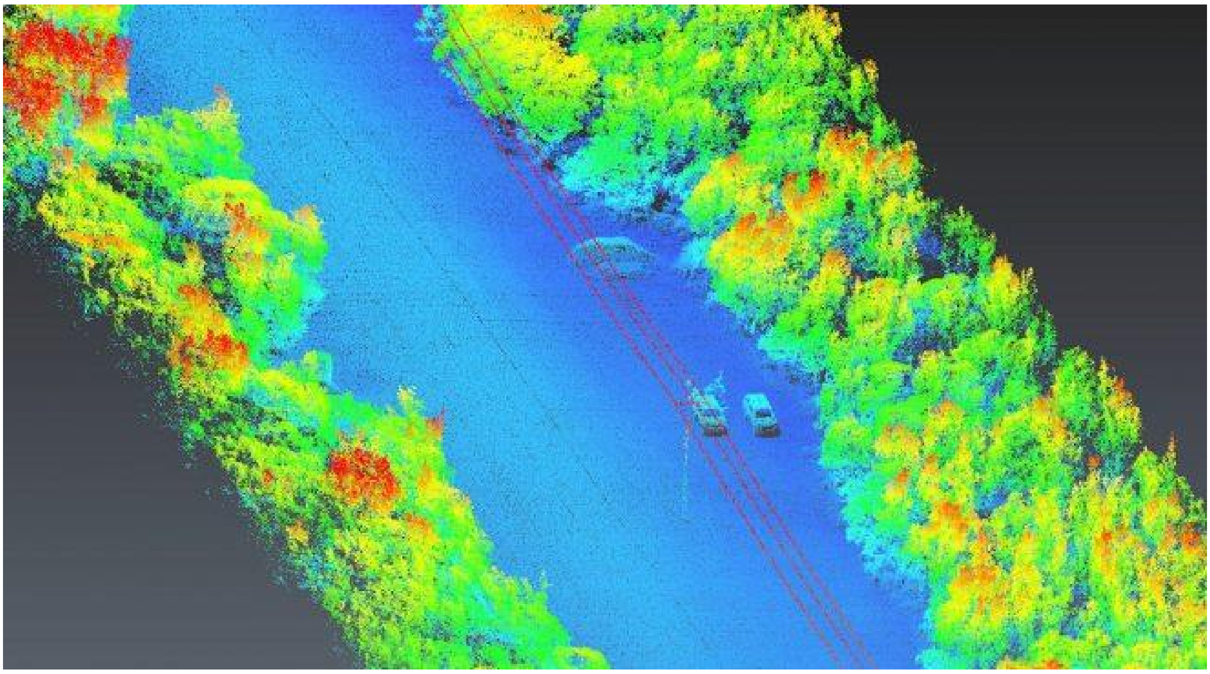
Fabrication and characterization of a RE doped optical fiber for LIDAR sources



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Devices and Technologies for Integrated Electronics and Optoelectronics

Fabrication and characterization of a RE doped optical fiber for LIDAR sources

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Dedication

All the praises are to God;

Special gratitude to my loving parents

Abstract

This research is dedicated to Study, Fabrication and Characterization of the amplifier based on Phosphate Glasses to manufacture the optical fiber for LIDAR systems. This experimental Thesis has been down in two Parts: The First part which is mainly focused on the material and fabrication of Phosphate Glass which is mainly done in DISAT laboratories of POLITO.

Furthermore, the second part of This Experimental Thesis is more focused in Final fabrication processes of Optical Fiber on drowning tower and characterization of the optical fiber and testing on the optical test benches, in collaboration with Photonext of ISMB.

This optical fiber must amplify the signal proceeding from a seed laser and allow the propagation of the signal for far distances. The power optical fiber device produced with this mode will be used as a source for a monitoring LIDAR system, which will be used in Aero planes for environmental applications. However, that's Crystal clear that it can be used Furthermore as a high-tech peak of technology for Advanced Driver Assistance Systems (ADAS).

Acknowledgement

I would like to use this opportunity to present my deepest appreciation to professors

Dr. MILANESE DANIEL, Dr. Diego Pugliese and Dr. Nadia Boetti For giving me this chance to join their unique Professional team, where I had time to experience both advanced research and Moreover boosting my professional career attitude. Although this was just beginning of my professional career path in my life, I am sure won't forget this unique team for rest of my life.

Special thanks for professor Dr. JANNER DAVIDE LUCA, for all his help regarding my thesis and innovative research collaboration where his work ethic speaks for itself in an ultra-professional way!

I would like Moreover to illustrate my greatest appreciation to Professor Marco Ajmone Marsan for great help during ASP (Alta Scuola Politecnica) where I have experienced my first professional research environment with the most brilliant students ever, I have observed in Italy.

I Moreover owe an important debt to Professors Dr. GHIONE GIOVANNI and Dr. BARDELLA PAOLO the first professors for acclimatize me with photonic and LIDAR systems world in photonic devices course.

Contents

Chapter1: Introduction

1.1 Introduction

This chapter will explain the basics of Physical descriptions to be known in order to understand the following Parts of this Thesis.

We will deal with some concepts like: LIDAR systems it would be analyzed from different technical and will be referred a little also to market and industry interests , Lasers different types and our main interest regarding this project, Optical Amplifiers pros and cons main Technical reasons of success, Optical Fibers then will Analyze Why the main interest is based on RE ions or Why have chosen Non silica Glasses as material in order to Synthesize the optical Fiber.

1.1.1 An introduction to Laser

The fabrication of a laser was first proposed by Schawlow and Townes in 1958 and the first experimental demonstration was realized by Theodore Maiman in 1960[2].

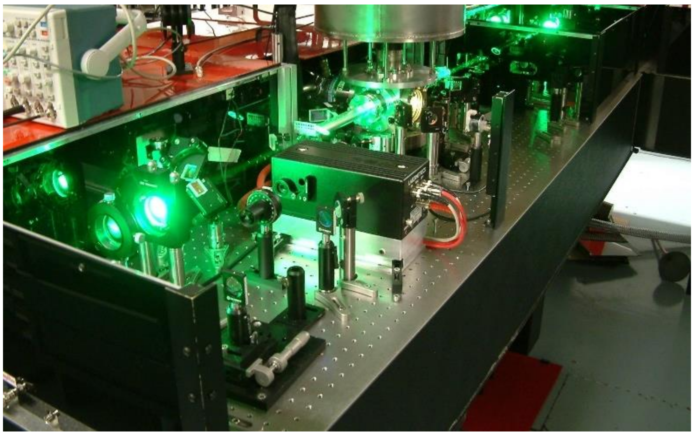

Figure1.1: Laser source and its propagation on the optical Test bench

Lasers are devices that generate or amplify coherent radiation at frequencies in the infrared, visible, or ultraviolet regions of the electromagnetic spectrum. Lasers operate by using a general principle that was originally invented at microwave frequencies, where it was called microwave amplification by stimulated emission of radiation, or maser action. When this extended to optical frequencies naturally becomes light amplification by stimulated emission of radiation, or laser action.[1].

From an electronics-engineering viewpoint, the developments that followed the operation of the first ruby laser in 1960 suddenly pushed the upper limit of coherent electronics from the millimeter-wave range, using microwave tubes and transistors, out to include the sub millimeter, infrared, visible, and ultraviolet spectral regions (and soft X-ray lasers are now on the horizon).

A laser can be classified as operating in either continuous or pulsed mode, depending on whether the power output is essentially continuous over time or whether its output takes the form of pulses of light on one- or another-time scale. Of course, even a laser whose output is normally continuous can be intentionally turned on and off at some rate in order to create pulses of light.

We will see in the further parts of this project where the pumping of the optical fiber will be done by 2 different methods either continues wave or pulsed wave sources.

1.1.2 An introduction to LIDAR

lidar is a system made of components; Lidar systems are made of a source, a power amplifier.

Lidar uses active sensors that supply their own illumination source. The energy source hits objects and the reflected energy is detected and measured by sensors.

there is a detector, the Activity of this research is on the laser source; because there is a source and detector.

Lidar system is made of a seed laser and power amplifier the main focuses is on the power amplifier optical amplifiers has many advantages such as choice of operating, wavelength (400-2000 nm), Low price with high volume production, Low optical and electrical power consumption and non-linear gain properties.

An optical amplifier; amplifies an optical signal directly, without the need to first convert it to an electrical signal.

Because amplifiers have the ability to increase the magnitude of an input signal, it is useful to be able to rate an amplifier's amplifying ability in terms of an output/input ratio. So, for this purpose one solution can be using Optical Amplifiers to amplify the input signal; One of the obvious advantages of fiber-based devices, over channel waveguides, is the ease of achieving a better mode match to transmission fibers, in addition to polarization insensitivity.

Light Detection and Ranging (LIDAR) is an optical sensor that radiates electromagnetic waves, with a wave length of about 850 to 1000 nm. This is in the area of infrared light on the border to visible light. If too much power is emitted, human eyes will be hurt. Therefore, the impulse has to be very short.

1.1.3 An introduction to optical amplifiers

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed [15].

Furthermore ,Optical fibers are dielectric waveguides with circular cross-section, mostly made of doped SiO2 from the geometrical optics standpoint, signal propagation follows the total reflection effect

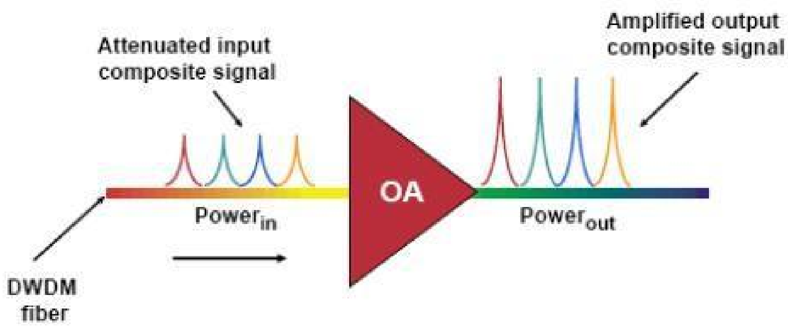

Figure 1.2 : General Block Specification of Optical amplifiers

In order to transmit signals over long distances (>100 km) it is necessary to compensate for attenuation losses within the fiber.

Several types of optical amplifiers have since been demonstrated to replace the OE – electronic regeneration systems. Since in OE systems there was always a huge need to convert the Electronic to optical systems conversions and vice versa.

We can name this reason as a key of success for the Optical communication systems.

There are many types of Optical Fibers we can name; However, the focuses of this project are based on the Rare Earth Doped Fiber Amplifiers.

Rare earth doped fiber amplifiers are finding increasing importance in optical communications systems.

Perhaps the most important version is erbium doped fiber amplifiers (EDFAs) due to their ability to amplify signals at the low loss 1.55[um] wavelength range.

Optical fibers provide several fundamental advantages for lasers and amplifiers:

Confinement of pump and signal beams which Moreover includes High gain efficiency, high power, high nonlinearities.

