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Preparation and Properties of Optical Fibre Glass for Communication

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Abstract— Optical fiber communication technology is fastest growing technology in the field of communication. This is mainly due to low transmission losses and low attenuation losses of the signal which has prime importance in the field of communication. Optical fiber uses glass as a core and cladding materials for transmission of the signal. Glasses used for the optical fiber should have low transmission and absorption losses and it should possess high chemical durability. The borosilicate glasses provides most of these properties so borosilicate glasses are used as a core and cladding of the optical fiber cable.
So in this study an attempt has been made for higher transmission capability, low absorption losses and to improve chemical resistant as well as mechanical properties. For completion of these properties four types of reference glasses were taken. The first series had variation of molar ratio of Na_2O/SiO_2, the second series had a variation of Al_2O_3/SiO_2, the third series had variation of ZrO_2/SiO_2 and the third series had the variation of Na_2O/SiO_2 along with doping of Gd_2O_3 and Y_2O_3. The samples were prepared through traditional melt technique with the help of an electric rod furnace. The prepared samples were characterized for density, chemical durability through ISI powder test method, structural analysis was carried out through FTIR spectrophotometry and compressive strength were also investigated.
Keywords— Optical fiber, chemical resistant, FTIR

I. INTRODUCTION

The optical fiber cable is used for transmitting signals with the help of electromagnetic waves in the range of optical frequency. Optical fiber cable are acclaimed as an alternative to copper cables wherever there is severe electromagnetic interference, in open-air systems the equipotential bonding is to be saved or where no electromagnetic radiation is wanted. Glass optical fiber cables are used for longer paths to construct optical network structures while for shorter paths plastic optical fiber cables are used and light-conducting plastics are used for these plastic cables and such as polymer optic fiber (POF) or polymer cladded fiber (PCF).

An optical fiber is a transparent, flexible fiber made of high quality extruded glass (silica) or plastic, somewhat thicker than a hair of human. It can function as a waveguide, or light pipe to transmit light between the two ends of fiber. In fiber-optic communications optical fibers are widely used, where they permit transmission over long distances and at high bandwidths than the simple wire cables. Fibers are used instead of metal wires because signals travel along the axis of fiber with low loss and are also immune to electromagnetic interference. Fibers are wrapped in bundles and used for illumination and they may be used to convey images, thus allowing viewing in limited spaces and for a variety of other applications like sensors and fiber lasers specially designed fibers are used. The demands for high-speed optical communications are increasing at a terrific rate. In order to satisfy this need for information flow over short and long distance networks, a more efficient use of available communication channels is required. There are three aspects to the development of new optical materials. First is the identification of glass compositions suitable for fiberization. Most widely used optical material is Glass and it contributes more than 90 percent of all manufactured optical elements. Usually for optical systems designers, glass has been the material of choice owing to its high transmittance, high degree of homogeneity, ease of moulding, shaping, machining and the wide variety of index and dispersion characteristics and relatively low cost. Optical fiber using glass should possess higher chemical durability as chemical durability is the ability of glasses to resist partial or total reaction with aqueous and atmospheric environments. A glass of high durability reacts only slightly with its environment, while glasses of low durability react very voluntarily.

In the present work, we characterized a high content borosilicate glass and compared them with the classical chemical composition and the objective of the present study was to analyze the effect of silica content change on the chemical durability and to increase the transmittance and reduce the absorbance of the glass. As high silica content has a tendency to improve glass-network interconnectivity and increase chemical resistance of glass by increasing the ratio of bridging oxygen and non-bridging oxygen. The relative percentage of non-bridging oxygen ions present in a glass structure determines its chemical durability. Generally, if a glass has a high percentage of non-bridging oxygen present (number of non-bridging Oxygen = number of alkali ions), the glass will

exhibit poor durability, however the percentage of non bridging oxygen is low (low alkali, high silica), the glass will have less tendency to corrode.

In the area of optical fibers the research efforts are concerned with two main directions: finding some materials with superior features and applying some modern technologies able to result in products with high quality features, at very convenient prices. Regardless of the chosen composition the dielectric material used to obtain optical fibers must have a very good transparency for the wave length of the light signal used and to have good chemical stability in time as possible as. Although such a silica fiber glass was also prepared that keeps low losses and possessing veryhigher transparency of electromagnetic radiation up to 2μm wavelength region, but above that region of wavelength it possesses again losses. Then in 1897 Rayleigh describe the concept of hollow waveguide. The almost losses occur in light transmission through the glass due to glass material, so if there is an air core through which light signal passes then there will be no any loss due to glass material. In order to be transparent in the mid infrared region, the multiphonon absorption edge of a material must lie at a longer wavelength than it does in traditional oxide glasses.

In optical fiber glass to increase the transmittance and in order to obtain active fibers and also to increase the refractive index doping of rare earth materials are used and in present dissertation doping of ZrO_2,Y_2O_3 and Gd_2O_3 has been done. For total internal reflection (TIR) to be occurring in hollow air core waveguide the refractive index of clad material must be less than one. It is possible in infrared region, not in visible region of wavelength.

Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower refractive index and light traveled through core by total internal reflection. This causes the fiber to act like a waveguide. The single -mode fibers are those fibers that support only to a single mode and fibers that support many propagation paths or transverse modes are called multi-mode fibers and are used for short-distance communication links and generally they have a wider core diameter and for applications where high power must be conveyed and for most communication links longer than 1,000 meters (3,300 ft.) Single-mode fibers are used.

II. LITERATURE REVIEW

Guiding of light by refraction, the principle that makes fiber optics possible, was first revealed by Jacques Babinetin and Daniel Colladon in Paris in the early1840s [1]. 12 years later John Tyndall included a demonstration of it in his public addresses in London. Tyndall also wrote about the property of total internal reflection in an introductory book about the nature of light in 1870.In the twentieth century Practical applications such as close internal illumination for the duration of dentistry appeared. Image transmission through tubes was demonstrated independently by the radio experimenter Clarence Hansell and the television pioneer John Logie Baird in the 1920s.

Alexander Graham Bell and Sumner Tainter discovered the Photo phone to transmit voice signals over an optical beam at Volta Laboratory in Washington, D.C., in 1880. It was a cutting-edge of communications, but it was unrealistic until the safe transport of light that would be offered by system of optical fiber subjected to atmospheric interferences. Light was guided through bent glass rods to illuminate body cavities [2] .In the late 19th and early 20th centuries. In 1963 a Japanese scientist Jun-ichi Nishizawa, at Tohoku University proposed the use of optical fibers for communications, as stated in his book published in 2004 in India. English scientist Charles K. Kao and George Hockham proposed optical fibers at STC Laboratories Harlow England [3], when they exhibited that the losses of 1000 dB/km in existing glass (compared to 5-10 dB/km in coaxial cable) was due to impurities, which could possibly be removed. Optical fiber was magnificently developed by Corning Glass Works in 1970 with attenuation low enough for communication purposes (around 20dB/km), and GaAs semiconductor lasers were developed at that time and that were compact and therefore suitable for light transmitting through optical fiber cables for long distances.

