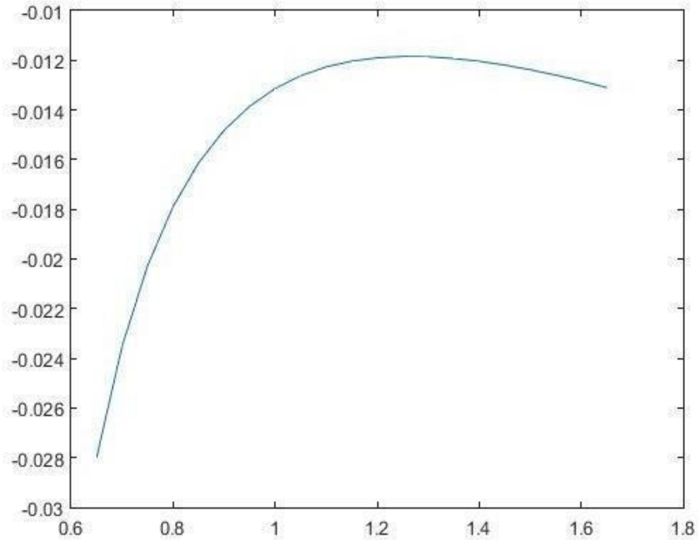
Figure: Wavelength Vs 2nd order derivative

For B2O3(5.2) the Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/dλ^2$
0.65	1.452907	-0.028002	0.105534
0.7	1.451625	-0.023516	0.075797
0.75	1.450535	-0.02027	0.055295
0.8	1.449584	-0.017888	0.040773
0.85	1.448785	-0.016126	0.030244
0.9	1.447964	-0.014818	0.022451
0.95	1.447248	-0.013849	0.016576
1	1.446574	-0.013138	0.012075
1.05	1.445931	-0.012625	0.008574
1.1	1.445309	-0.012268	0.005814
1.15	1.444702	-0.012034	0.00361
1.2	1.444104	-0.0119	0.001829
1.25	1.443511	-0.011846	0.000373
1.3	1.442918	-0.011858	-0.00083
1.35	1.442324	-0.011926	-0.001834
1.4	1.441725	-0.012039	-0.002682
1.45	1.441119	-0.012192	-0.003404
1.5	1.440505	-0.012378	-0.004025
1.55	1.439881	-0.012593	-0.004566
1.6	1.439246	-0.012833	-0.00504
1.65	1.438597	-0.013096	-0.005461

The Output Plot of B2O3(5.2)---

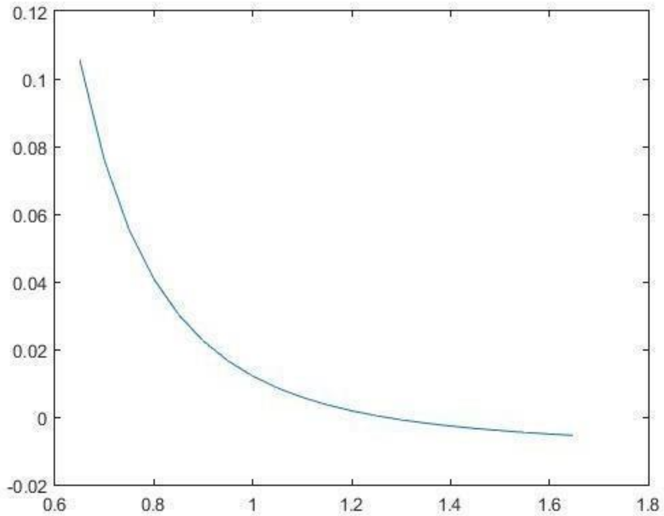
1st order derivative(nf)



Wavelength (λ)

Figure: Wavelength Vs 1st order derivative

2nd order derivative(ns)



Wavelength (λ)

Figure: Wavelength Vs 2nd order derivative

For P2O5(10.5) the Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/dλ^2$
0.65	1.463386	-0.027698	0.105471
0.7	1.46212	-0.02321	0.075919
0.75	1.461045	-0.019954	0.055526
0.8	1.46011	-0.01756	0.04107
0.85	1.459279	-0.015782	0.030582
0.9	1.458524	-0.014456	0.022816
0.95	1.457828	-0.013468	0.016961
1	1.457173	-0.012737	0.012473
1.05	1.456551	-0.012205	0.008983
1.1	1.45595	-0.011827	0.00623
1.15	1.455366	-0.011572	0.004033
1.2	1.454791	-0.011417	0.002258
1.25	1.454223	-0.011341	0.000807
1.3	1.453656	-0.011332	-0.00039
1.35	1.453089	-0.011377	-0.00139
1.4	1.452518	-0.011468	-0.002232
1.45	1.451941	-0.011598	-0.002949
1.5	1.451357	-0.011761	-0.003565
1.55	1.450765	-0.011953	-0.0041
1.6	1.450162	-0.01217	-0.004569
1.65	1.449547	-0.012409	-0.004984

<u>The Output Plot of P2O5(10.5)---</u>

1st order derivative(nf)