Furthermore, among optical Fibers to choose the Phosphate one with the following description:

High dopant concentration phosphate laser glass fiber offers the potential for high gain per length coefficients, Phosphate glasses includes advantages of a high solubility for RE ions (allowing the high dopants), chemical durability, ion-exchangeability, wide bandwidth capability, and low up conversion characteristics.

1.1.4 An introduction to Erbium-doped optical fiber amplifiers

The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber.

Two bands have been developed in the third transmission window – the Conventional, or C-band, from approximately 1525 nm – 1565 nm, and the Long, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands.

The principal difference between C- and L-band amplifiers is that a longer length of doped fiber is used in L-band amplifiers. The longer length of fiber allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain.

EDFAs have two commonly used pumping bands – 980 nm and 1480 nm. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and Therefore wavelength stabilized laser sources are typically needed. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980 nm and 1480 nm pumping is generally utilized in amplifiers.[3]

There are many Pros and cons also for this kind of Optical Fibers as any other research field which we will name bellow:

Among all disadvantages we can name: Gain saturation effects. ASE – amplified spontaneous emission. There is always some output even with no signal input due to some excitation of ions in the fiber – spontaneous noise or difficulty of Integration of it with other devices since the size of this device can be in KMs length.

However, it has many Impressive Advantages which made its future brighter which we can name as: Large dynamic range; Low noise figure; Polarization independent and Suitable for long-haul applications.

1.1.5 Fiber lasers Amplifiers and fabrication

Fiber lasers have potential for use in both long-haul (1.5um) and local area Network (1.3um) Communications as optical amplifiers.

Non communication applications include use as super luminescent sources for fiber optic gyroscopes and Low-cost Sources in various instruments for optical measurements.

Benefits of lasers in fiber form ,optical fibers are basically waveguides for electromagnetic radiation at optical frequencies .When light passing through the fiber core is incident at the interface it will be totally reflected if its angle of incident is greater than the critical angle (Since phi (c)=arcsin (n2/n1)) Fibers can be classified into two main types: Single-mode and Multi-mode.

The simpler type is the single-mode Fiber, in which the core size and refractive index difference are small, allowing only the wave guide mode of lowest order to propagate.

One of the benefits of Lasers in Fiber Form is that a large population inversion density is attainable, as the result of the guiding structures of the fiber by keeping the pumping light tightly confined in the Transverse Direction over The Distance required for its absorption.

There are four principal rare-earth Candidates for use as a dopant for fiber amplifiers in optical communication systems; erbium, Neodymium, Praseodymium and dysprosium [4].

The fiber fabrication process, in general, consists of two steps, the preparation of the bulk performs and the formation of a long fiber.

Non silica oxide glass optical fiber fabrication Drowning; to have the core rode stretch the core rode

inside the tube in order to growing it and Draw it with Drawing Tower.

The different temperature of the Drowning it depends on the glass which are using; the glasses are drowning at 2000c but drown it at 600c because its low melting glass.

we want the most efficient guiding of the light inside the core it’s better in results .the optical fiber by itself is waveguide can clearly have a linear waveguide instead of fiber having a bulk material and then one can create some waveguide but in the case the waveguide is the optical fiber which guides the light inside the core.

How to guide the light inside the core by putting a cladding that surrounds the core and thanks to the optical mechanism of Snell’s effect of the principal of total internal reflection the light is confined inside the core .and its guide in the most efficient way.

we don’t use the polymer coating because it's not so easy to implement the coating of the fiber it’s not so easy to implement the coating of the fiber as is not easy to put polymer that surrounded out of this glass; one need some advanced facilities that up to now don’t have it .

so we’ll make only the glass based optical fibers.by using polymer it offers higher flexibility; it protects from external environment from moisture from external agent; dust and so on . but since it only improves the mechanical properties like strength not the optical properties and don’t have the facilities to make it; so, won’t use it.

By putting the fiber in the optical bench maybe it’s more stable and more protectable. but for our purpose it is ok even if we don’t have a polymer.

1.1.6 RE doped ions

Among the most popular solid-state gain media are the rare-earth-doped laser crystals and glasses; more recently, ceramic media have started to attract increasing interest. In any case, these media are doped with rare RE ions, which are nearly frequently trivalent (i.e. have a triple positive charge). Divalent RE ions have Moreover been used in laser devices, but only in relatively exotic ones for cryogenic operation.

In most cases, the RE ions replace other ions of similar size and same valence (charge state) in the host medium; for example, a Nd^{3+} ion in Nd: YAG (yttrium aluminum garnet) substitutes an yttrium (Y^{3+}) ion. The concentration of laser-active RE dopants in the host medium is in most cases only a small molar percentage, although there are cases such as potassium ytterbium double tungstate (KYbW) where each unit cell contains a laser-active ion.

A characteristic property of the trivalent RE ions is that their electronic transitions usually occur within the 4f shell, which is somewhat shielded from the host lattice by the optically passive outer electronic shells. (Ce^{3+} with its 5d–4f transitions is an exception.) This reduces the influence of the host lattice on the wavelengths, bandwidths and cross sections of the relevant optical transitions.

Note that the RE elements include all the lanthanides except for the radioactive promethium, plus scandium and yttrium. All the laser-active RE ions are actually lanthanides. Therefore, lasers based on rare-earth-doped gain media are sometimes called lanthanide lasers.

Technologically the most important are ytterbium- and neodymium-doped gain media for lasers and erbium-doped fibers for erbium-doped fiber amplifiers.

Other rare-earth-doped ions are yttrium (Y3+), samarium (Sm3+), europium (Eu3+), gadolinium (Gd3+), terbium (Tb3+), dysprosium (Dy3+), and lutetium (Lu3+). These are normally not used for laser action but sometimes as a co dopant, e.g. for quenching the population in certain energy levels by energy transfer processes, or for realizing stature able absorbers, or as optically passive constituents of laser crystals. [11]

We will use Ytterbium and terbium in the project.

1.1.7 Phosphate Glasses for LIDAR applications

Why do we use the phosphate glass? Because the Fiber which are going to manufacture is not a typical fiber that's why make with phosphate is because with phosphate are able to make short length because can do doping with high amount of fiber, Although one can obtain this in silica glasses within 10 meters, can make it in some centimeters with respect to the silica which is a large advantage to use phosphate glasses instead of silica glasses.

The addition of various dopants, such as alumina, alkali and earth-alkali oxides, was demonstrated to reinforce the phosphate glass network. Moreover, when RE ions were added, the glasses proved to be suitable materials for lasers, revealing an interesting combination of low nonlinear refractive index and high optical gain.

Finally, their mechanical reliability allows the integration of phosphate fibers with commercial silica fibers through cleaving and arc fusion splicing [40].Phosphate glasses used for lasers in the eye-safe wavelength region usually incorporate erbium (Er3+) as activator ion, with emission centered at around 1550 nm corresponding to the radiate decay from the 4I13/2 excited state to the ground state 4I15/2 (see Figure 1.1)

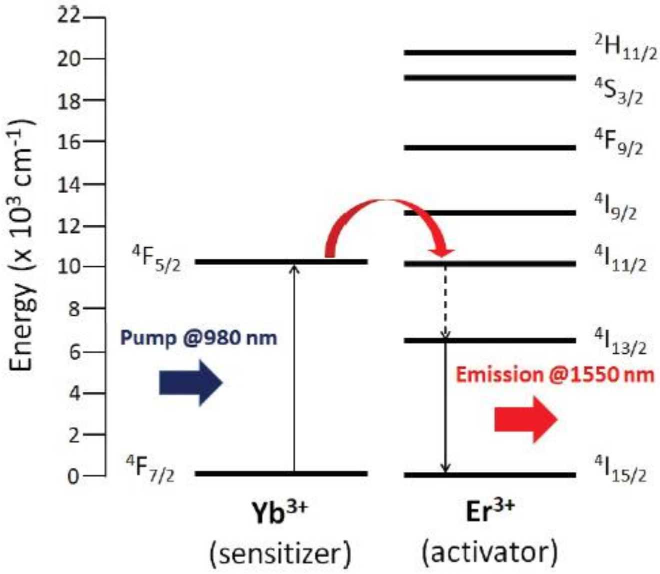

Figure 1.3: Energy level diagrams of Yb3+ and Er3+ ions. The main pumping mechanism of the sensitizer-activator scheme is Moreover reported

The lifetime values of the excited state corresponding to the upper laser level provide useful indications of the population inversion ability of the emitter.

A higher lifetime value is preferred because that will allow the large population inversion needed for high gain and low noise optical amplifiers. In the case of lasers, high lifetime values will permit lower pump power to reach the laser threshold, with resulting higher efficiency in laser emission and lower heat accumulation in the material. Silica, provides the lower oscillator strength of the 4I13/2-4I15/2 transition, displays generally a higher lifetime value (10.80 ms) than phosphate glass (8.25 ms) [4]. However, phosphate glasses maintain high lifetime values even for high erbium concentrations: values of 7.5 ms are reported for an erbium concentration of 6 * 10^20 ions/cm3[12].

Therefore, what explained until now in This chapter was the opportunity to learn the basics of physical definitions understood why will use a non-silica glass for the optical fiber and are ready to observe Methods and Techniques for design of the optical amplifiers and the procedures employed

for the fabrication of the glass. Furthermore, will observe another section which is dedicated to the Final fiber Synthesizing process, Cleaving Process; Splicing Process of Optical Fiber.

Chapter2: Materials and methods

2.1 Phosphate Glass preform fabrication and characterization

The book (No silica oxide Glass fiber laser sources) will explain about phosphate have to test which is the refractive index of the Glass manufactured so have a specific NA(We cut the slice from the end of the Tube);because make a Tube Directly Therefore it can be observed that the Tube Fabrication Then can be Cut and published and measure Together the refractive index after this have to publish all the Tube and then Don't need to make Thermodynamic analysis because know the glasses and then make fibers basically ,then when have made all this well come back to the model and will observe if it works and then if it doesn't work The guy who made simulation will rear range it in order to pick it with the experimental values which one has measured .

The reason why is interested in Phosphate Fibers instead of silica Fiber is Because the fiber is not a typical fiber; because with phosphate are able to approach the same goals with a short length because can do the doping with a high amount of fiber; Since obtaining this in silica with 10 meters. Although, we can make it in some centimeters with respect to the silica. Which means one will have the same amount of doping in a much smaller length.

The Cladding and the core are two main parts of Optical Fibers the Rod is doped with the Ytterbium and Erbium for many reasons mentioned in the sections 1.1.6 and 1.1.7.

2.1.1 Cladding tube fabrication

2.1.1.1 Casting rotation for Cladding Tube:

The main part of safety was that used a somewhat helpful spectacles for prohibition of the radiation effects since by casting which has been done by rotation of horizontal it's possible to be dropped the pieces of hot particles. so, I put some gloves.

This technique as was mentioned before is a casting rotation the spectacles use are glasses against UV radiation because there is heat and black body.

The material is made in the oven .just take the chemical materials from the bottom of machine ,here there is the molten ;if one wants to make a cylinder one needs to use this I have a molt ;where I cast the glass (a Cylinder) .The reason why heat the molt is because if the casted glass is cold the glass will collapse to the powder because will have a high temperature a giants the low temperature .