Glass is an amorphous solid (non-crystalline) material that exhibits a glass transition, which is the revocable transition in amorphous materials (or in amorphous regions within semi crystalline materials) from a hard and relatively brittle state into a molten state. Glasses are typically brittle in nature and can be optically transparent. Point defects and structural imperfections are more important in crystals than in glasses, although as set out above topological defects can also exist in glasses. Impurity atoms and molecules are a problem in both crystals and glasses. In particular, rare earth (RE) and transition metals (TM) ions are of great concern because of the ability of *f* electrons and *d* electrons to absorb efficiently at wavelengths inside the optic window. The RE resonances are numerous, but each is fairly well localized in energy even in a glass because the *f* electrons are well shielded from the bonding environment, which determines the nature of the electron distribution for outer electrons. Specific RE resonances can therefore often be avoided by a judicious choice of the transmission wavelength .The same is not

Silica glass can be doped with various materials. One purpose of doping can be to raise the refractive index (e.g. with GeO_2 or Al_2O_3) or to lower it (e.g. with fluorine or B_2O_3). Doping is also possible with laser-active ions (→ rare-earth-doped fibers) in order

to obtain active fibers, to be used e.g. in fiber amplifiers or fiber lasers. The fiber core and sometimes the fiber cladding are doped, so that the material is effectively e.g. an aluminosilicate, germanosilicate, phosphosilicate or borosilicate glass**.** So this dissertation will focus only on minimization of attenuation and as we know that for the low attenuation, chemical durability of the glass is an important parameter. The chemical durability in the optical fiber should be as high as possible so that more and more signal is received at the receiver side.

III. EXPERIMENTAL PROCEDURE

A. Composition And Preparation Of Glass Samples

Composition of samples and sample codes are given in following table 1.

Table 1

Sample Code	SiO_2 `(Wt.%)	Na_2O `(Wt.%)	B_2O_3 `(Wt.%)	Al_2O_3 `(Wt.%)	ZrO_2 `(Wt.%)	Gd_2O_3 `(Wt.%)	Y_2O_3 `(Wt.%)
A0	74	16	10				
A1	72	18	10				
A2	70	20	10				
A3	68	22	10				
B0	71.5	16	10	2.5			
B1	73	15	9	3			
B2	74.5	14	8	3.5			
B3	76	13	7	4			
C0	72.5	16	10		1.5		
C1	72.5	15.5	10		2		
C2	72.5	15	10		2.5		
C3	72.5	14.5	10		3		
D0	69.5	16	10			1.5	1
D1	71.5	14	10			1.5	1
D2	73.5	12	10			1.5	1
D3	75.5	10	10			1.5	1

Principle constituents are 72% SiO_2, 18 % Na_2O, 10 % B_2O_3 and doping of ZrO_2, Yttrium and Gadolinium to be done. Raw materials as AR grade Quartz, calcium carbonate, calcium fluoride, sodium carbonate, potassium carbonate, magnesium oxide, boric acid and alumina were taken as batch chemicals and homogeneously mixed in the mortar (bowl) with the help of pestle. Homogeneous mixture is transferred into an alumina crucible and it is placed into the glass melting furnace up to the melting point of the glass which is 1400ºC and hold for 3Hrs. The temperature in the furnace was maintained constant with an automatic temperature indicator cum controller within +/- 10 ^{0}C. The melting of glass at 1400 ^{0}C was performed for nearly about 3 hours. Now casting of the glass into the rectangular mould on the preheated alumina plate and it is placed into the annealing furnace at the 500ºC for 1 hr. to remove the stress and strain in the glass and left for cooling up to room temperature. After that cutting, grinding and polishing operations are performed and go for characterization.

B. Measurement and characterization technique

1) *Chemical Durabili Measurement:* According to Morey " the resistance which glass offers to the corroding action of water, of atmospheric agencies(primary water and carbon dioxide) and of aqueous solution of acid, bases and salt is a property of great physical significance an**ty**d is denoted by the term "chemical durability". The subject of chemical durability of glass or its resistance to weathering is recognized as the most important property in glass technology. The glass is used in large proportions comparative to other competing materials. The chief reason of its preference over other article is only the resistance of such attacks. An example is the use of glass container of which enormous numbers are used for keeping of different commodities ranging from milk to medicines and acids. In this field the superiority of glass leaves it without a competitor. For the measurement of chemical durability ISI powder test method has been followed.

a) ISI TEST: In this test 5 gm. glass powder (-25 +36 mesh) is reacted with 100 ml double distilled water at 100°C for half an hour in a chemically resistant conical flask of 250 ml capacity, filled with reflux condenser. The test was performed as per schedule and the alkali extracted was titrated against N/100 HCL. The chemical attack of glass is measured in terms of volume of N/100 HCL required to neutralize the extracted alkali.

2) *Fourier transforms infra-red (FTIR) spectroscopy:* Fourier transform infrared spectroscopy (FTIR) [7] is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. The goal of any absorption spectroscopy is to measure how well a sample absorbs light at each wavelength. Infrared bands in the spectra at different wavelengths are given in table 2.

Table 2. Infrared bands in the spectra

Wavenumber(cm-1)	Functional Group
400-500	Si-O-Si (bend)
500-560	P-O (bend) (crystalline)
560-600	P-O (bend) (amorphous)
720-840	Si-O-Si (tetrahedral)
860-940	Si-O (stretch)
1000-1100	Si-O-Si (stretch)
1100-1200	P-O (stretch)
1200-1300	B–O bond stretching vibrations
1400-1530	C-O (stretch)
2100-2360 2700-3000	Si-H Hydrogen bonding
3000-3700	O-H (stretch)

3) *Density Measurement of glass samples:* The density of a body is the ratio of the weight of the body to that of an equal volume of the water displaced by that body. While selecting the material for the determination of the specific gravity or density, it is necessary to obtain the sample as pure as possible.

Density of the glass samples would be calculated by Archimedes' principle.

Archimedes' principle - It states that the upward buoyant force exerted on a body immersed in a fluid is equal to the weight of the body displaces. It is calculated by following formula.

$$\rho = \frac{w_a}{(w_a - w_b)} \rho_b$$

Where w_a is the weight of sample in air, w_b is the weight of sample in buoyant and ρ_b is the density of buoyant.

4) *Compressive strength measurement of glass samples:* Compressive strength can be determined by the following formula:

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$\sigma = F/A$

Where, F = Load applied [N]

A = Area [m^2]

In the study of strength of materials, the compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures.

Compressive strength is often measured on a universal testing machine; these range from very small table-top systems to ones with over 53 MN capacities [8]. Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard.

IV. RESULTS AND DISCUSSION

A. *Chemical Durability Measurement*

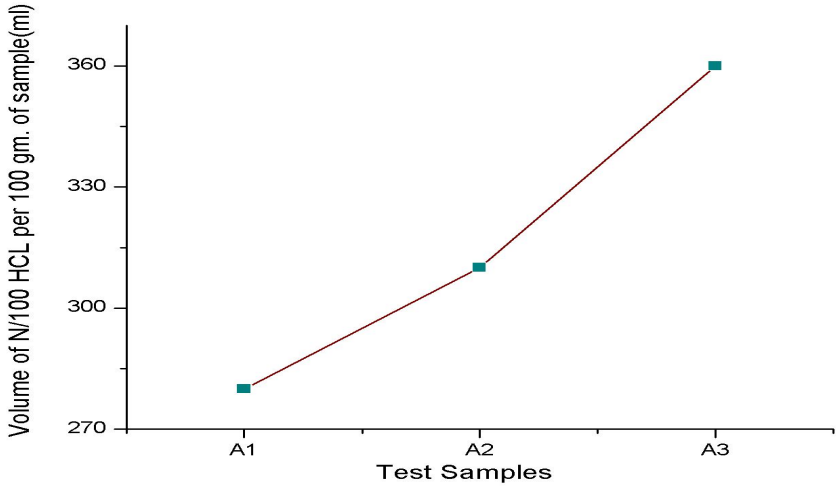

Figure 1: Chemical Durability of Type A Glass

Description: Figure 1. shows that as weight percentage of Na_2O increases and weight percent of SiO_2 decreases the consumption of volume of N/100 HCL increases because Na_2O acts as network modifier so it forms bond with non-bridging oxygen but its bond strength will be week because of lower valancy of Na_2O due to that leachability increases and chemical durability of the glass decreases.