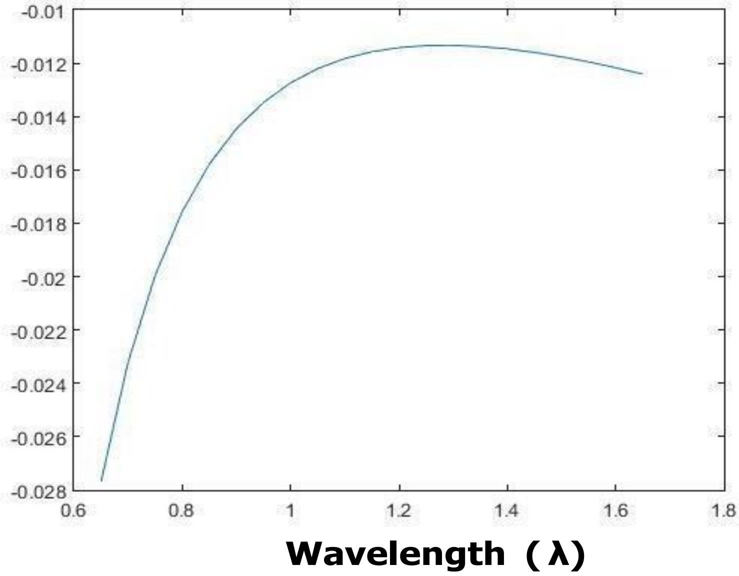


Figure: Wavelength Vs 1st order derivative

2nd order derivative(ns)

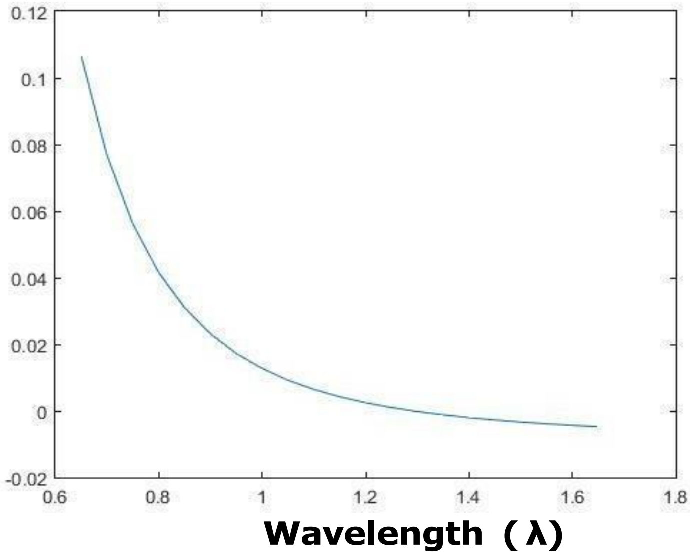


Figure: Wavelength Vs 2nd order derivative

Here , all the plots of different types of Fiber Optics materials are combined altogether. Here it is ---