So, by stressing radiating is too high that will break it the temperature is 330c this machine is called furnace machines. While is wanted to make a new material from the beginning one can make the new glasses in the clean rooms.

Like here one can simply mix some reagents and then one put in the container in the corrosive; one heat at high temperature then one cast; this is the process.

Here the prof used the mask because here might be the projection of hot glass. do the rotation while is horizontal.

So, took out the material from furnace then clamped it then test it. It's the rotational casting technique this would be the cladding of the fiber. the speed of rotation is about 3000[rpm]; and now because of residual stress put an annealing to eliminate or reducing the maximum residual spices inside the glass. The temperature used is the TG of glass .and stay for 3-4 hours. In the fallowing days will cut a slice at the end of tube and polish at the optical quality to measure the refractive index have to observe if the numerical aperture is ok for making the fiber.

Note:TG: glass transition temperature.

We have two furnaces ;one is for glass and the other one is for the body heat it with a temperature of 330c for the glasses the temperature is 1330c .When have put the body then have melt the glasses and pure it in the body and then will do the rotational casting.

Rotational Casting Technique:

The rotational casting is carried out by casting the molten glass into a cylindrical mold which is then tilted horizontally and rotated at a rotation speed ranging typically from 1000 to 2000 rpm while the glass inside the mold is still liquid. As the liquid cools down, it forms a glass tube inside the mold, which is then loaded into a furnace for glass annealing.

Despite being a "manual craft" operation, if processed under the same conditions, the tube inner diameter value is commonly reproducible within +- 5 %. The typical roughness value of the inner tube surface is below 10 nm. Such pristine surface is indeed particularly suitable for the development of optical fibers.

The rotational casting process takes place in a matter of seconds, making it a very fast production technique if compared to the two approaches described above. The main limitation of the rotational casting technique regards the range of inner tube diameter values achievable. Uniform tubes with small or large inner diameters can be difficult to achieve in a reproducible manner. Also, the technique is foremost restricted to glass compositions that display a low viscosity once molten. Silicate glasses, for instance, are unpractical for implementing the rotational casting technique.

It is valuable to remind that the material for optical Fiber Glass was put inside from the bottom of the Furnace Machines in working Temperature of 1350 (Centigrade) So the materials was mixed and made ready inside a small clean room then it has been molted till 1350 degrees moreover was added with strong Metal attaches. Therefore casting the molt was done by Casting Rotation Techniques; there is a molt where is Casted the molt with the Cylindrical Shape which is also warmed up it to 330 c in order to help the integration of casting process since both should have a matched temperature since by so much differences in the temperature of the process the perform will break because of So much Thermal stress.

While processing the casting of hot glass its strongly recommended to use the Protective glasses against UV radiation because of Safety Protections.

Finally, the melted Glasses are put away from Furnace to the Rotational casting machine in order to cast at 300 rpm Speed so a Tube shaped optical preform is done by the end of process and this would be used as the cladding of the fiber this. An annealing process is done at the end in order to eliminate or minimize the stretching effect regarding to the Temperature differences at the TG of the Glass and will leave it for 5 hours inside the oven machine.

2.1.1.2 Refractive index Sample preparation

We want to cut the ending of the tube and this one will be the sample of the glass to measure the refractive index. All the personal effects related to this Tube is related to my thesis.

the core which is a rod will be put at the end Therefore have the space of rod reserved and free in the tube. This is the cladding that was excited from the casting of the last time as said before will exit it from furnace after 5 hours. We cut the end of the cladding with creaser cutter inside of this machine one will observe some oil, otherwise if cut without oil it will break. So, we'll put some paper inside the hole Therefore if the oil enters will not goes inside the cladding so much.

The thickness of the fiber we'll decide based on the inner diameter of the tube; the external diameter of the tube and the specifications. First, should make a sample and measure the refractive index. To have as much as possible the planner cutting, will use preforms between cladding and cladding of the fiber. The core which is the red is doped with erbium and ytterbium clearly the cladding is not doped; don't need to dope it .so for alignment of the position to cut will move the blade or by moving the preform to have an ideal place to cut.

So, for starting will turn on the power (chose the ideal power) and then the Cesar cutter will cut the cladding by itself without any external forces. Notice: should commonly have the cutting oil in the Cesar cutting machine. in the beginning have put the power at 100c then change it to150c then mount the sample on heater by some wax (Glue). Then after the machine cut the sample want to observe the inner diameter will measure it with digital calipers (5.2[mm]) was the inner diameter.

Firstly, want to clean the inner surface of the Tube. We will clean it simply with Ethanol.

Then will need to polish the external surface of the tube but after the refractive index measurement. We will check the refractive index if its ok to have the prime numerical aperture between the core and the cladding. it's a property of glass.

The thickness of the Fiber would be decided based on inner diameter of the Tube the external diameter of the Tube and the required specification of this project.

The Preliminary part for measuring the refractive index is to cut a sample with the help of Caesar cutter machine at the end of Cladding in order to measure the refract index of our sample.

We need to mount the sample on one iron shape equipment.

The Cutting Process Will be done automatically by cutting machine which has an automatic Function after the preform is Assembled on the Holder which is a part of the machine by choosing the power of force and the exact place to be cut all the cutting process will be done automatically.

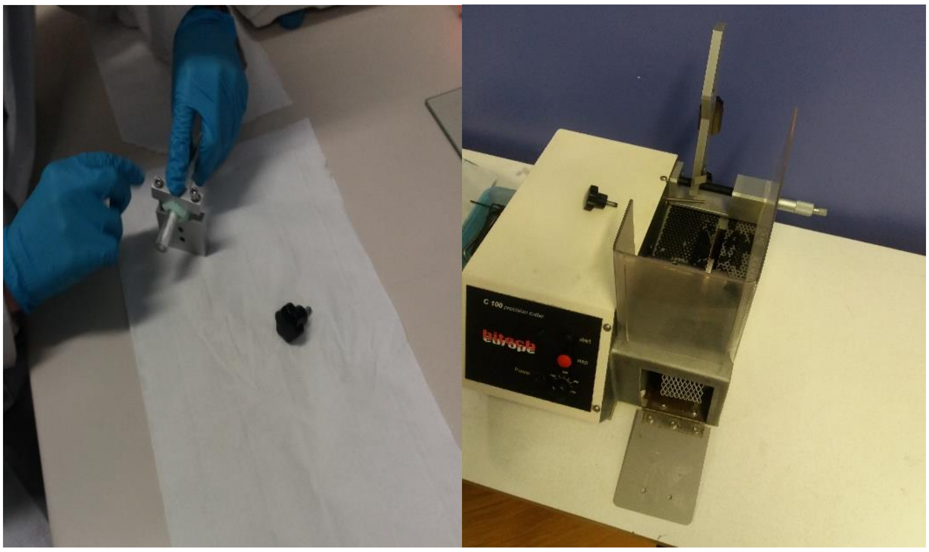

Figure2.1: Left: The instrument which will clamp the preform for cutting the sample on it. Right: creaser cutter Machine

There is foreseen some oil inside the cutting machine in order to avoid the stretch effect on the preform.

Figure2.2: Heating Machine for mounting the Sample

If one observes the sample under the microscope will observe some sharp sides which is not so homogenous; therefore, will polish it a little bit by hand to make smoother as possible.

The wax Glue was put on the heating machine in order to melt it. Will remove a few micrometers of the material; the only aim is to be flat it was around 1.4[mm] Therefore one can remove 200[um] of the sample in the maximum valid indication.

Therefore, the glue was warmed up to the 170c Therefore make the glue melted and stretchable on theory have calculated the refractive index about 1.5. The material of the paper which was used as layer between heater and the sample is 'Kim Tech brand' (delicate task wipers).

Cleaning the inner surface of the tube after cutting the sample is necessary in order to make empty the inner surface from small particles which was added to the tube by Cutting the Cleaning process has been done with Ethanol and Paper.

Moreover, the wax (glue) was put at the center. Then will put the sample on the center of the Iron on the heating machine where there is the wax and then turn the heater 'off' and then 'solidification the sample with re mystics'. Therefore by solidification then the sample sticks .this is the technique to make the fiber sample stable .so by turning on the heater turned the temperature to 170c then have put the iron which is the place want to keep the sample on it on the paper (Which is the correction between heater and the iron) Moreover will put the sample in the corners of the heater just because should have a temperature balance between the sample and the wax(glue), which is melt and has shaped to the liquid one Therefore it has high temperature after some time when the wax has totally transferred from solid to liquid shape will put the sample on the iron and then turn off the heater . (We will do it for 'Thermal stresses). Notice that this is not a thermal annealing; but it's only a thermal treatment just to put the sample there. do this technique for polishing surely, don't go for refractive index with iron cladding Therefore we’ll warn it up again then the wax will melt and will extract the sample.

It can be observed a very interesting Cycle for this process :firstly, melt the glue put the sample on the glue then take the Iron holder of the sample from heater and put it on the polishing holder then polish the sample and finally the reverse process will be done for extracting the sample :Take away the Iron holder from polishing instrument ,put it on the heating machine and heat it in order to melt the solidified glue .Therefore, taking away the polished sample from the polishing holder .

The reason why we polished the sampled refractive index was to obtain the optical quality since otherwise we won’t be able to measure the refractive index

In the following part you would be introduced to the second part of the project which is Polishing the external surface of the Tube in order to reach the optical transparency: polishing is done by ‘Silicon carbide polisher which is used by water for eliminating the effects of

tightly temperature while polishing by hand to make the surface of the sample with somewhat more homogenous. Then the glass would be polished to the refractive index.

After all, we need to check if the refractive index is ok to have a good numerical aperture between the core and the cladding; that’s why we will do the polishing after the refractive index measurement.

The inner diameter of the cladding was: 5.2 millimeter as was measured in laboratory which will indicate a good size for our application .

2.1.1.3 Polishing of the sample

One experimental Technique would be to color the sample Therefor by polishing the sample during the process it makes more declaration of homogeneity target in the surface of the sample. We want the sample on the holder (Geake)

Figure 2.3 Left: Geake Equipment from body side of view Right: Polished Sample of Optical cladding preform

Moreover, it is used a microscope to observe the surface quality of the sample need to take care; the pressure of the sample in order to prevent any scratches on the sample surface; so, need to be more careful in order to prevent scratches. The reason why we are interested in avoiding scratches in our sample is that while measuring the refractive index of the sample there is this possibility that the refractive index won't be measured correctly during the coupling by the prism. The first material will use for the polishing is Alumina 9 micron (Which is the size of the powder);then will go to the Alumina 3 microns ;then will go to the Diamond paste 3 microns;(for an important precise optical measurements will Moreover use Diamond paste 1 micron; however ,for refractive indexes 3 micron Diamond paste is adequate and the 1 micron Diamond paste is not used)like ,if is needed to make a waveguide on the bulk glasses one need to polish dramatically carefully Therefore one will need to use Moreover 1 micrometer Diamond paste ;but for refractive index measurements 3 micron diamond paste is enough ;for the goal don't need how much thickness polish from the surface precise .but for some purposes as to make UV visible or FTIR spectroscopy usually used samples as 1 [mm]thickness Therefore with this scale meter are able to measure the exact measurement . one notice is that since alumina is not crucially useful for environment, will collect its waste under the polishing machine with a Tank.