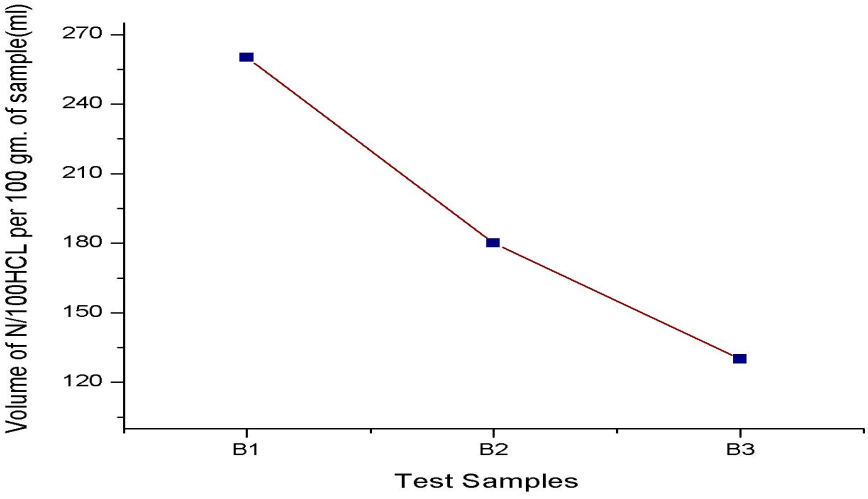

Figure.2: Chemical Durability of Type B Glass

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Description: Figure 2. Shows that as weight percentage of Al_2O_3 increases the consumption of volume of N/100 HCL reduces because Al_2O_3 acts as network formers along with SiO_2 and it provides strength to the glass networks also some amount of Al_2O_3 acts as a network modifier where it forms bonds with the non-bridging oxygen. Due to its high valancy its bonds strength is higher so leachability decreases which ultimately enhances the chemical durability.

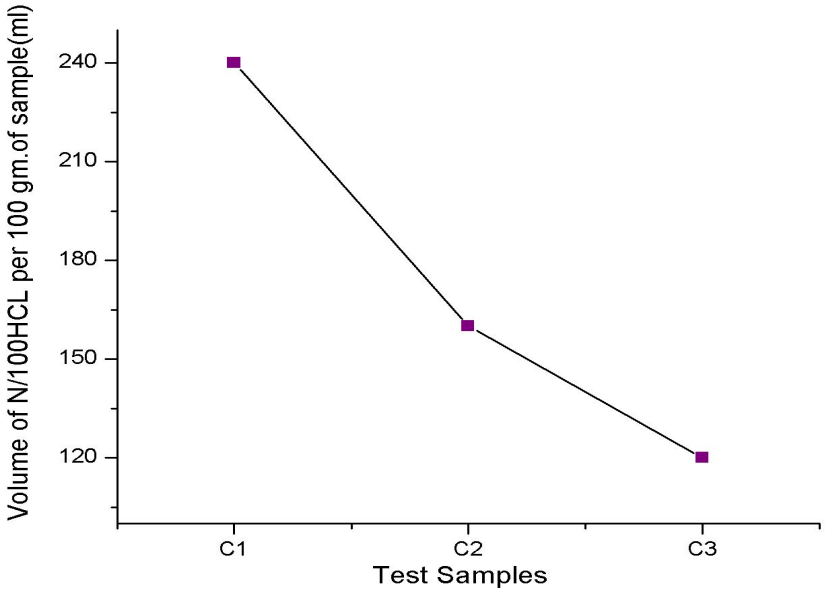

Figure.3: Chemical Durability of Type C(ZrO_2 doped) Optical Fiber Glass

Description: Figure 3. Shows that as weight percentage of ZrO_2 increases the consumption of volume of N/100 HCL decreases. As it has been mentioned earlier that rate of alkali extraction decreases when parts of SiO_2 is replaced by any other divalent oxides. Some of these divalent oxides like Magnesia, Lime and Zinc oxides are most effective. ZrO_2 yields even more resistant glass and hence chemical durability of glass increases

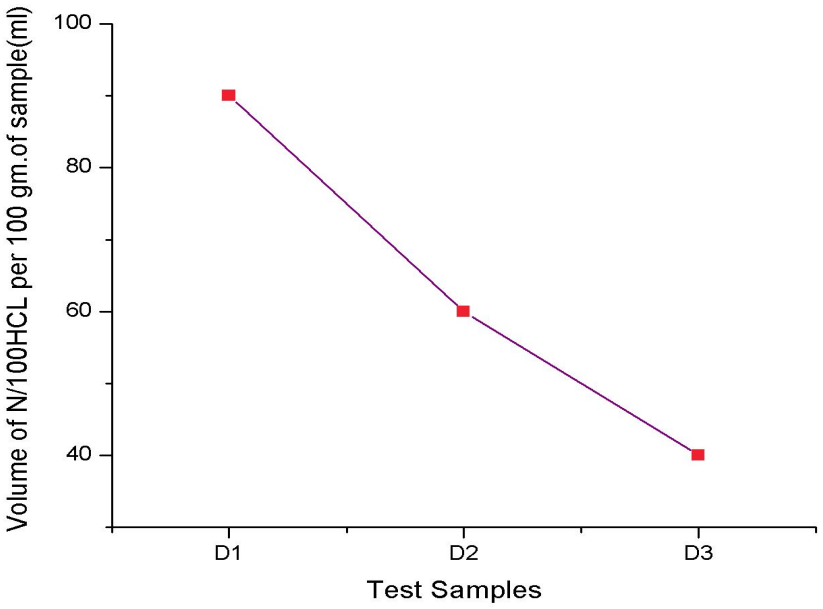

Figure.4: Chemical durability of type D (Gd_2O_3 & Y_2O_3doped) Optical Fiber Glass

Description: Figure 4. Shows that chemical durability of the glass increases due to increase in content of SiO_2 and decrease in

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content of Na_2O. Due to decrease in content of Na_2O rate of alkali extraction decreases so chemical durability of the glass increases.