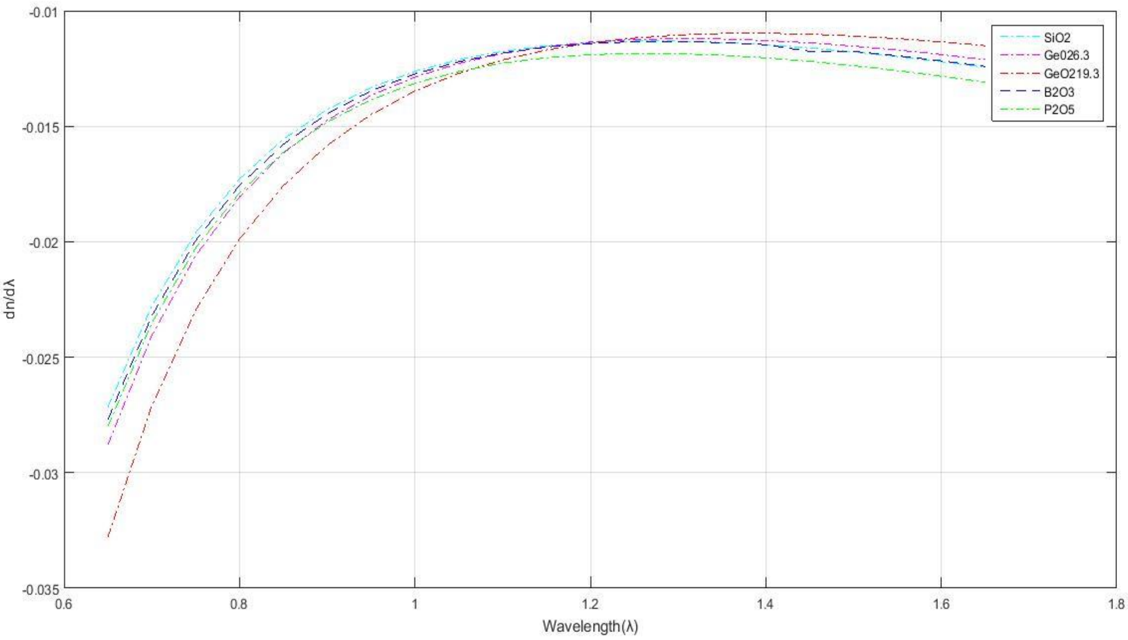


Figure: 1st order plot of five materials

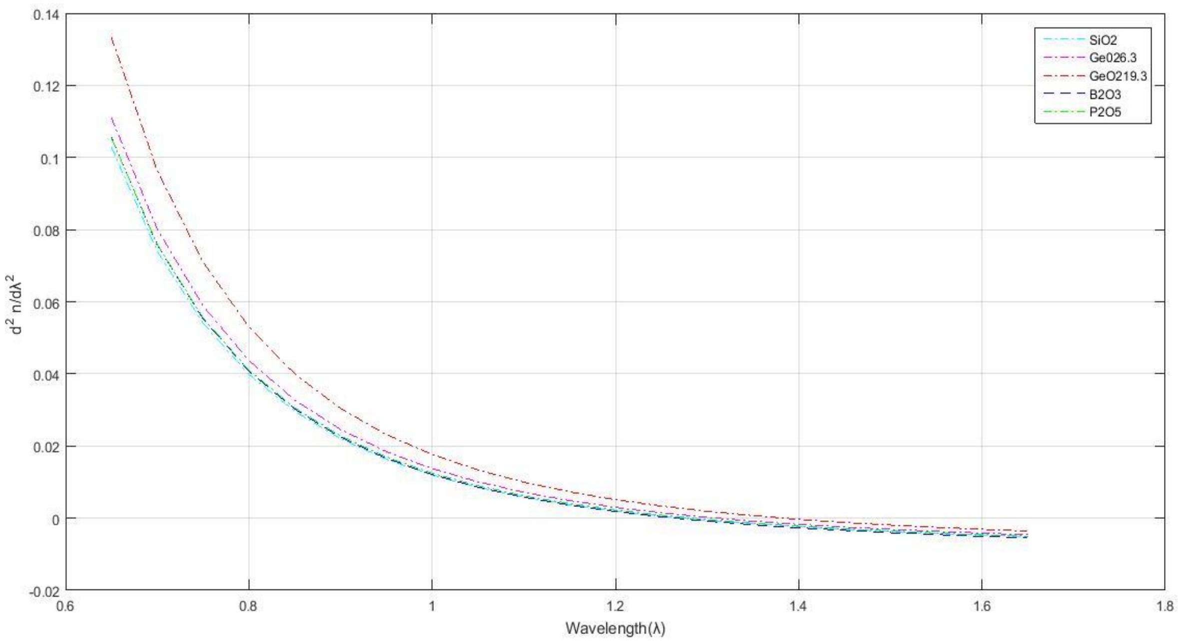


Figure: 2nd Order plot of five materials

(The Curves intercepted the X axis is the ZMDW of corresponding Material.)

Chapter – 5

Result and analysis- II:

5.1 Computation of Fluoride Glass Fiber Materials:

In our study, we moved towards the Fluoride doped fibers. So we studied the nature of these materials. It is found that ZBLAN and ZBG both have a ZMDW at 1.625 μm. The 1.625 μm is enough close to 1.55 μm. We studied another material HBL(a) and ZBL(a)both have a ZMDW at 1.65831 and1.695815 respectively and we have studied another material ABCY found the ZMDW at 1.481 μm. It is also just lower than the target wavelength of 1.55 μm. But it is not the end both the materials has a flat dn/dλ vs λ curve and they are almost at zero material dispersion at 1.55 μm.

Sellemeier coefficient of various fluoride glasses:

Material	$A \times 10^6$	$B \times 10^3$	C	$D \times 10^3$	$E \times 10^6$
ABCY	7.67742	2.169195	1.42969	-1.28304	-5.35487
HBLa	-28.61020	3.11470	1.50294	-1.17821	-2.64123
ZBG	93.67070	2.94329	1.51236	-1.25045	-4.01026
ZBLAa	-300.80370	4.03214	1.51272	-1.21921	-6.77630
ZBLAN	93.67070	2.94329	1.49136	-1.25045	-4.01026

Here, from the table we have collected the values λ of coefficient of Fluoride glass material and put it in the above equation (2)--

and simulate this equation through matlab and got the curve of different optical fibers .

<u>For ABCY material Output data table</u> :

Wavelength(λ)	Refractive Index(n)	$nf=dn/d\lambda$	$ns=d^2n/d\lambda^2$
0.9	1.431328	-0.00831	0.017442
0.95	1.430933	-0.00754	0.013511
1	1.430571	-0.00694	0.010495
1.05	1.430236	-0.00648	0.00815
1.1	1.429922	-0.00612	0.006303
1.15	1.429623	-0.00584	0.004832
1.2	1.429336	-0.00563	0.003648
1.25	1.429059	-0.00547	0.002687
1.3	1.428788	-0.00536	0.001899
1.35	1.428522	-0.00528	0.001248
1.4	1.42826	-0.00523	0.000705
1.45	1.427999	-0.00521	0.00025
1.5	1.427738	-0.00521	-0.00014
1.55	1.427478	-0.00522	-0.00046
1.6	1.42716	-0.00525	-0.00074
1.65	1.426952	-0.0053	-0.00098
1.7	1.426686	-0.00535	-0.00119
1.75	1.426417	-0.00541	-0.00137
1.8	1.426145	-0.00549	-0.00153
1.85	1.425868	-0.00557	-0.00168
1.9	1.425588	-0.00565	-0.0018
1.95	1.425303	-0.00575	-0.00191
2	1.425013	-0.00585	-0.00201

The Output Plot of ABCY materials :