One important item while polishing with Alumina is that while polishing is needed to clear it crucially fast with water; because if one doesn't do it dramatically fast then Alumina will steak on the polishing plane.

We have sampled three different parts of equipment to the polishing machine one part just for guiding the Alumina while rotating to the polishing plate and one other part which is the polishing plate.

Since haven't used alumina Therefore its material has been sediment Therefore had to shake it before polishing to make the liquids all homogenous ;the liquid will be doped by the liquid guide on the plate by automatically rotating ;if want can easily align its value which how much to come through by easily opening or closing its door ;rpm is the velocity power at the beginning of the polishing will go crucially slow ;before polishing have colored the surface of the sample by a black marker to observe and be sure that polisher is doing well. had Moreover one hook which had two belaboring's and put the sample holder between it Therefore it starts to rotate on the plate and by time it was polished. Starts to rotate on the plate and by time it was polished. On the sample holder there is a piston on which can manually make some alignments Therefore as much as one will have less force.

so at the beginning have started a slow rotation and by the time have increased the speed .so when have started the scale of The Geake was on 7p[um]so when it comes to 17[um]it will remove 100[um]of the surface Therefore one complete round of scale is 200[um].

Here the Black colored area is getting removed Therefore one is able to understand the homogeneities of the glass surface the last polishing was done by hand therefore was not so much precise.

This is a long process Therefore being patience is really important.

The reason why at the end of each step one has to clean everything is Because if it remains some particles of 9[um] of Alumina and then will do the same polishing with 3[um] Alumina without cleaning it; it will cause some scratch on the sample.

So, have to be clean since don't want residual contamination from the step before; otherwise it's not prime. the maximum RPM for this process is 33 but 30 is Moreover ok.

For polishing the tube Moreover will have two ways one is by hand and one is by polishing machine; so, one mount the tube in the machine and then rotates and one use some silicon carbides sheets but those applies some forces at the end can control better all the items by polishing by hand.

With 3micro Alumina will remove 40[um]of the sample surface Therefore at the variety of speed; pressure and time the material which is removed is less clear because this is

3[um]Alumina; the relation is 25rpm the diamond is instead used only to confer to the sample the optical quality (transparency).

On the machine can be observed the time of the polishing Process .so at the end of first step will check the sample with microscope to observe if the surface is all homogenous and there is not any stretch ,there was one hole shape in the right bottom as have been observed but it was a bubble and it was ok .

Since with 3 micro Alumina and Diamond paste spread it by hand not automatically Therefore don't use the liquid guider and remove it after cleaning. Moreover, use Ethanol for cleaning the equipment. For both Alumina will have the same plate but for Diamond have to change each time are using it.

Al2o3: Alumina (Aluminum oxide); Laboratory grade Aluminum Oxide sheets engineered to provide the best possible burr free materials sectioning. So, started from 10[um] of the scale and then reach it to the 14[um] will stop it .at the third step have to change the plate and use one which is dedicated to Diamond.

So, by pasting the Diamond paste on the plate dedicated to it by time will observe the glass becomes more transparency like a crystal by polishing just to know that Moreover change the hook and used one dedicated to diamond.

So first have put the plate then have added the hook and test it if it's by tangent to the plate; then will put some water. here put water because the plate should be every time wet. Then press the sample holder at the maximum force (to have the highest contact) and then will do it by highest speed up to 15 minutes .so one will observe the transparency of the glass is changing to the mirror shape .at the end will do the back process to remove the polished sample from sample holder ;by heating on the heater .for the refractive index since need to couple only need one side to polish it .just notice that it is logical that as much more one will use the Diamond paste one will Moreover have more mirror shaped ;Moreover when more velocity ;or more pressure one will put (force).while are using Diamond paste it won't influence the thickness of glass but just the quality of glass Therefore won't check the thickness scale of sample holder .so at the end when have heat it up and when the glass can be separated from the sample holder then are able to remove glass Therefore will wait until the glass is fresh and then will clean it by the Ethanol .

Since with Alumina 9micron went really slowly at the end have been observed that don't have any scratches; Therefore, the polishing was done by patience and accuracy in an ideal case.

2.1.1.4 Polishing of the Cladding Tube

This part of project is dedicated to the polishing of the tube ;the other surface of the platform :Therefore , its necessary to polish the fiber and in the same time rotate one preform because otherwise one will lose circularity ;because if have a circular shape and only one will polish in one direction without rotating ;so the circularity will be lost.

Moreover, preserve the circularity.to have a useful fiber it is needed to polish well the preform. for polishing will use the silicon carbide sheets will use 8 different silicon carbide;

the first one would be the most harsh one and it will take more time because in the beginning will have the contamination of the molt or the residual of the molt ;so the first one is to eliminate ideally the imperfections !The first step is to l put the 4000[mm] sheet under the preform in order to keep the surface of the preform while polishing .the sheets would be:120,320,600,800,1000,1200,2500 and in the end with 4000.

For the first two silicon carbide sheets will use water to decrease the temperature of the glass while polishing. it is needed to remove the contamination from the molt a tip for polishing is that will pull the preform by oil because during the polishing if some particles will enter inside will damage the inner surface of the tube !The reason is because of the core which we should put inside of this cladding

Since if it remains some particles inside the fiber and you will put the core inside the cladding those particles can affect the quality and performance of the final optical fiber produced.

Therefore, will fill the oil to 600 but for the first two sheets its highly recommended. Moreover, will put two pieces of Napkin in the two sides of the fiber to present the interface of any particles.

Alcohol-Etilic; is a simply alcohol which will use for cleaning will put the mask on the face for powders which will be dispersed in the air by polishing processes. so, start with 120; will use water to decrease the temperature.

Won't be used during the drawing process at ISMB Therefore Don’t put too much time for polishing this part of the fiber.

The first sheet (Polishing step) in which will remove the contamination from the mole is fundamental for having a spectacular quality at the end.

Because if one has some sketches remained from the first silicon carbide sheet then one is not able to remove with the other further sheets; because one is going to smooth and one will need a neat base.

However, for the other sheets will spend around 20 minutes of working process per each sheet; for the first sheet don’t need a precise time; will keep going by polishing and will decide to stop by observing the performance when is completed.

The time is important in this part of research in order to change pieces of sheets by time to improve the performance /speed.

The main point is that if don’t remove the sketches with the first sheet, won't be able to remove with next numbers or at least one will need more and more time.

what will happen if will start drawing the fiber in the drawer tower without polishing the fiber the homogenous of the preform to the mold will break the fiber because when one arrives to that point it would be broken; otherwise could skep this process.

Since During the polishing for the second sheet there is water Therefore it will not create crash!

At the end of polishing with the first sheet Therefore will change the sheet to totally in order to prevent sketches or something else (the sheet which is under preform 4000).

Notice that bubbles are not a problem for the process Therefore will neglect the bubbles in the outer surface.

Figure2.4: Final Preform picture after all polishing procedure

Notice that except for the second sheet will clean the sheet which is under the preform and will re-use it. From 600 on there is no necessity to use water any more cause it's not required.

The polishing has been separated in two different days according to the large diversity of the patience needed for increasing the accuracy.

If the fiber optic is more transparent it can better guide the light; there is a model already done and have to manufacture the fiber after the manufacture of the fiber have to test it and then compare the results with the theory. Now will end up with 2500 and 4000.

For the last sheet (4000) in the last step have added the pieces of Diamond paste just to end it up ideally Moreover with water.

So, at the end cladding will be done also. with ethanol and paper inside and outer surface of the fiber optic.

After this process one of the colleagues will moreover do a precise cleaning of inner surface of the fiber optics if she observes any requirements to do so!

2.2. Optical Fiber Drawing

2.2.1 Introductory of drawing tower

This is the drowning tower use to drown fiber and it's a soft glasses dedicated tower that means cannot drown the silica fibers for example but use it for the soft glasses ;soft glasses means that they have a lower temperature than silica; it is a somewhat helpful glasses that they have characteristics that is lower in non-silica ;our drowning tower is a small one with respect to the commercial one because use it as a research Therefore are able to drawn 200 until 300 [meters]of fiber that is evidently great number but clearly for the commercial purposes it won't be enough Therefore how is the principle working ; will have a local ferniest that are graphite ring ; the graphite ring is heated by induction system up to the temperature that one need ;normally for phosphate is about 600 to 700 degrees ;then one will have a preform that is made of glasses that one wanted to use ;one will insert the preform gradually from outside ;as can observe there is a [micro meter]linear stage there that one will mount the preform on to the linear stage ;one start the movement from LabVIEW program and then the preform will start to be inserted in the hot point ;when it is hot the glass is soften and fall down because of gravity force and then going down it Moreover becomes thin .

Therefore took this thin part of glass and one will attach on the dram and then will start the rotation on the winding channel at the end one will produce one fiber depending on the dimension of one preform speed of the insertion ;speed of one rotation ;one will end up with a certain dimension of one fiber that one can calculate .at the end one will have a fiber exactly like the previous one just scaled down Therefore what will do is to change diameter but won't change the ratio between core and cladding Therefore will use two different glasses to prepare preform because are preparing a single mode fiber that means it has only one cladding ;what will do for the preform is that if the core has a more sizable dimension than fiber will resize it this process is called stretching and help to have a wonderful fit ;so will stretch the core to a certain dimension then one will insert this stretch core inside the cladding tube and then will reach to a preform.

Therefore at this point if it is willing to prepare the fiber for a double cladding fiber then have to prepare this operation in a double time : one have to stretch again the core cladding system to insert the core cladding system inside another cladding Therefore it's one step more .

There are some cases in which the glass is crucially viscosity, therefore one has a problem in heating it coming down (drowning) Therefore that's why in some of companies they will attach a weight to fiber.

With the lab view; will control the position of the preform speed of insertion of preform inside the ferniest ;the speed of winding dram and Moreover other is the online measurement of the diameter that is here with laser and there is Moreover attention meter that presents the attention of fiber because if one have a high attention : one can break the fiber during drowning normally if the attention is too high the glass is a little bit too cold .

Therefore normally one will increase a little bit the temperature since should prepare a rod to be able to insert the cladding Therefore will measure the rods geometry when are drowning the fiber will put some vacuum in order to have a fabulous addition between cladding and the rod inside because one will have some small spaces between this two and in order to avoid that space inside the fiber since

want a neat addition between two glasses will put here the vacuum Therefore they are forced to stay together Therefore have measured the fibers dimensions put the picture:

So will check the calculations ;One can observe the glass ,the graphite ring ,the induction coil that eats the inside of graphite ring and there is water cooling that is circulating since till now will have only one glass won't use the vacuum and then will have nitrogen that is coming ;because Moreover will have a clean air with no humidity and Moreover to keep the oxidation for the graphing .

In the stretching where reduce the dimension; will have a motor that is moving and rotating with a certain speed and need to reduce the speed of rotation Therefore need some gear and have different numbers for the reduction.