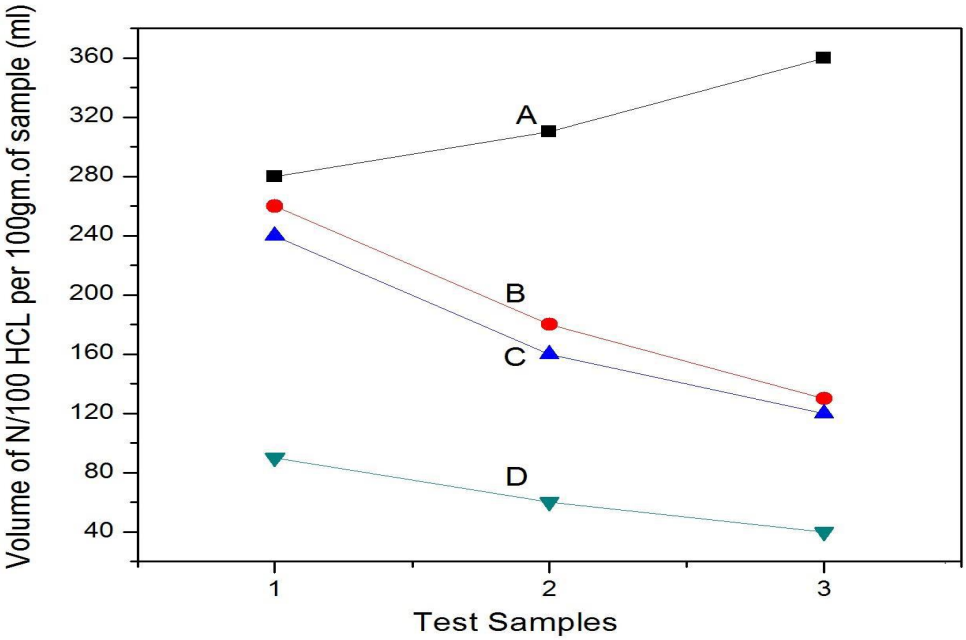

Figure.5: Comparative Chemical durability graph of all type A, B, C and D glass samples

Description: Figure 5. Shows that chemical durability is increases for ZrO_2 doped optical fiber glass and it is maximum for Gd_2O_3 & Y_2O_3 doped optical fiber glass.

B. FTIR Spectroscopy Analysis

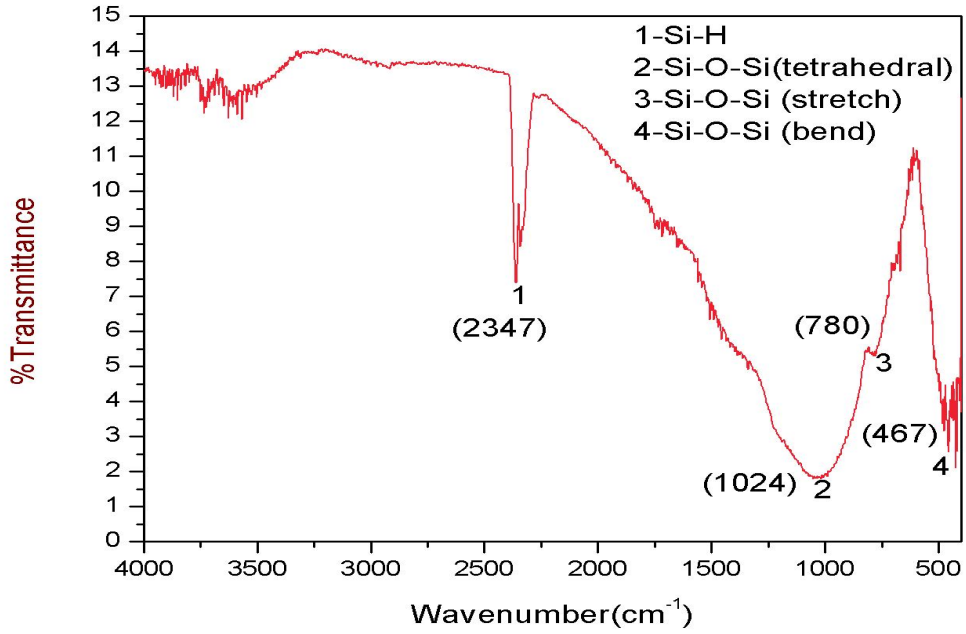

Figure .6: FTIR spectra of A1 glass sample

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Description: The absorption band around 2347cm^{-1} shows Si-H bond, 1024 cm^{-1} shows Si-O-Si(stretch) bond,780 cm^{-1} shows Si-O-Si(tetrahedral) and wave number 467 cm^{-1} shows Si-O-Si (bend) bonding as shown in figure 6.

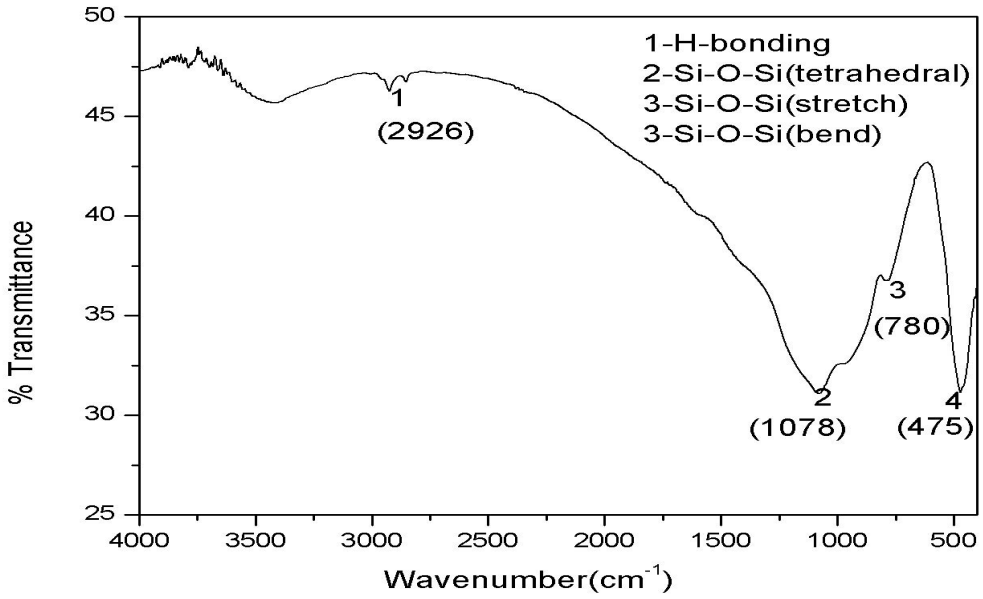

Figure 7: FTIR spectra of A2 glass sample

Description: The absorption band around 2926 cm^{-1} shows H- bond, 1078cm^{-1} shows Si-O-Si (stretch) bond, 780 cm^{-1} shows Si-O-Si (tetrahedral) bond and 475 cm^{-1} shows Si-O-Si (bend) bonding as shown in figure 7.