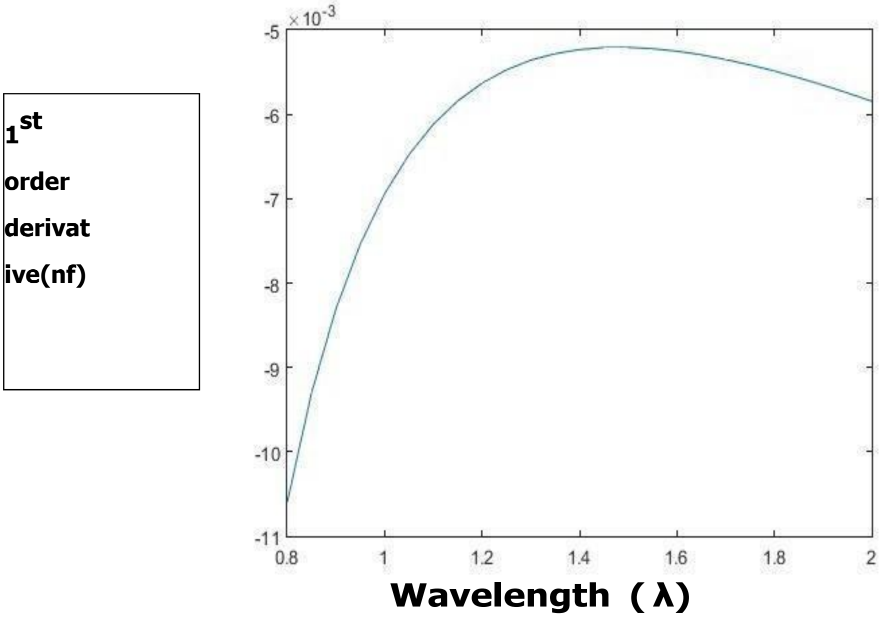


Figure: Wavelength Vs 1st order derivative

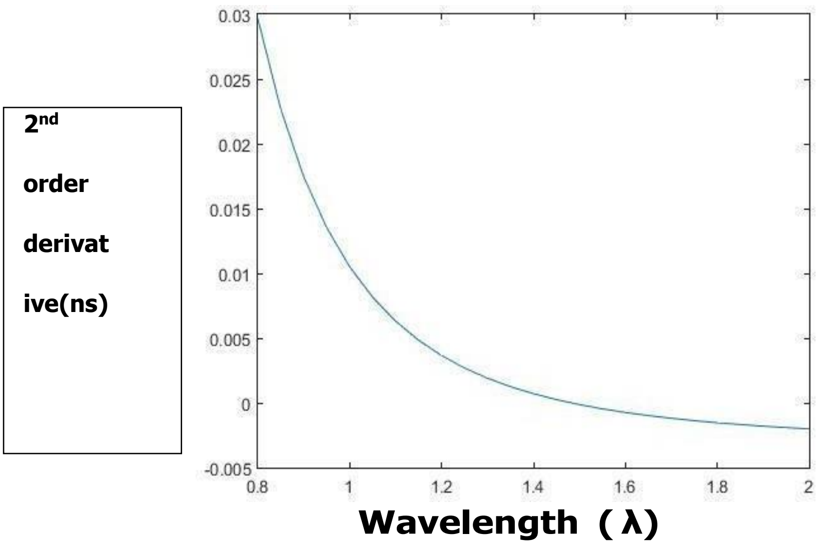


Figure: Wavelength Vs 2nd order derivative

For HBLA material Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/dλ^2$
0.9	1.505786	-0.01048	0.025025
0.95	1.505291	-0.00937	0.019781
1	1.504845	-0.00848	0.015728
1.05	1.504439	-0.00778	0.012556
1.1	1.504065	-0.00722	0.010047
1.15	1.503716	-0.00677	0.008039
1.2	1.503387	-0.00641	0.006419
1.25	1.503074	-0.00612	0.005099
1.3	1.502774	-0.00589	0.004015
1.35	1.502484	-0.00571	0.003118
1.4	1.502202	-0.00558	0.00237
1.45	1.501926	-0.00548	0.001743
1.5	1.501654	-0.0054	0.001214
1.55	1.501386	-0.00535	0.000764
1.6	1.501119	-0.00532	0.00038
1.65	1.500853	-0.00531	0.00005
1.7	1.500587	-0.00532	-0.00023
1.75	1.500321	-0.00534	-0.00048
1.8	1.500053	-0.00537	-0.0007
1.85	1.499784	-0.00541	-0.00088
1.9	1.499513	-0.00545	-0.00105
1.95	1.499239	-0.00551	-0.0012
2	1.498962	-0.00557	-0.00132

The Output Plot of HBLA materials

Wavelength (λ)

1^{st} order derivative (nf)

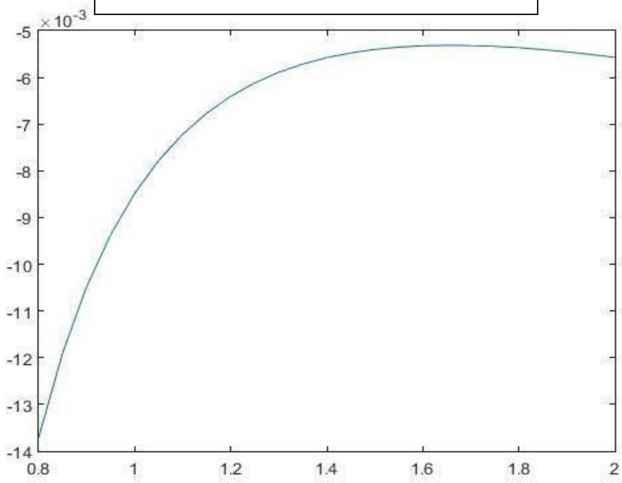


Figure: Wavelength Vs 1^{st} order derivative

Wavelength (λ)

2^{nd} order derivative (ns)

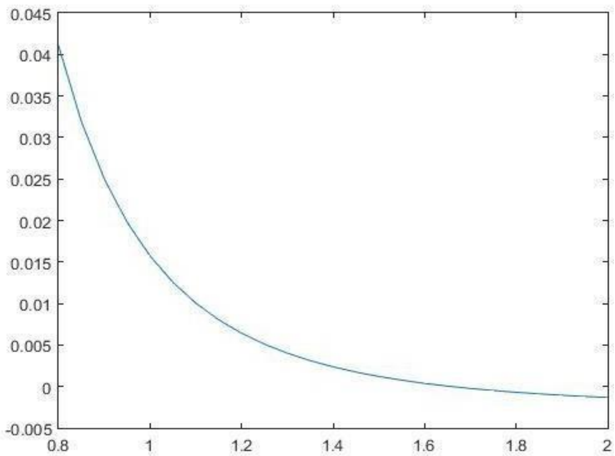


Figure: Wavelength Vs 2^{nd} order derivative

For ZBG material Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/d\lambda^2$
0.9	1.515121	-0.01097	0.027902
0.95	1.514604	-0.00974	0.021686
1	1.514143	-0.00878	0.016984
1.05	1.513723	-0.00802	0.013373
1.1	1.513338	-0.00743	0.01056
1.15	1.512978	-0.00696	0.008342
1.2	1.51264	-0.00659	0.006574
1.25	1.512318	-0.00629	0.005148
1.3	1.51201	-0.00607	0.003989
1.35	1.511711	-0.00589	0.003038
1.4	1.51142	-0.00576	0.002251
1.45	1.511134	-0.00567	0.001594
1.5	1.510853	-0.0056	0.001044
1.55	1.510574	-0.00556	0.000578
1.6	1.510297	-0.00554	0.000182
1.65	1.51002	-0.00554	-0.00016
1.7	1.509742	-0.00556	-0.00045
1.75	1.509464	-0.00558	-0.0007
1.8	1.509184	-0.00562	-0.00092
1.85	1.508901	-0.00568	-0.00111
1.9	1.508616	-0.00574	-0.00128
1.95	1.508328	-0.0058	-0.00143
2	1.508036	-0.00588	-0.00156