So will switch on the inducting system and it will go to the 300 Degrees and Therefore the glass will go to 300 degrees as well Therefore will stay for like 20 minutes in order to leave the glass be stabilized and then will start to increase the temperature to about 600 :if achieved 37% that was around 780 degrees .So will put 1.1 [mm/min] for speed for feeding speed of the preform and 5[v]that is the voltage put for rotation of the small motor what will do is to put a gear box to reduce less speed because with the other one the reduction was too low Therefore it was faster Therefore if the wheels are faster the stretching would be smaller Therefore would be slimmer.

For the motor will have the range like between 5 to 23 [v] and Therefore in this case can arrange the speed. The initial position for the lab view -50 [mm] is a relative position of a relative stage.

If the feeding speed would be so much then it won't go down and it will stop.

The 36% is the percentage of power that one is using (‘V MF’) for the machine for the induction. Our Ciller for water cooling is in the other room!

Put the picture have to do the calculations to understand how much should be the parameter of the drowning.

When the fiber that want to produce is more than 200 then the problem that can deal with would be the bending the fiber would be more fragile (so it's better to be less than 200).

This would be a multimode fiber because the ratio between the inside and the outside is just around ‘2’; probably will have a sizable core.

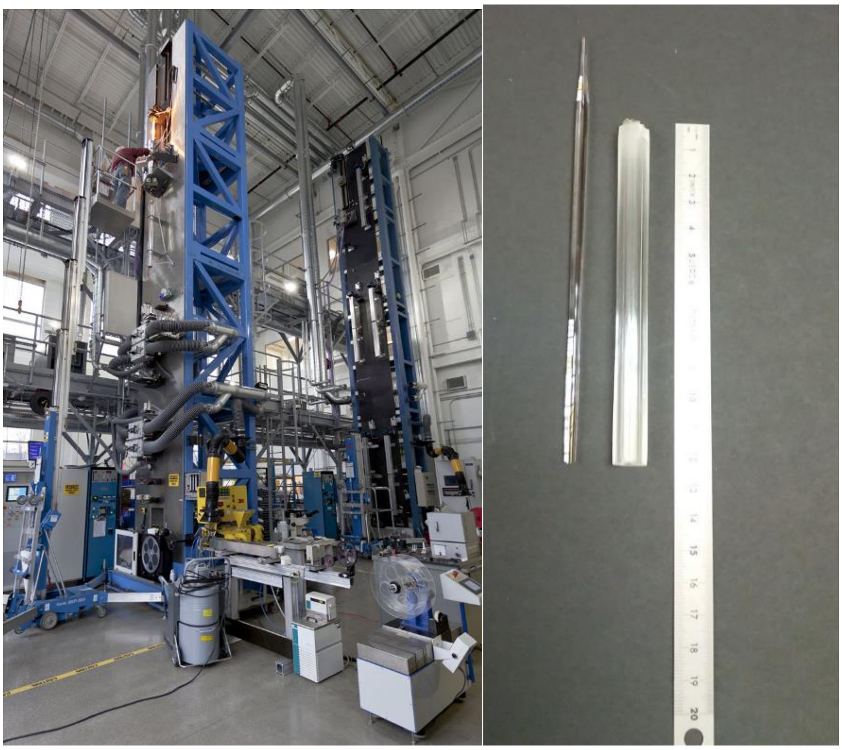

Figure2.5: Left: a sample of optical fiber drawing tower Right: Core and Cladding Before putting in the drawing tower

If do the 1 of speeding and 8.5 for the drowning will obtain a fiber that has around 120 for the external and the internal would be around 50 Therefore this can be one solution; then can try to have it a media: for the application which is an amplification it really doesn’t matter how much would be exactly the dimension . We just should take care of the other dimension since have to have a match.

Another option is to use 245[u meter] and 100[u meter] for the core the temperature is the same as before ;A tip: will prepare some tapes for preparing the fiber optics by processing should achieve around 125 from the calculation list since there would be some transitions during the processing, will wait till the items receive more stabilization.

During the changing of temperature sometimes happen that the fiber optics would be broken.

So what will do now is just to do the translation ;one will move a little bit (one shift by motor because otherwise one will have an overlap of fibers that one are scrolling in the other hands one should have the fibers close to each other ;so will change the speed of translation ;because ,otherwise one will finish everything (space) the motor is moving on the Dram ; its translated for the Dram can easily say that every line of scrolled fiber is one meter .

As can observe now the fiber is sizable but the speed of the rotation is lower Therefore one observes with the same rate of transition (Translation?!) one fiber has more space one line to the other.

The step motor which is installed in the drowning tower is used only for stretching Therefore that's why won't use it today; because now will have the winding Dram that is using the same job.

Since every parameter is kept fixed if one only decreases the speed of Drowning one will have a more Sizable fiber in [u meter] The roller which is inside the pc is a digital roller ;we use it to measure ;there is a program (software) that one can calibrate it use a grating written on the Glass ;we put just this grating and measure it and then set the value of this grating that know; Therefore will calibrate it and then set the value of this grating that know ;so will calibrate it and from the calibration and one can draw a circle or Moreover shape measured on the axis ;the brand of the motor is Maxon .

We firstly should do the quality of the fiber what can do? First of all, will insert the fiber under microscope and observe if everything is ok; then will go to the (medio?) and will observe if can measure (the second characteristics?) for example; like if one put a light inside and one won't have any absorption and one will observe if the light is guiding inside fiber.

Notice that if the fiber is a great one Therefore it should moreover guide with bending then one will measure the loss therefore, will do a measurement of:

-Half band measurement :

The losses of this somewhat helpful glasses which are working with (Non silica) when it's admirable is about 2[dB/m] that means one power is half after one meter (50% of efficiency).

For ending the process: close the compressor but will keep the nitrogen until the temperature is under 300 of degrees; because it's better for the graphite ring; for the oxidation of graphite ring.

So, from now on the fiber sample one will observe won't be drowning anymore since are not feeding or rolling anymore.

If one observes the fiber sample one will observe some bobbles under the microscope and that's due to the cutting.

All the machine is designed for a silica glass Therefore all the design is for the silica and this means that is not great for the fiber because they are too strong Therefore what need to do is to adjust the parameters like the attention ,the clamping force in order to have something that is compatible with the glasses .

Although it's better to use them since will reach result with respect to the result achieved by hand.

In 3D printing performing you ;It could be a good method to obtain different geometry because with Rotational casting you would be only available to obtain the circular cladding but there are also some methods in which you are able to obtain octagonal shape square shape ;as you know with the Rotational casting method you are able to obtain only some specific ratios between dimension of the hole and the external of the tube . but with 3D method you are able to obtain different shapes and dimensions.

2.2.2 scroll the preformed Optical Fiber on Spool

we are going to scroll the fiber on the spool if the fiber is large or on the dock (when the fiber which is cut is not so much normally one won't use a meters of fibers for testing one will use just 20,30,40 cm and its done so far for sending the fibers to other places can Moreover use one meter of that ; if scroll them on spool it will happen that will take so much time).

In the beginning have opened the clamps of scrolling motor then have changed the direction of it because have to go in the reverse mode with compared to the other one for scrolling back the fibers to the spin, have a motor.

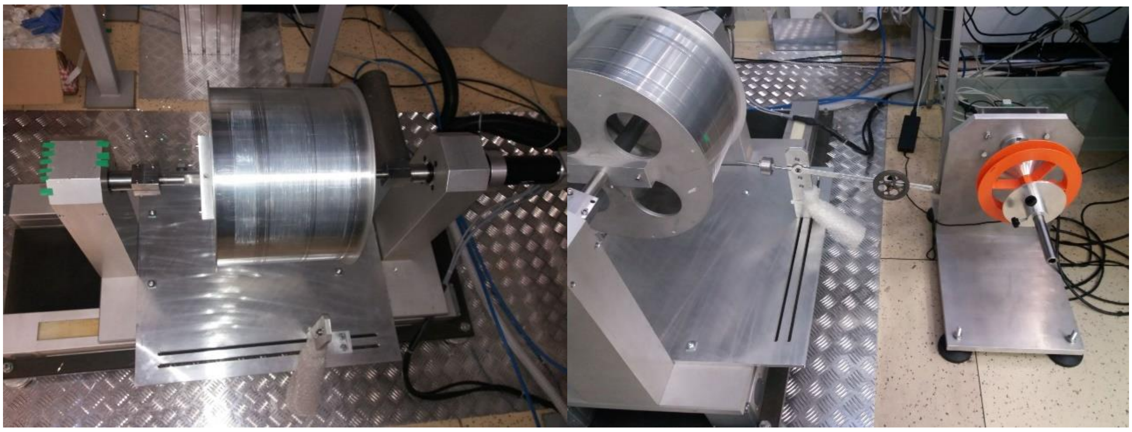

Figure2.6: Left: The Scrolling motor Right: winding drum

In order to control better this process, have used a LabVIEW software which is connected to the Scrolling machine one can observe in above pictures Therefore by changing the parameters like the Drawing Speed [m/min] and Feeding speed [mm/min] will reach different values of Optical Fibers.

We have the most Sizable part of fiber at the end of spin, there is pictures one can put here:

As know have synchronized both two motors one which is controlled by lab view sand the other one which is being controlled by second motor which have made it because otherwise would have a break or overlap of the fibers.

So, have made some different types of fibers some for the other laboratories and some for the laboratory Therefore can use them for some observations with the microscope do some measurements on the dimension of the fiber and Moreover for Testing of cutting; Normally in the commercial fiber not the fiber; they have a stage on the tower that is putting a polymer around the fiber during the drowning and it's called coating because it's quite thin .

So there is a special part which fiber goes through the liquid polymer and then there is an UV light that make the polymer structure and one can have two different kinds of polymer the one that one will prepare by UV light or the one that one will put with temperature Therefore in this case one will need a small and the fiber should pass through the oven .

We have cut the samples and put them on the spool but just to remind one as one can remember had different dimensions of the fibers.

So, have done different sections with different dimensions. for measuring the diameters, have a microscope and on the top of it there is a web cam Therefore will connect it to the pc Therefore one can measure the dimension of the fiber.