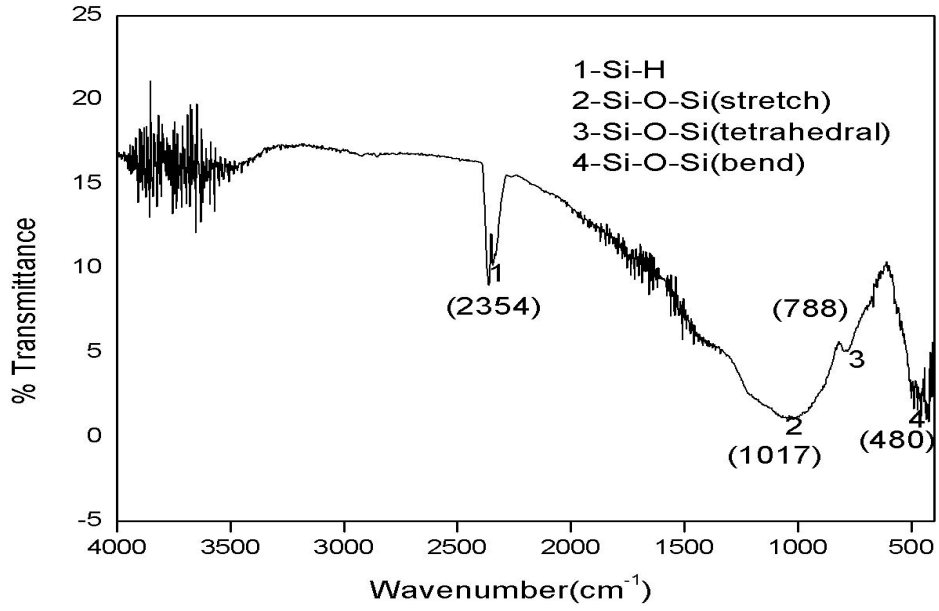

Figure 8: FTIR spectra of B1 glass sample

Description: The transmittance band around 2354cm^{-1} shows Si-H bond, 1017cm^{-1} shows Si-O-Si (stretch) bond, 788 cm^{-1} shows Si-

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O-Si (tetrahedral) bond and 480 cm^{-1} shows Si-O-Si (bend) bonding as shown in figure 8.

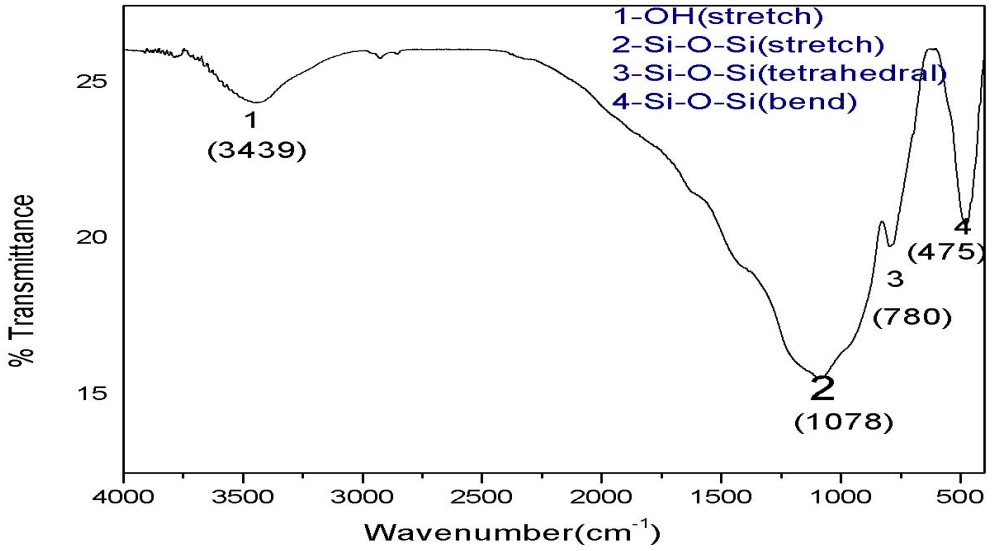

Figure 9: FTIR spectra of B2 glass sample

Description: The transmittance band around 3439cm^{-1} shows O-H(stretch) bond,1078cm^{-1} shows Si-O-Si (stretch) bond, 780 cm^{-1} shows Si-O-Si (tetrahedral) bond and 475 cm^{-1} shows Si-O-Si (bend) bonding as shown in figure 9.

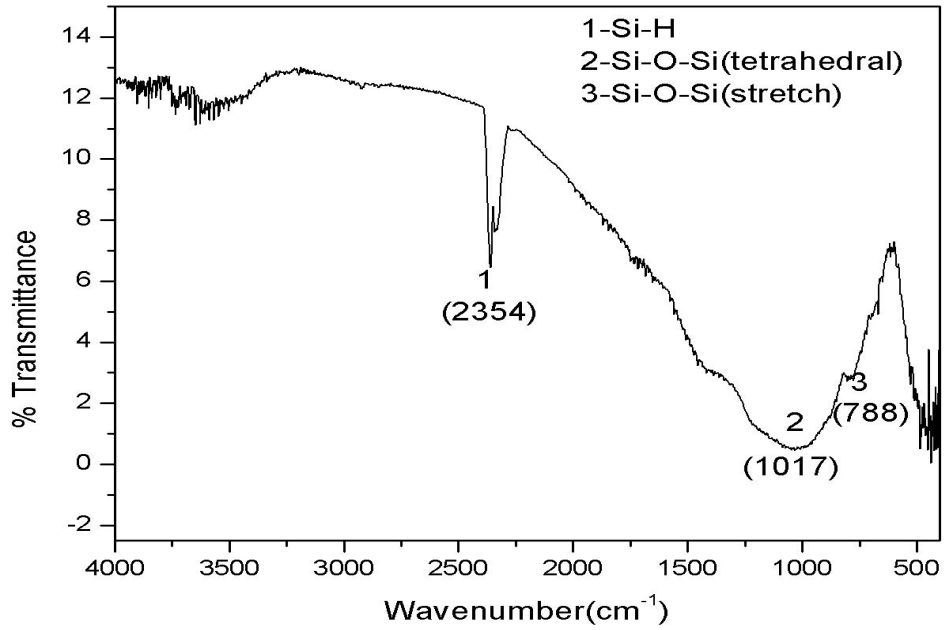

Figure 10: FTIR spectra of C1 glass sample

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Description: The transmittance band around 2354cm^{-1} shows Si-H bond, 1017cm^{-1} shows Si-O-Si (stretch) bond, 788 cm^{-1} shows Si-O-Si (tetrahedral) bond and bonding as shown in figure 10.

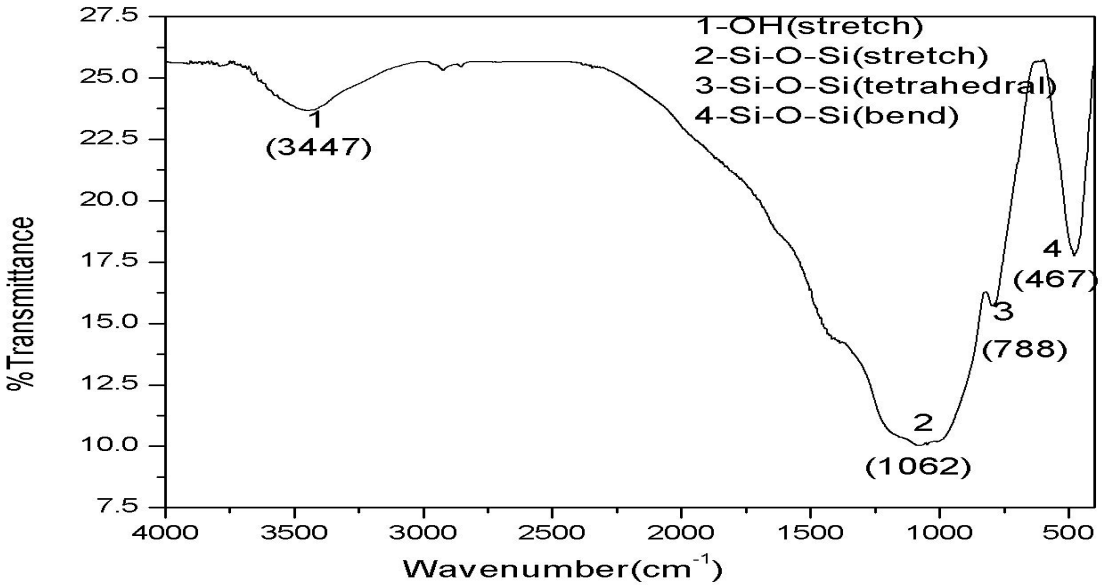

Figure 11: FTIR spectra of C2 glass sample

Description: The transmittance band around 3447cm^{-1} shows O-H(stretch) bond,1062cm^{-1} shows Si-O-Si (stretch) bond, 788 cm^{-1} shows Si-O-Si (tetrahedral) bond and 467 cm^{-1} shows Si-O-Si (bend) bonding shown in figure 11.