<u>The Output Plot of ZBG materials :</u>

Wavelength (λ)

1^{st} order derivative(nf)

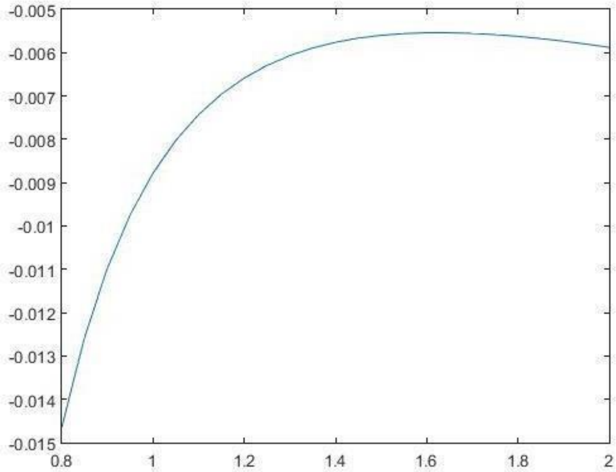


Figure: Wavelength Vs 1^{st} order derivative

Wavelength (λ)

2^{nd} order derivative(ns)

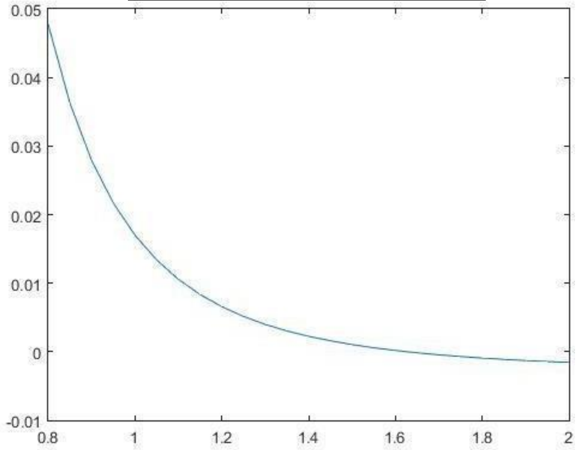


Figure: Wavelength Vs 2^{nd} order derivative

For ZBLAa material Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/d\lambda^2$
0.9	1.516247	-0.01124	0.023049
0.95	1.515713	-0.01019	0.019007
1	1.515225	-0.00933	0.015657
1.05	1.514777	-0.00862	0.012886
1.1	1.514362	-0.00803	0.010591
1.15	1.513973	-0.00755	0.008685
1.2	1.513605	-0.00716	0.007097
1.25	1.513256	-0.00684	0.005767
1.3	1.512921	-0.00658	0.004648
1.35	1.512597	-0.00637	0.003703
1.4	1.512283	-0.0062	0.002901
1.45	1.511976	-0.00608	0.002216
1.5	1.511675	-0.00598	0.001629
1.55	1.511378	-0.00591	0.001124
1.6	1.511084	-0.00587	0.000686
1.65	1.510791	-0.00584	0.000306
1.7	1.510499	-0.00584	-2.6E-05
1.75	1.510207	-0.00584	-0.00032
1.8	1.509914	-0.00587	-0.00057
1.85	1.50962	-0.0059	-0.0008
1.9	1.509324	-0.00595	-0.001
1.95	1.509026	-0.006	-0.00118
2	1.508724	-0.00606	-0.00135