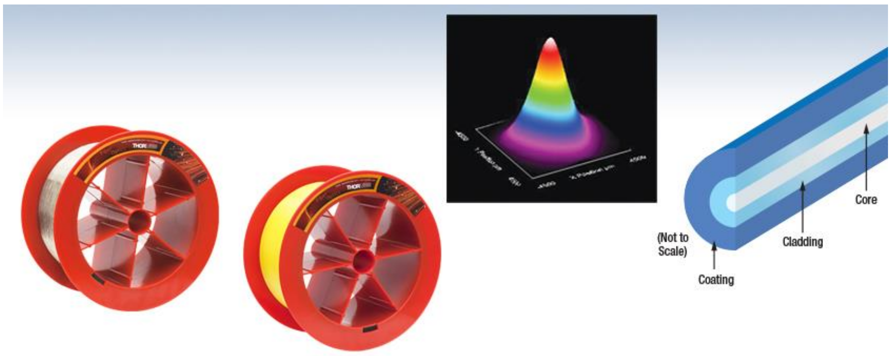

Figure2.7: Scroll the Single Mode Fiber

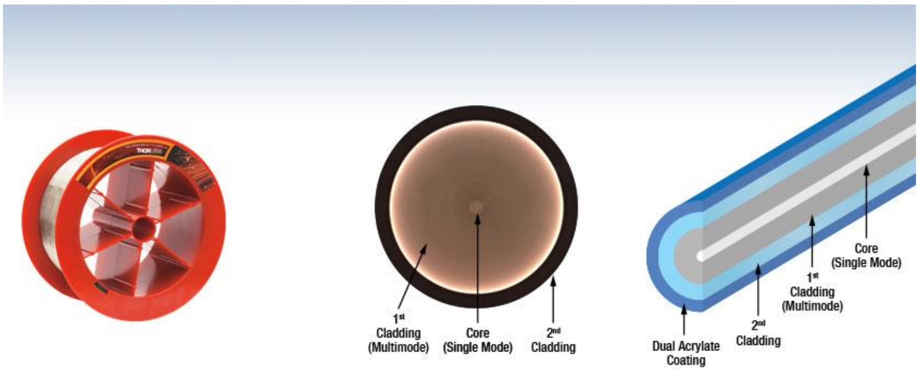

Figure2.8: Scroll the Double-Clad Fiber

for the fibers just notice that as the diameter of fiber is sizably small the probability to have a break in the fiber would be less on the contrary if the fiber is thicker the probability to have a break would be more from mechanical point of view ;how the material behaves ;if one do a small fiber is easier to work with them.

Sometimes it happens that the fibber would be broken under attention because there are some defects in the fiber. Use some instruments to cut the fibers or to join the fibers together.

The instruments for cleaving or cutting fibers are the commercial instruments Therefore all the parameters are set for commercial fibers Therefore the fiber that are made by silica glass Therefore when one want to use them for other purposes one have to change this parameters like the purposes ;but when one want to cut the fiber normally one have to put two items that clamps the fiber to hold the fibers with a certain force this force is normally too much for the fiber since it will breaks already the fiber Therefore one to change this clamping force to reduce it another point is that after clamping the fiber is put under

attention (a little bit) and again the attention is too much for the fiber ,so when one usually cut one fiber by diamond the intention makes the fiber breaking along alien Therefore when one want to go for the fiber ,so when one usually cut one fiber by diamond the intention makes the fiber breaking along alien Therefore when one want to go for cutting one fiber should use another recipe (a new menu) with a lower clamping force and lower attention ;in order not to break the fiber .

so, one has to clean one fiber ideally then cut them (90 degrees) then machine will put them aligned; one towards the other; then the electric arch discharges in that point and they are used just there (attached together; That it observes [ms] like being the same fiber).

Because one will lose a small amount of light in that point.

It is somewhat joining them ideally but when one want to do it with the fiber is more difficult especially when one want to put together one of the fiber with one of the commercial fiber :

they don’t match because they are different Moreover it would be possible that the refractive indexes would be different in that case because one can have more loss of light in that area .

So what have to do in that case for example (what have found)is to apply the electric discharge not in the middle but to do it on the silica fiber Therefore that the other one just to be melted by the heat that is on the fiber because the arch itself is too powerful for the purposes Therefore it's like not symmetric slice manage to do it Therefore it's something that one can learn it in the lab but it's not a really simple process because every time that one have changed one recipes of one fiber one have to change all the parameters .

Recipe is the list of all of one parameter which is stored.

2.3 Optical Fiber characterization

So, the idea is to characterize the fiber now and the fiber is one did together; so, what have to do is to try to measure the fiber to observe if the fiber is working; is guiding the light to measure the losses.

the first item can do is to put the fiber and to launch the laser light from one side and to observe what is coming from the other side and to check it into the camera is an old one but still is working Therefore it would be connected to the PC and hopefully it will work: because the problem is that it's an old and she couldn’t understand why sometimes it was working and sometimes it didn’t.

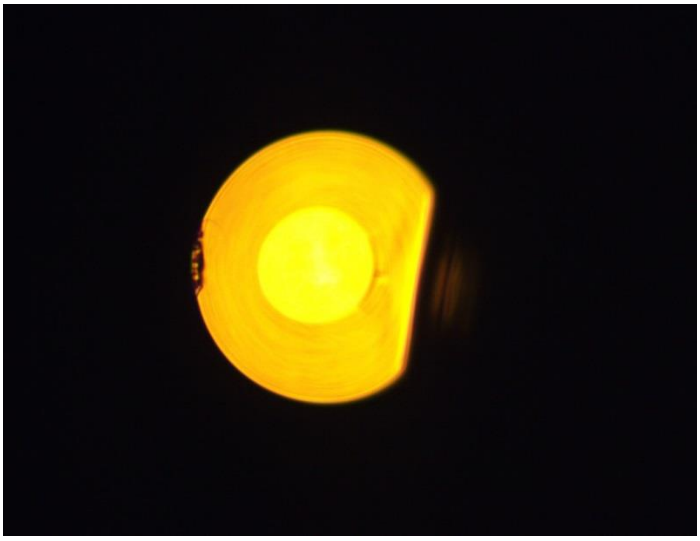

Figure 2.9:   Fiber Cross Section at the optical Microscope

The figure 2.9 shows the cross-section of the fabricated fiber as we can see the dark areas can be configured out since, between core and cladding, has confirmed an efficient adhesion between the two different glasses which has caused this bubbles also

The laser used is a 1.3[um] laser because this wavelength is not absorbed by Erbium and Moreover Erbium Therefore it's a wonderful wavelength to check the guiding inside the fiber; because it's not absorbed.

Because; otherwise if one launches the light at which is absorbed by the IONS; one is not observe in what is guided; because there is an interaction Therefore it's not a wonderful wavelength

As one can observe the phosphate fiber is quite strong and flexible but sometimes fibers are less resistant specially if the Diameter of the fiber is more Sizable.

So, in this case as could be remembered we did three different Dimension Therefore what can do is just to check one of this because the process, glass is the same.

This operation can be done in different ways ;one is to use the machine like an instrument like this one that is called leaver that will cut the fiber and one can cut it straight or angled as one need ;one have different order/dimensions ;so one can cut the fiber from a small size like 80[um]to 1[mm]for example.

One just need to change the holders to keep the fiber in place what the instrument do is to clamp fiber ;then put the fiber with a little bit of Tension then with the wedge are doing small scratch beside of the fiber and then because of the Tension the fiber breaks ;but breaks in a controlled way crucially straight and clean cut ;the problem is that all the instruments are designed for commercial fibers Therefore; silica glass fibers that is strong .

So for the purpose all the parameters like clamping is too high, the Tension is too high ; Therefore what one have to do is to change the parameter in order to work by using its menu one are able to create a new recipe .but since the fibers are typically a little bit different dimensions or whatever sometimes one have to adjust it in order to work properly with one fiber .

Another way is to use it manually which means to use this kind of scribe that is Diamond wedge scribe one does the same process but manually.

The camera which is used is an infrared camera.

Therefore what can do is to put the fiber on the table ; observe how much fiber have and then one cut it manually and with help of microscope one will go much closer to have a close touch of the end of port of laser the start point of the fiber ;then will Moreover put the light on the microscope which is one can observe two fibers on the left one have a silica one the one connected to the laser.

On the right: one will observe the phosphate fiber and the appearance is not spectacular

The right one which cut with the hands manually is not so straight. but now the fibers are not far away from each other and Moreover the focused not the same as one will observe.

Since the cut was not so ideal then did another cut on the fiber since the important which is the core had not a neat cut.

During observing the fiber under microscope, it can happen that one can observe it and the other one can't observe that one should just align it.

So, during the coupling of the fibers are able to observe under microscope and able to align it thanks to three axes the movement of the opto-mechanical stage.

If one fiber has a large core (multimode) therefore it is not difficult to couple the light inside the 50 large core.

The problem is there when one work with single mode fiber in which the core is for example 7[um] then one has to couple 7[um]with 7 [um]in this case one is 7[um]to 50[um] will through the light.

What will do from the other side is to cleave fiber from the other side to have a wonderful output and then will try to observe in the camera.

we have silica to non-silica fibers Therefore they are ''Bulk coupled ' it means they are just one face to the other face are not connecting them together (Fusing them together) just one in front of the other (Very close) Therefore this is just a way to send one light because the light in this case is coming directly from the laser .so one wall write about the characterization of the fiber one will write one need to check if the fiber is working correctly Therefore one of the items one have to check is Guiding the light because otherwise not a real fiber Therefore how do one find it

one launches the laser light from one side and one will observe what will happen inside the fiber Therefore one will explain it one can describe the light inside the fiber in two ways:

using geometrical optics that's approximation one can't explain everything in this case

Then one can treat the light as an electromagnetic wave à beam propagation

So, one can put all the electromagnetic equation and then one can study how the electromagnetic that is wave is propagating inside the fiber.

one can observe that the light can travel inside one fiber through modes (different modes)and depending on the dimension of the fiber change of refractive index between core and cladding one can have one or more modes ;when one have a single mode fiber one can have in the fiber only one mode that is the Gaussian mode fiber traveling inside one fiber.

When one have a multimode fiber one have many modes one can have few modes fiber one will solve the Maxwell's equation through the fiber; just to reach points that one will have a fundamental mode that is a Gaussian mode then one will have the second order mode going up and down; then one have a free mode.

Our laser is a critically small source, a dramatically low power it is somewhat less than 1[mw] for the safety can put the glasses which will protect from the propagation (cutting the infrared light glasses)

One has to care in two points à1.one is that one has to have one beam inside the camera and the other one is to align well two fibers because otherwise light is not entering the fiber;

We made the fiber and it should include core and cladding; the light must be confined inside the core Therefore one should observe lighter –the core compared to the cladding.

When one will prepare the fiber used a tube for the cladding and a rod for the core ;when one put the rod inside the clad what one have is something like there is some space in the picture of monitor(pc)since one have an area without material (just vacuum) Therefore one need a little bit of space one try to make this space as small as possible but Moreover one will need a space Moreover because along YouTube ;normally the tube is not ideally straight : Therefore one need a little bit of space because otherwise one cannot put inside the rod the core then one will put the vacuum; but sometimes it happens that it doesn't close ideally some open parts remains and in this case in some part of the fiber there somewhat smile shape which is quite often one will have a small smile ;this is a little bit open part of the fiber where the vacuum was not effective and it was not ideally closed .

However, this is not a problem since the air still has a refractive index that is lower than one glass Therefore one will still have guiding.

Sometimes; Moreover, one can have a sort of cracks inside the structure the cracks are usually where one will have the open part of fiber .and it's because of the pressure and Moreover probably there is some stress inducing the glass due to this void.

What will do is to decreasing more and more the light Therefore by decreasing the light one observing that one will have the light only in the core because mostly the light should be in the core and Moreover try to increment the light adjusting by coupling better two fibers.

By charging the position of the two fibers as known since one is multimode and the other one is single mode and are going from a smaller core to a larger one in this case will have more opportunity of changing the position unless reach the maximum value and will go to the cladding part .our fiber is 125[um] one (the smallest one) with 52[um] of core size.