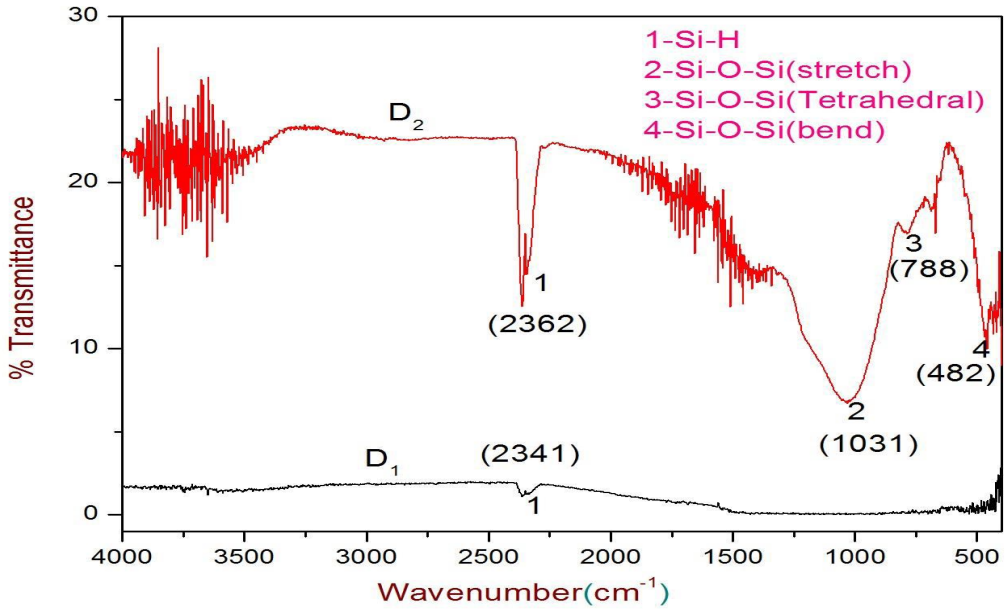

Figure 12: FTIR spectra of D1 & D2 optical fiber glass

Description: The transmittance band around 2362cm^{-1}shows Si-H bond, 1031cm-1 shows Si-O-Si (stretch) bond, 788 cm^{-1} shows Si-O-Si (tetrahedral) bond and 482 cm^{-1} shows Si-O-Si (bend) bonding shown in figure 12.

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C. Compressive Strength Measurement

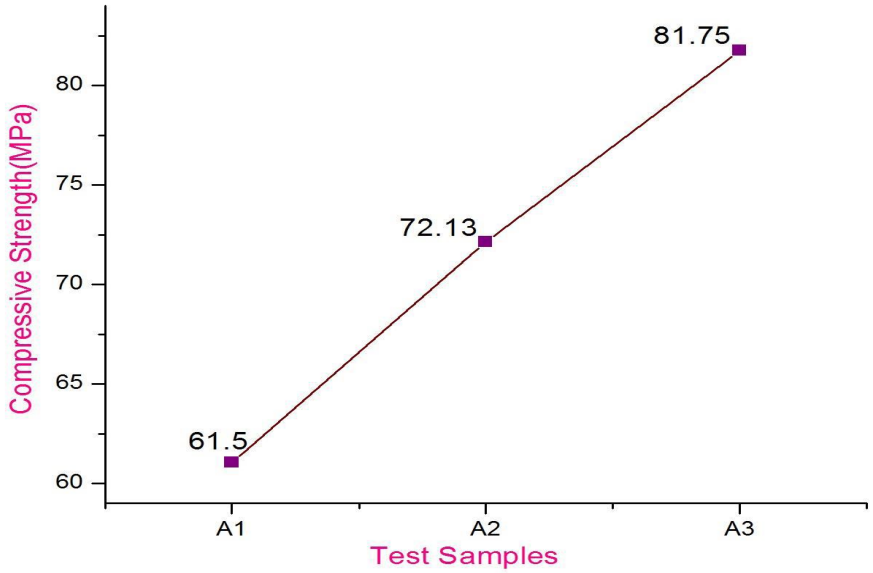

Figure 13: Compressive Strength of type A Glass sample

Description: As shown in figure 13. Compressive strength of type A glass increases due to increasing of Na_2O amount and decreasing the amount of SiO_2 .

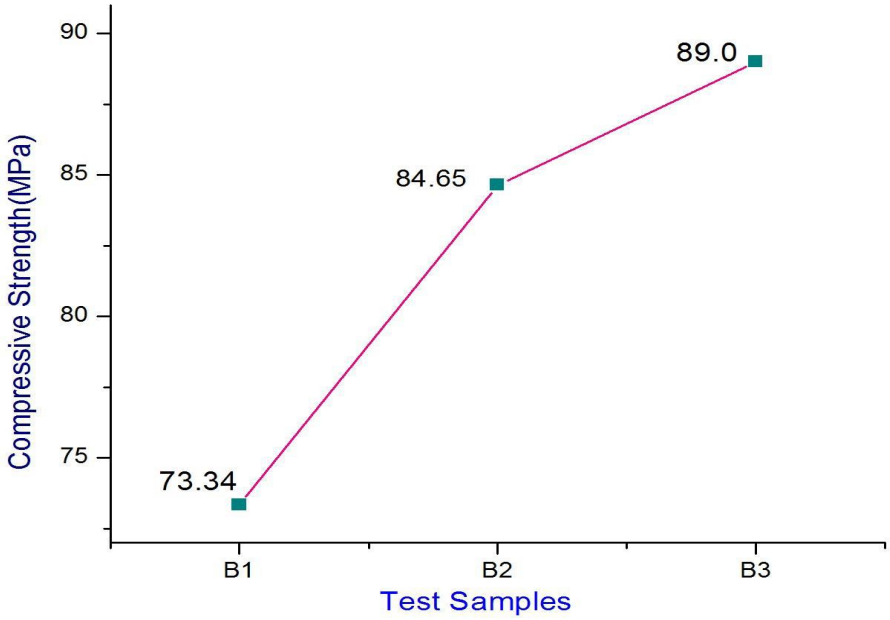

Figure 14: Compressive strength of type B Glass sample

Description: As shown in figure 14 compressive strength of type B optical fiber glasses are increases due to adding the Al_2O_3 . Due to addition of Al_2O_3 it form aluminate compound due to this compound formation compressive strength increases.