<u>**The Output Plot of ZBLAa materials :**</u>

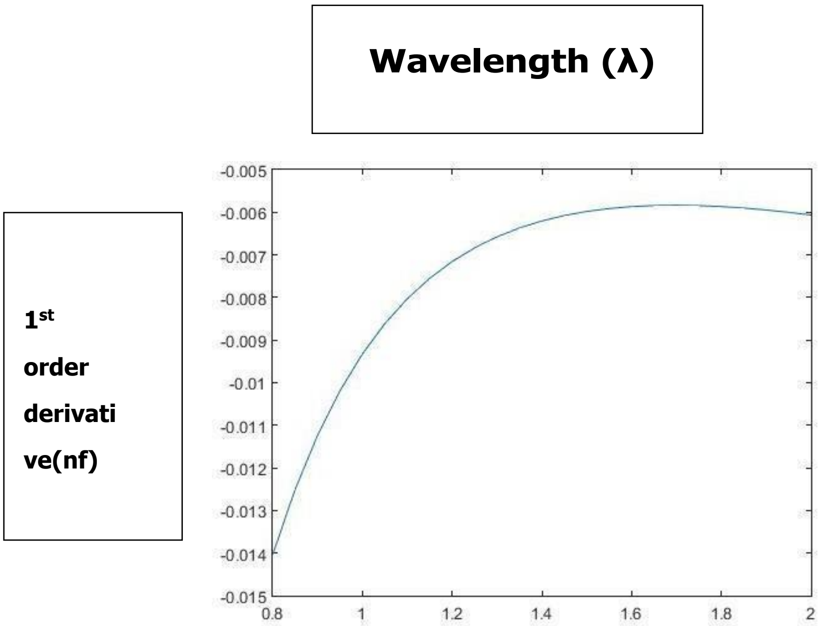


Figure: Wavelength Vs 1st order derivative

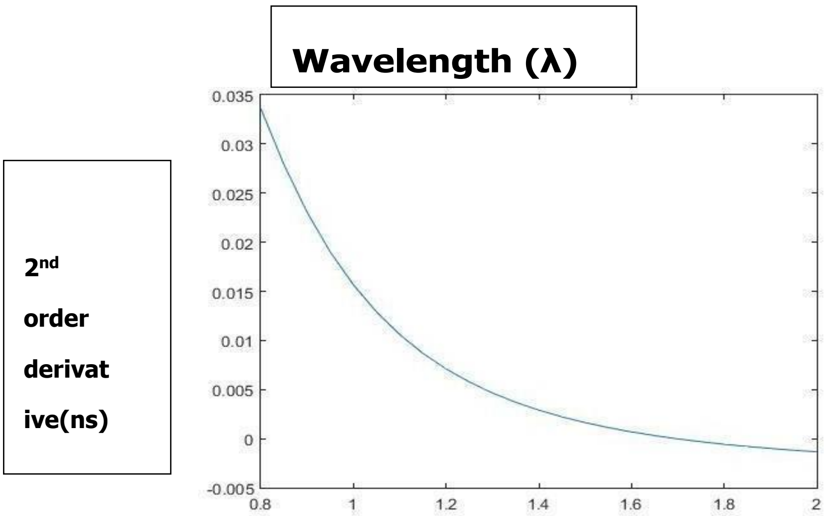


Figure: Wavelength Vs 2nd order derivative

For ZBLAN material Output data table :

Wavelength(λ)	Refractive Index(n)	nf=dn/dλ	ns=$d^2n/d\lambda^2$
0.9	1.494121	-0.01097	0.027902
0.95	1.493604	-0.00974	0.021686
1	1.493143	-0.00878	0.016984
1.05	1.492723	-0.00802	0.013373
1.1	1.492338	-0.00743	0.01056
1.15	1.491978	-0.00696	0.008342
1.2	1.49164	-0.00659	0.006574
1.25	1.491318	-0.00629	0.005148
1.3	1.49101	-0.00607	0.003989
1.35	1.490711	-0.00589	0.003038
1.4	1.49042	-0.00576	0.002251
1.45	1.490134	-0.00567	0.001594
1.5	1.489853	-0.0056	0.001044
1.55	1.489574	-0.00556	0.000578
1.6	1.489297	-0.00554	0.000182
1.65	1.48902	-0.00554	-0.00016
1.7	1.488742	-0.00556	-0.00045
1.75	1.488464	-0.00558	-0.0007
1.8	1.488184	-0.00562	-0.00092
1.85	1.487901	-0.00568	-0.00111
1.9	1.487616	-0.00574	-0.00128
1.95	1.487328	-0.0058	-0.00143
2	1.487036	-0.00588	-0.00156

The Output Plot of ZBLAN materials :

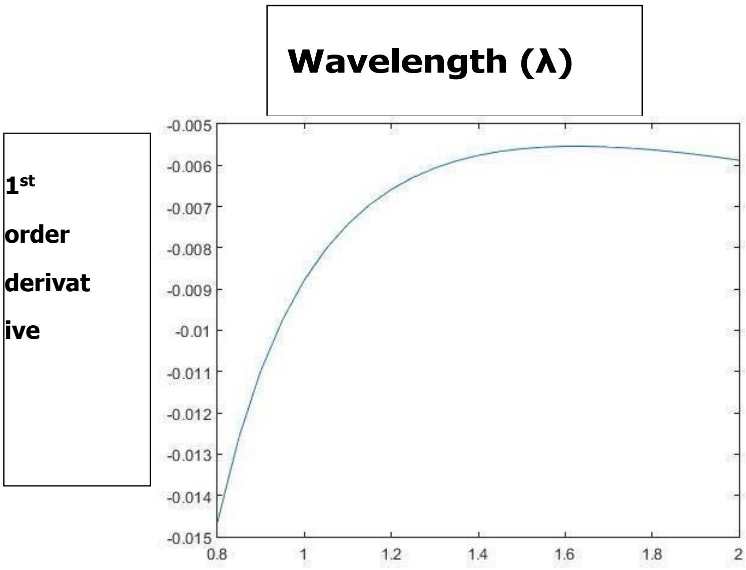


Figure: Wavelength Vs 1st order derivative

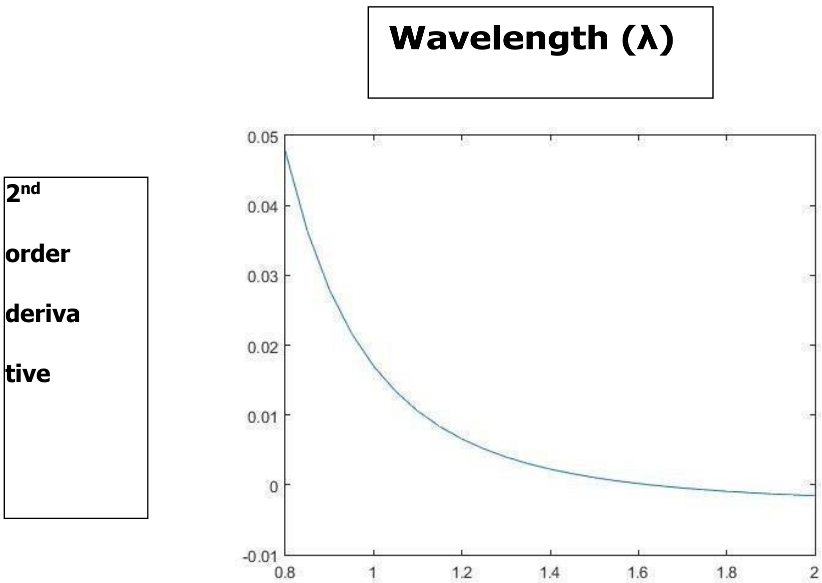


Figure: Wavelength Vs 2nd order derivative

Here, all the plots of different types of Fiber Optics materials are combined altogether . Here it is ---