As the lasers are used to cut materials like metal Therefore in this case one should take care while working with powerful lasers ;something like [KW].however ,the laser which are working with is less than 1[mw] consider that all that laser should work on the safety area with all safety rules because they are absolutely dangerous .

Moreover one should consider that if the laser is not co limited its going out from the fiber Therefore it means that the power is spreading critically fast ;if one have a lens it can space well for meters and this can be dangerous it can make one blind (this type laser) Since lasers can have different wave lengths are in infrared range. the lasers with colors are those between infrared and UV.

We want to try to measure the losses fiber (it means how much light) Is lost along one fiber due to the effect to impurity –material and Therefore on.so what need to measure :1.a power meter ,so something that measures that power of that light ;so one need to put a detector that is able to observe the infrared because otherwise it is not possible to measure it. and the detector should be calibrated. calibrated for that specific wavelength; so, in this case as said are working with 1.3 this means that need a calibration for 1.3: so, will put Lambda ;1.3in power meter.

Consider that dBm=10log power with respect to 1[mw]. so 1[mw]is 0 dBm and dB is the ratio between the starting and the output Therefore if one says that the power is -3dB as decreased -3dB it means that is 50% is the half power.

if one has a passive fiber this is just transmission Therefore one will have typically the same power.

If one has an increasing power in the output it doesn’t mean its producing power it means it's using the power from the source that is called pump source. While pumping the fiber Therefore giving energy to the fiber.

2.4 Optical Fiber Cleaving and Splicing Process

The instrument which are going to work with is Fujikura CT-105/106 which is a large diameter optical fiber cleaver the fact that one observe the light inside the fiber that is changing the shape is because of different modes one have inside the fiber; Therefore one are coupling the light inside the fiber in different modes.

Figure2.10: Fujikura CT-105/106 for the Cleaving process

But since here has a sizable core compared to the standard fiber; is not difficult to couple.

Coupling the light would be difficult if one has a small fiber.

So, will use the 80[ma] laser and will switch on; move the fiber with help of 3D axis optical stages .in general this type of items is called Opto-mechanics.

Web: Thorlabs: one can observe lots of optical Devices.

so, will insert the Data in excel file:

Just in case sometimes it happens that during the process of measurement one fiber will break therefore what one does is to do all measurements from the beginning with another fiber.

CW: means that one has commonly a power; it’s a stable power like one will switch on the light and the light would stay on. the opposite is the pulse; in this case one will have pulses like Nano second pulses and the behavior could be different the laser that is pumping is frequently continuous wave.

It's Moreover possible that the fiber changes the position during the measurement Therefore want to measure the correct value for the power measurements and this can be one reason for why are doing multi times measurements.

First of all, before using the cleaver machine it is commonly better to use gloves because it's possible when someone’s hand have sweat or the oil on the skin and when one touch them then the fiber would be touch with then Therefore that’s why it's Moreover better to clean it.

The other part is related to the holders that are different for different dimensions of the fiber Therefore for example one have a fiber that is around 125 Therefore need to use (for the lower part 125 and the upper part insert U=8400?!!) to use the instrument one need to change them for the fiber

When one has a fiber with a plastic coating on it (like Polymer coating) that makes them more resistant à Therefore one will remove coating from one side but not from the other side Therefore one can have different dimension from one-side to the other.

One has to make tensions in a wise way; Moreover, when one use different dimensions since one can break one fiber or damage one holder

So, the machine will clamp the fiber from the both sides and then firstly will put some tension on the fiber and then one clamp it but it could happen that the tension is too high for the fiber Therefore it could happen that one has to decrease the tension.

So one will switch on the machine .first one have to set right menu that means one have to choose in the menu which one need as can observe there are some standard recipe but this are for silica that is not really what need and then there are others where one will use for the fiber (we have defined them before) .we can try the one “bio 121 ”that should be similar to the fiber .

It can happen that holders don’t close because they are not well positioned during changing them. after fixing it one can chose them correctly. then one will press the set key and it will start increasing tension Therefore it could happen that the fiber breaks.

If the machine was not able to correctly increase the tension it can be due to the fact the fiber is short or dimension of the fiber are not well suited with clamp .so in this condition the fiber is not well clamped Therefore Moreover try to increase the clamping force.

Or can define the new recipe (menu) with the data; with increased force (Gram force) Moreover in another laboratory will have a slicer the one that can fuse together the two fibers and this instrument is superb when one wants to observe the fiber; so, one can observe both fibers.

So one will need to Moreover change the claddings of this machine in order to be able to clamp one fiber .the clamping magnetic of this machine is really strong .so are able to observe how was the cleaving what is normal with phosphate is that they are not commercial fiber its more complicated to work with them .so it's possible to cut the fiber it doesn't work .however ,before it was working but its normal .

The reason why will put plastic on instrument is because of the dust because this are quite expensive instruments and dust is not a pleasant phenomenon for them. for cleaving one will have a step by step process which is defined on the LCD of instrument. the tension force before was 2000 Gf (Gramm force) and now will put like 2400 Gf (we will put a more sizable one).

©FUJIKURA LTD.

Figure 2.11: Fiber fusion splicer, Fujikura FSM-100P

In the Photonext website one will find the manual instrument Therefore one can use it inside of this thesis since its commercial but one can say in the references that the images were taken from the instruction manual of the machine Moreover for the other one "FSM100 or 110"but can easily find this instruments in the website like splicer ,cleaver ,… and one can Moreover read about the project .

Chapter3: Design and Results of Glasses

Introduction

This chapter explains the last step of This Practical Thesis which is dedicated to Testing and measurement of Optical fiber will start with measuring the refractive index of the optical fiber both for core and cladding and then will finalize it with Attenuation losses measurement according to the cutting back technique.

3.1 Refractive index measurement of the core and cladding

In optics, the refractive index or index of refraction of a material is a dimensionless number that describes how fast light travels through the material. For example, the refractive index of water is 1.333, meaning that light travels 1.333 times as fast in vacuum as in water.

This is described by Snell's law of refraction, $n1.\sin(\theta1) = n2.\sin(\theta2)$, where $\theta1$ and $\theta2$ are the angles of incidence and refraction, respectively, of a ray crossing the interface between two media with refractive indices n1 and n2. The refractive indices also determine the amount of light that is reflected when reaching the interface, as well as the critical angle for total internal reflection and Brewster's angle. The refractive index is one of the most important parameters in the optical fibers since the larger the index of refraction, the slower light travels in that medium.

When the sample is coupled by the prism inside the Metricon machine; Then the measurement of the refractive index is done with 5 different wavelengths of the laser which are used to illuminate the sample so we will have the refractive index at 5 different wavelengths.

There is connected an air compressor to the machine since the Hydraulic Actuator of the piston prism is working with the force which is made by this air compressor.

The measurement process is like one can make a reference with the Auto ref case then by coupling the sample you are able to measure the refractive index. Before starting the measurements its highly recommended to simply clean the surfaces of the prism and the sample in order to reach the maximum accuracy.

The machine wants to work with in order to measure the refractive index has 5 different wave lengths there is two handles for horizontal and vertical alignments and there is one power selector which should be turned on inside to be able to reflect the lasers on the sample. with these 5 different wave lengths use to eliminate the sample Therefore will have the refractive index at 5 different wavelengths. So, will do coupling the sample with prism and will do the measurements. The reason why will have the air compressor connected to the machine is because the piston is working with air.

The name of the program will use is Model 2000s and it is Metricon. Which is the name of the machine Moreover.

According to the website [13]: compared to instruments based on optical interference, ellipsometry, or Abbe refractometry, the 2010 IM's prism coupling technology provides unmatched index accuracy, resolution, and minimal sample preparation is required. The system Moreover measures dispersion, index gradients, dn/dt and loss of optical waveguides.

Applications over view:

_optical waveguides

_index measurement of bulk /substrate materials/liquids.

–Surface Plasmon (SPR) and waveguide sensors.

_characterization of Nano materials.

_measuring dispersion.

_polymers /polyimides /photo resists.

_index / birefringence /orientation of film and bulk polymer materials.

–dn/dt measurements, …

The following is a representative list of films, substrates and bulk materials types which can be measured by Metricon 2010/M system. (free-standing films or bulk samples of any of the below film materials are also measurable):

Films: SiO_2 (doped and undoped), silicon nitride, plasma SiN, silicon oxynitride, photoresists, polyimides, polyanyline, liquid crystals, PMMA, holographic gels, sol gels, silicon, SiC , diamond, epi garnets, electro -optic polymers, AlGaAs, $BaTiO_3$, GaN, InP, ITO, KTP, MgO, PZT, PLZT,Si, Ta_2O_5, TiO_2,YIG, ZnS, ZnSe, ZnCdSe, ZnMnTe, ZnMgTe.

Bulk or substrate materials: Quartz, optical glasses, chalcogenide glasses, sapphire, PET, polycarbonate, polyethylene, polystyrene, $LiNbO_3$, $LiTaO_3$, SiC, ZnS, GaP, GGG, MgO, YAG and other laser crystals.

So with Metricon make a reference, enter on the laser a visible and make another reference .So with Auto-ref put the sample wavelength and then start to measure :but before one start sampling one will simply clean sample with Ethanol and will tape the sample from back where will couple it Therefore like the mirror will be on the side of the glass; Therefore then will couple the sample by prism (as said before will simply clean the sample and the prism by Ethanol) and will put the door on the machine.There is Moreover one another handle which will use to easily regulate the coupling of the sample.

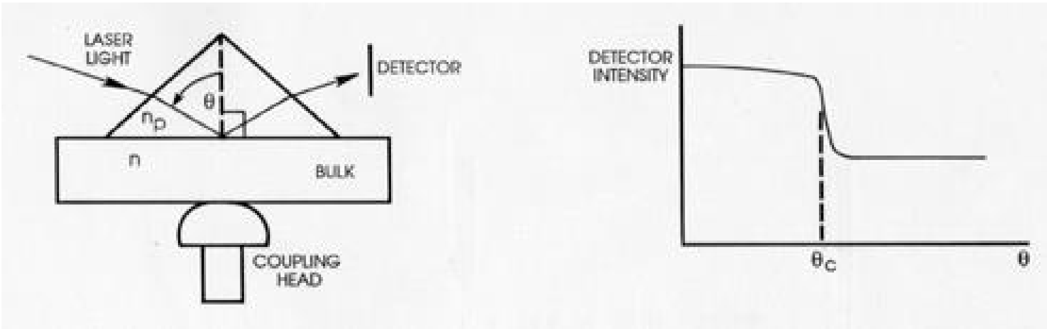

Figure3.1: Measurement principle for Bulk material

If a material of index n is in contact with a prism of index np, as the sample and prism are rotated with respect to the stationary laser beam, light striking the base of the prism will be totally reflected to the system photodetector until the angle of incidence becomes less than the critical angle, θc where:

$$\theta_c = \arcsin(n/n_p)$$

The Model 2010/M determines the critical angle automatically and since np is well known, the film index is easily determined from equation of critical angle.