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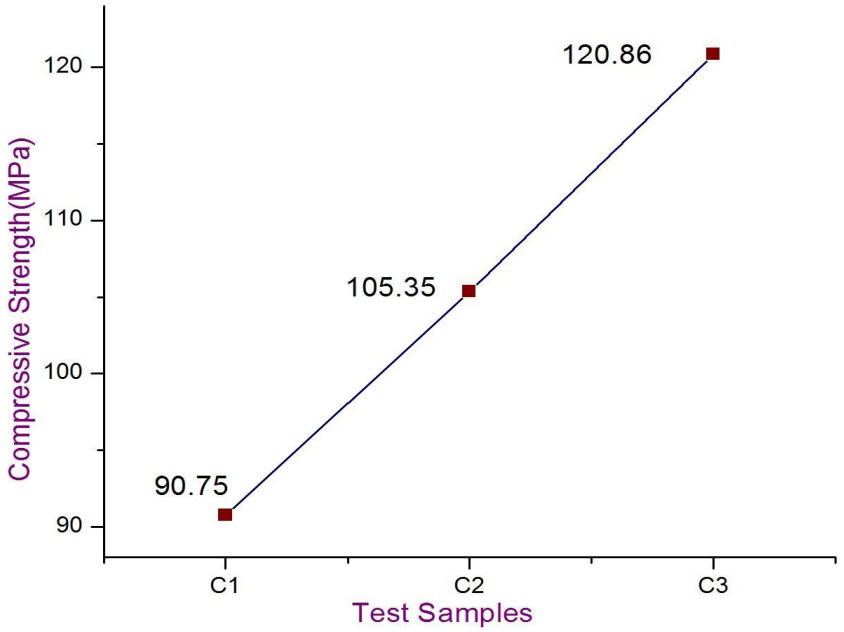

Figure 15: Compressive Strength of Type C Glass

Description: As shown in figure 15 compressive strength of type C optical fiber glasses are increases due to partial substitution of Na_2O with ZrO_2 .

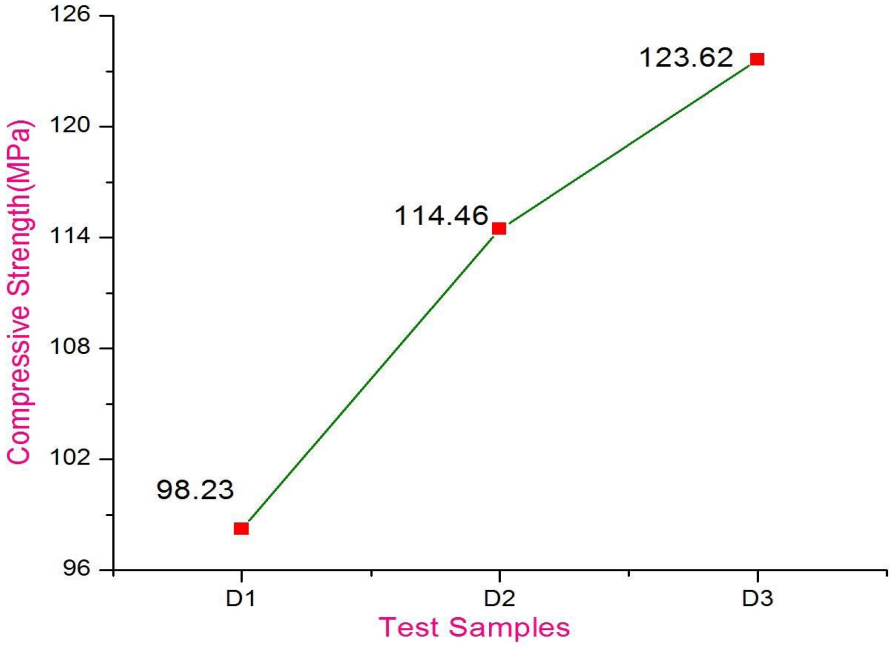

Figure 16: Compressive strength of type D optical fiber glass samples

Description: As shown in figure 16 the Compressive strength of type D optical fiber glasses are increases due to addition of $Al_2$03, ZrO2, Gd_2O_3 and Y_20_3 .

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D. Density Measurement

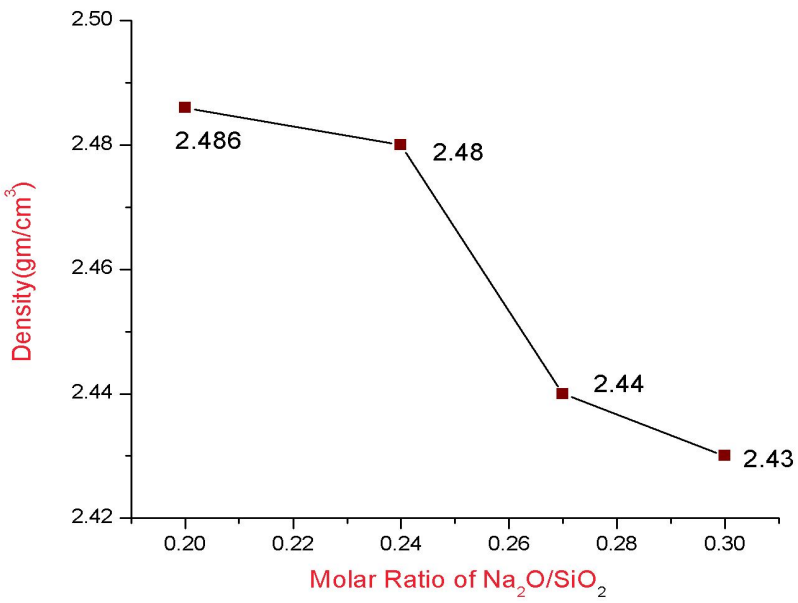

Figure 17: Density of type A Glass sample

Description: As shown in figure 17 density of type A glass samples decreases due to higher density of SiO_2 (2.65 g/cm³) is replaced by Na_2O having lower density of 2.27 g/cm³.

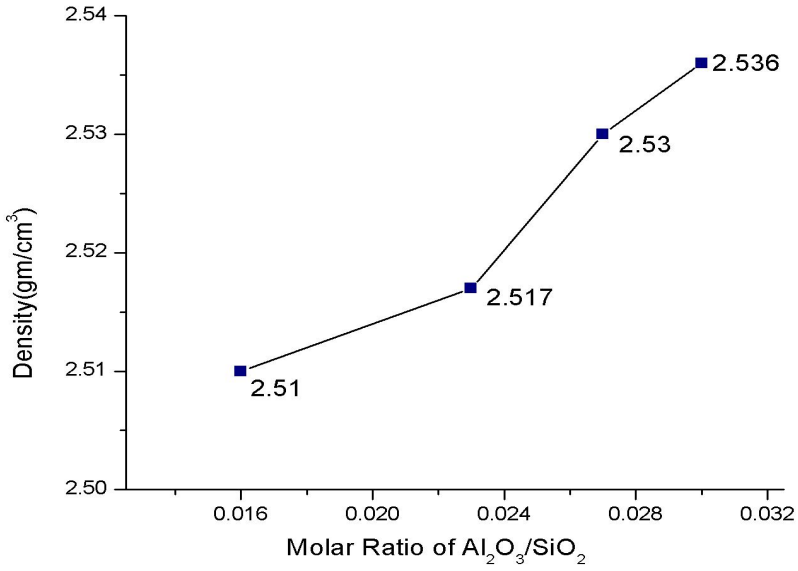

Figure 18: Density of type B Glass sample

Description: As shown in figure 18 density of type B glass increases due to lower density of SiO_2 (2.65 g/cm³) is replaced by Al_2O_3 having higher density of 3.95 g/cm³ and also due to lower molecular weight element is replaced by higher molecular weight element.