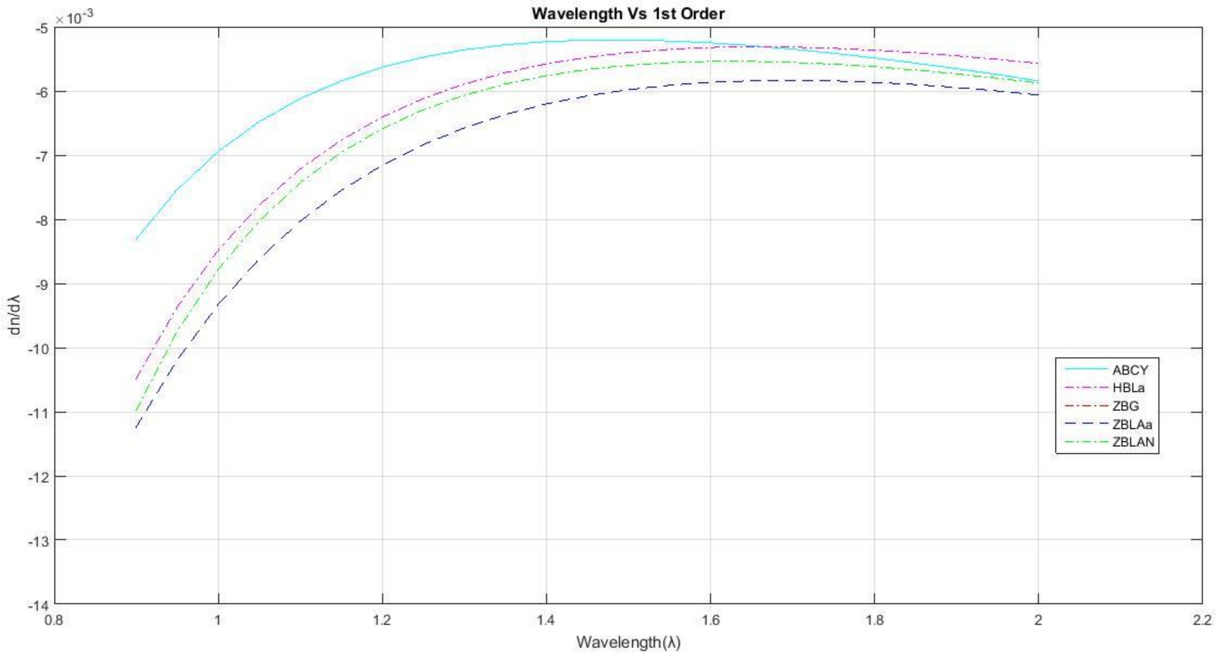


Figure: 1^{st} order plot of five Fluoride materials

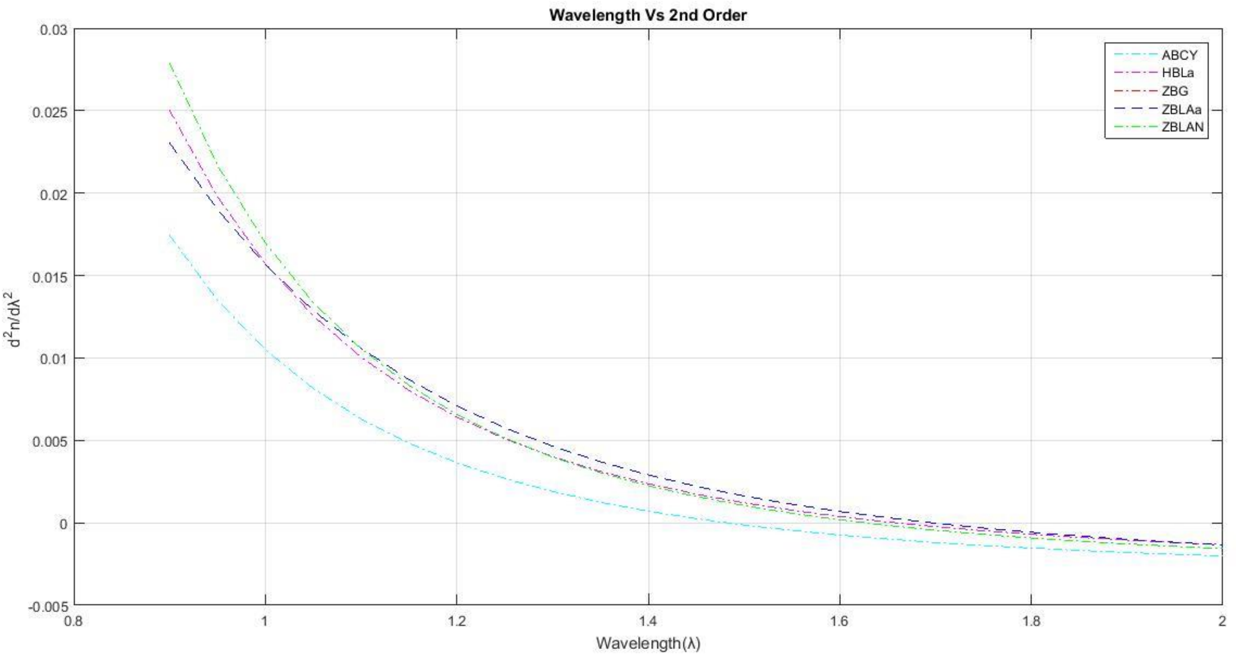


Figure: 2^{nd} Order plot of five Fluoride material

(The Curves intercepted the X axis is the ZMDW of corresponding Material.)