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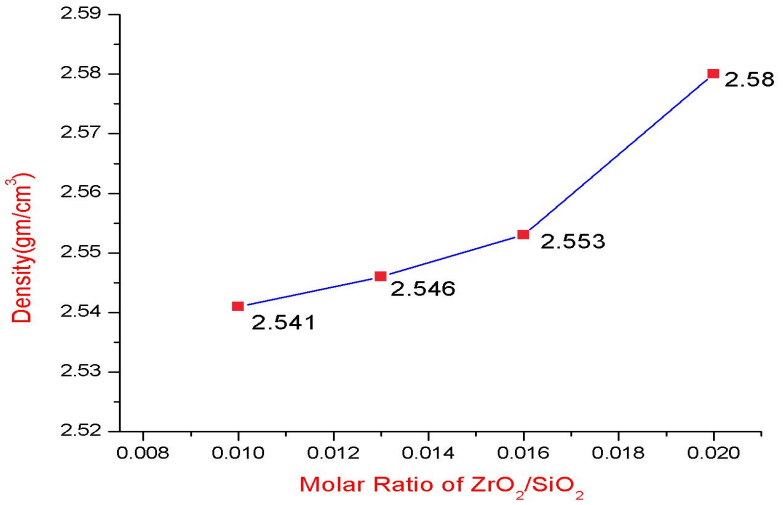

Figure 19: Density of type C Glass sample

Description: As shown in figure 19 density of type C glass increases due to lower density of SiO_2 (2.65g/cm³) is replaced by ZrO_2 having higher density of 5.68 g/cm³.

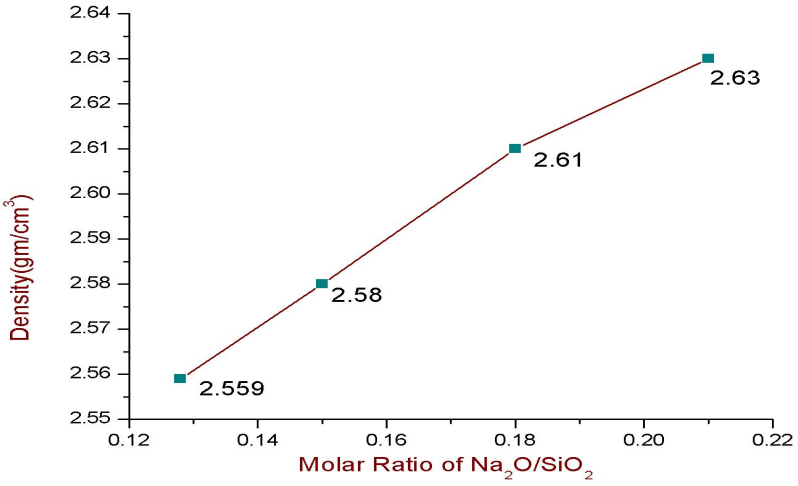

Figure 20: Density of type D optical fiber glass sample

Description: As shown in figure 20 density of type D glass increases due to lower density of SiO2 (2.65 g/cm³) is replaced by Gd_2O_3 and Y_2O_3 having higher density of 7.41 g/cm³ and 5.01 g/cm³ respectively.

V. CONCLUSIONS

Al_2O_3, ZrO_2, Gd_2O_3 and Y2O3 increase the chemical durability of the optical fiber glass samples. Percentage transmission increases with increase in chemical durability. Absorption % decreases with increasing transmittance. From the FTIR spectra of the samples the types of various bonding between the elements were found out. Density of glass increases with increase in weight percentage of rare earth materials. High atomic number of rare earth materials results in very high density of glass. Compressive strength of the glass sample increases.

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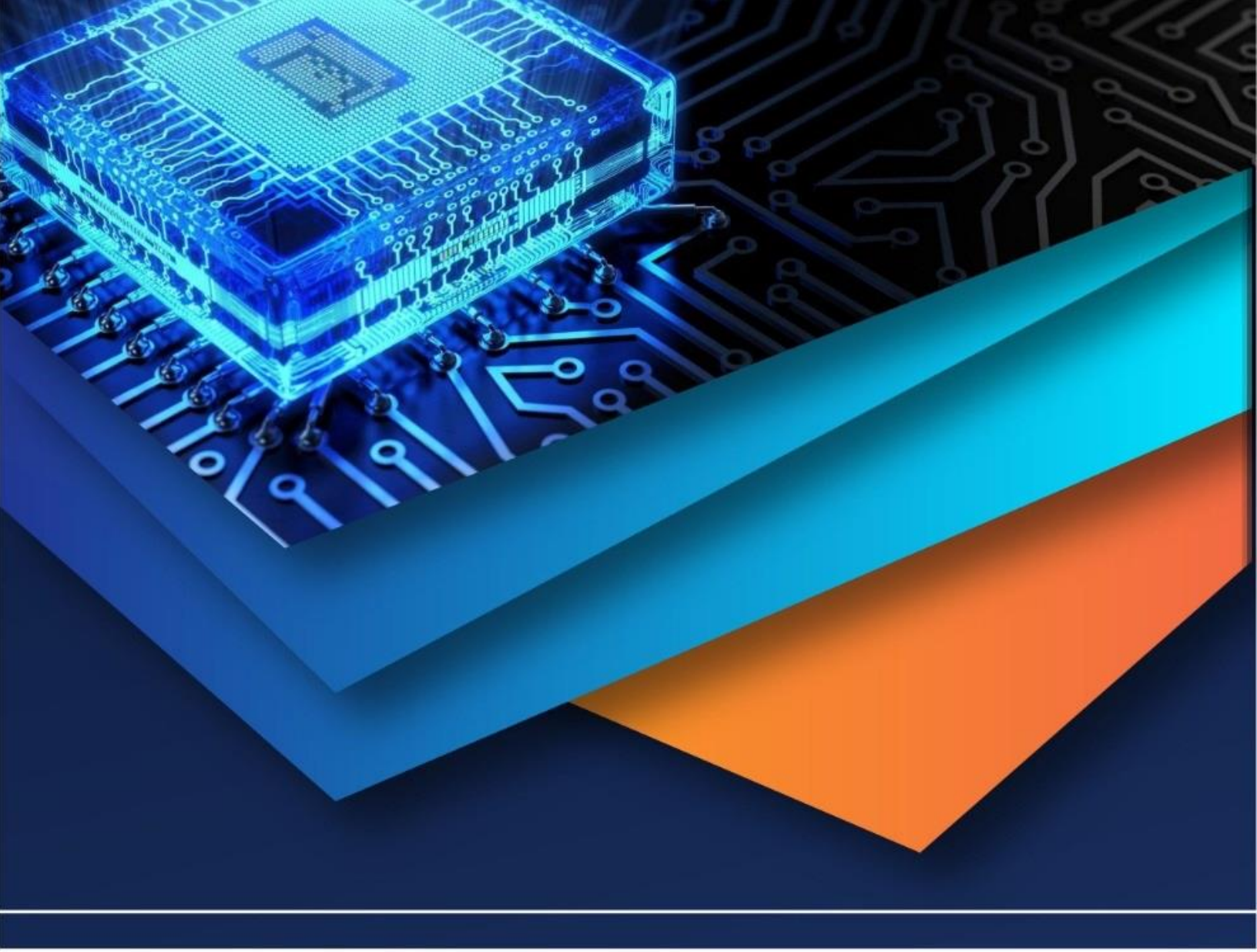

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