Various Fluoride glasses for application in infrared fiber optic communication :

Concentration (mole %)

material	ZrF4	BaF2	LaF3	NaF	HfF4	AIF3	CaF2	GdF3	YF3
ABCY		**22**				**40**	**22**		**16**
HBL		**33**	**5**		**62**				
ZBG	**63**	**33**						**4**	
ZBLAN	**53**	**20**	**4**	**20**		**3**			

Zero Material Dispersion Wavelength Of Different material :

Materials	ZMDW
Pure SiO2	1.272
B2O3(5.2)	1.264
GeO2(6.3 and 19.3)	1.309 and 1.383
P2O5(10.5)	1.282
ABCY	1.481
HBL(a)	1.658
ZBG	1.625
ZBLA(a)	1.695
ZBLAN	1.625

CHAPTER - 6

Conclusion :

Conventional doped silica fibers have Zero Material Dispersion at 1.27μm Wavelength. But the conventional minimum loss is at 1.55 μm Wavelength.

1. We observed GeO_2 doping moves ZMDW closer to 1.55 μm wavelength at 1.383 μm.
2. The fluoride materials ABCY and ZBLAN has ZMDW at 1.481 μm and 1.625 μm Wavelength, which are too closer to minimum loss wavelength.
3. We observed B_2O_3 and P_2O_5 both doping move ZMDW at 1.264μm and 1.282μm wavelength not closer to 1.55μm.
4. The fluoride materials HBL(a),ZBG and ZBLA(a) has ZMDW at 1.658 μm,1.625μm and 1.695μm wavelength, which are too closer to minimum loss wavelength.
5. The study of dn/dλ vs λ curve shows flatness of the curves at ZMDW for the above materials between their ZMDW and 1.55μm respectively.
6. Small change in wavelength in this region, will not destruct the balance between the ZMDW and minimum loss wavelength which should provide flexibility of the transmission wavelength and allow the low cost lasers to act as source.

FUTURE SCOPE OF WORK

From our study, we have decided the small change in wavelength will not destruct the balance between ZMDW and minimum loss wavelength which provides flexibility of transmission wavelength and low cost laser act as a source .

So , in future we will work with this type of low cost materials and hope will get good result in our study .

ACKNOWLEDGEMENT

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REFERENCES :

1. A. Ghatak and K. Thyagarajan, “Introduction to Fiber Optics”, Cambridge University Press, 1998.

2. T.Okoshi, “Optical Fibers”, Academic Press.1982. New York.

3. S. Mitachi, "Dispersion measurement on fluoride glasses and fibers", Lightwave Technology Journal of, vol. 7, no. 8, pp. 1256-1263, 1989.

4. Govind P. Agrawal, Nonlinear Fiber Optics, 3rd ed. (Academic Press, San Diego, CA, USA, 2001)

5. T. Miyashita, T. Manabe, "Infrared Optical Fibers", Microwave Theory and Techniques IEEE Transactions on, vol. 30, no. 10, pp. 1420-1438, 1982

6. S. E. Mechels, J. B. Schlager, and D. L. Franzen, “Accurate Measurements of the Zero-Dispersion Wavelength in Optical Fibers”, Journal of Research of the National Institute of Standards and Technology, 102 (3), 1997, 333- 347.

7. G. Pan, N. Yu, B. Meehan, T. W. Hawkins, J. Ballato, and P. D. Dragic “Thermo-optic coefficient of B2O3 and GeO2 co-doped silica fibers” Optical Materials Express Vol. 10, Issue 7, (2020) 1509-1521.

8. Takashi Harada et.al." Effect of B2O3 Addition on the Thermal Stability of Barium Phosphate Glasses for Optical Fiber Devices", Journal of the American Ceramic Society 87(3) 2008, 408 – 411.

9. E. D. Palik, Handbook of Optical Constants of Solids, Academic Press, New York (1985).

10. F. Gan, "Optical properties of fluoride glasses: a review," J. Non-Cryst. Solids, Vol. 184, (1995) 9-20.

11. Kimura T "Basic concepts of the optical waveguide. Optical Fiber Transmission". Ed. K. Noda. North Holland Studies in Telecommunication, 6, North Holland, Amsterdam. 1986.

12. C. Jauregui, J. Limpert, and A. Teunnermann, "High- power fibre lasers," Nature. Photonics 7, 861 (2013).M.
E. Fermann and I. Hartl, Nat. Photonics 7, 868(2013).

13. M. Zervas and C. Codemard, "High Power Fiber Lasers: A Review," IEEE J. Sel. Top. Quantum Electron. 20, 219 (2014).

14. Pinnow D.A., Dabby F.W., Camlibel I., Warner A.W., Van Uitert L.G. "Preparation of high purity silica Material". Research Bulletin, 10, (1975) 1263-1266.

15. Kirchhof J., Unger S., Knappe B. "Fluorine containing high-silica glasses for speciality optical fibers." Advanced Materials Research, 39-40, (2008), 265-268.

16. Carson S.D., Maurer R.D. "Optical attenuation in Ti- silica glasses"., Journal of Non-Crystalline Solids, 11, (1973),368-380.

17. Kamradek M.,Kasik I.,Peterka P.,Aubrecht J.,Honzatko P.,Podrazky O.,Mrazek J.,Kubecek V."Silica-and germanate-based glasses doped with rare-earth elements for photonics devices".In: Proc.25th International Congress onGlass,(2019),Boston.