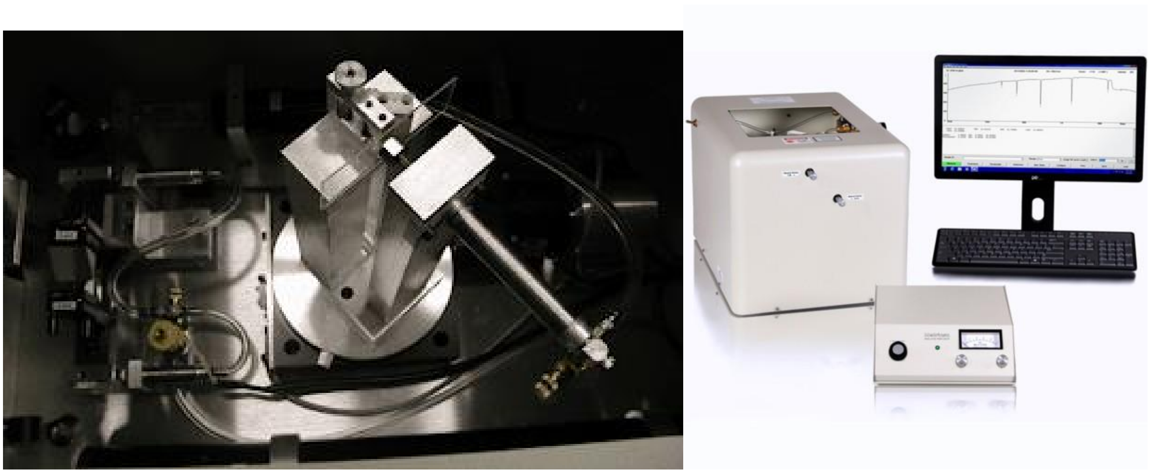

Figure3.2: Metricon machine. Left: Interior components of Metricon. Right: Metricon machine instruments

Before Starting the measurement, procedure rechecks the following Checks:

Check to ensure the LASER power supply output connector (white two lead connectors) is connected to the laser power supply.

Open the compressed air (CDA) valve by turning the knob CCW two turns.
Check to ensure the sample holder pressure gauge located on the right position.

Turn ON the 633nm HeNe LASER by moving the red switch to the ON position. The switch light will turn On. It's better to Allow the LASER to warm up for a while before starting the test measurements.

We can scan start around 1.59 so we make a reference like a baseband and by putting the mode on the Auto ref one is able to measure the refractive index. Therefore, the value of the reference was given in the manual by the mode Auto scan its possible to see the shape of refractive index and in this case the Knee shape on the monitor will declare the value of the refractive index. if the knee shape has a 90-degree shape then we reach that it's a good refractive index measurement otherwise we should retry it again.

In order to be sure if the sample is homogeneous one technique can be to measure the refractive index in different points of the sample so by coupling and measuring the refractive index you are able to increase the test accuracy .In the way that if the glass is homogenous the refractive index won't change.

There are some mechanical segments on the machine which let you to regulate the position of the sample before coupling.

This knee shaped line provides the refractive index. for selecting different wavelengths will turn off previous one and then will select next one by turning it on .the offset is just for regulating signal before pulsing .then by selecting auto scan on the software to be able to observe the shape of the diagram .so by regulating horizontal and vertical angle of the sample will make the knee shape and then will measure the refractive index.

So will do this measurement twice with two different sample point to observe if the sample is homogenous ;so if the refractive index is not changed in the second time then can say that the sample is homogenous .so during the Testing deal with two different problems :one was related to the scanning rate which since was out of the range couldn't observe the knee shape the other comes from when changed the position of the sample since the position point was not Therefore agreeable couldn't observe Moreover the knee shape.

Probable problems can come from:

One didn't align the sample in a proper way.

Forgetting to turn on every device power for machine.

So, for example have chosen two points for the sample corner.

Wavelength [nm]	Refractive index
633	1.5816
825	1.5756
1061	1.5717
1312	1.5685
1533	1.5661

Table3.1: Refractive indexes measured by Metricon machine for Core Glass

Wavelength [nm]	Refractive index
633	1.5774
825	1.5713
1061	1.5675
1312	1.5642
1533	1.5620

Table3.2: Refractive indexes measured by Metricon machine for Cladding Glass

So, have measured all this refractive index then will take the norm of the refractive indexes like N=radical of | (N2)2+ (N3)2 | and will compare it to the old glass composition which was actually measured before and is quite similar behavior to the glass.

3.2 Optical Fiber characterization

In this part we are going to get more familiar with a Technique which is Called “Cutting back ” for optical fibers :

The cutback method involves comparing the optical power transmitted through a longer piece of fiber to the power transmitted through a shorter piece of the fiber. The cutback method requires that a test fiber of known length 'L' be cut back to a shorter length. It needs access to both ends of the fiber

The fiber is displaying a numerical aperture Therefore we are going to measure the refractive index at 5 different wavelengths

So We will do the cut back for optical fiber: because need to be independent from the losses caused by the input and the output and all the system if one cut different pieces one only observes the fiber loss; one can extrapolate the fiber loss.

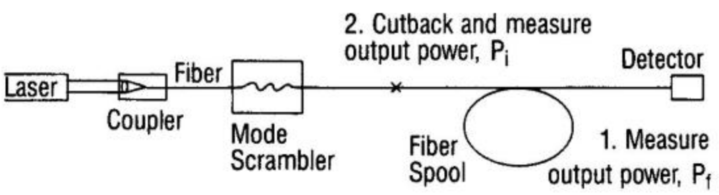

Figure 3.3: Schematic of laboratory set-up for Cutback Method of optical Fiber

In figure 3.3 you can see the schematics of laboratory setup with the help of the instruments have been shown in the picture.

Consider that the Detectors are used at the end of optical fibers are Digital optical meters which are able to measure output power of Optical fibers. We will cut the end of optical fiber and the measurements will be done for 5 different lengths of our optical fiber then we will see how will be our results of attenuation losses .in part 3.3 you can find much specified details of results.

3.3 Attenuation

Attenuation (loss) can be expressed as a logarithmic relationship between the optical output power and the optical input power in a fiber optical system. It is a measure of the decay of signal strength, or loss of light power, that occurs as light pulses propagated through the length of the fiber.

The length of the fiber, is given in kilometers, and the attenuation coefficient, Γ, is given in decibels per kilometer (dB/km). Because the designers of optical fiber systems need to know how much light will remain in a fiber after propagating is given to a distance, one of the most important specifications of an optical fiber is the fiber's attenuation.

In principle, the fiber attenuation is the easiest of all fiber measurements to make. The method which is generally used is called the "cutback method." All that is required is to launch power from a source into a long length of fiber, measure the power at the far end of the fiber using a detector with a linear response, and then, after cutting off a length of the fiber, measure the power transmitted by the shorter length. The reason for leaving a short length of fiber at the input end of the system is to make sure that the loss that is measured is due solely to the loss of the fiber and not to loss which occurs when the Light source is coupled to the fiber.

$$\alpha(dB/m) = \frac{10\log_{10}(Px/Py)}{L}$$

Different launch conditions can lead to different results. For multimode fiber, the distribution of power among the modes of the fiber must be controlled. This is accomplished by controlling the launch spot size, i.e. the area of the fiber face illuminated by the light beam, and the angular distribution of the light beam.

When the launch spot size is smaller than the area of the fiber face and the numerical aperture NA of the input radiation is smaller than the NA of the fiber, the fiber is said to be underfilled. Most of the optical power is concentrated in the center of the fiber and mainly low-order modes are excited.

Original Data									
DeltaL	L	I	P		Slice #	L	I	P	Slice #
cm	cm	mA	dBm	uW		cm	mA	dBm	
	113	90	-11,75		3	68		-10	10
-5	108	90	-11,4		4	73		-10,25	9
-5	103	90	-11,35		5	78		-10,35	8
-5	98	90	-11,15		6	83	80	-10,8	7
-5	93	90	-11,1		7	88	80	-10,9	6
-5	88	90	-10,9		8	93	80	-11,1	5
-5	83	90	-10,8		9	98	80	-11,15	4
-5	78		-10,35			103	80	-11,35	3
-5	73		-10,25			108	80	-11,4	2
-5	68		-10			113	80	-11,75	1

Table3.3 :Caliber Fiber Loss

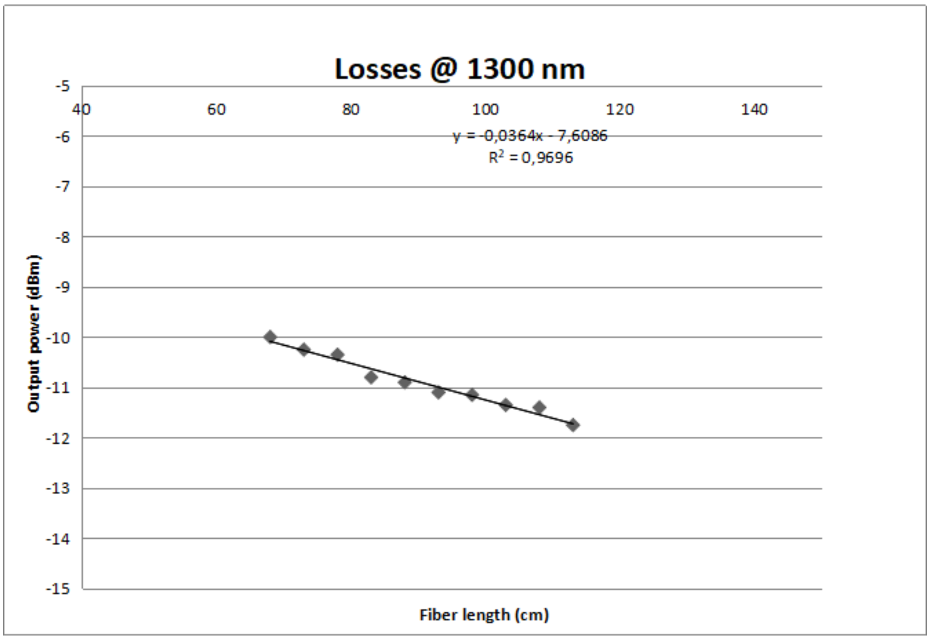

Figure3.4: Caliber Fiber Loss Diagram, Output Power Vs. Fiber Length

The attenuation value, can be evaluated through a linear least square fitting of the experimental data which is -3.75dB/m where the fitting value (for whole length is -3.642424 dB/m). This value is mainly due to absorption and scattering effects. As expected, the result is considerably higher than silica attenuation losses (0.2dB/m);

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Appendixes

Appendix A:

Optical Test benches:

Figure A.1: A Sample of Photonic Test benches

This laboratory which one can observe in the photo is for Photonic Devices Group of POLIMI which is equipped with five optical benches suitable for a broad range of measurement. Each setup is equipped with microscope and/or visible cameras; micro- and Nano-positioning system for fiber and objective butt-coupling; thermo-electric controller for temperature stabilization of the samples; manual or automated polarization controllers; PC for bench management. Four setups are equipped with a PC-controlled fiber positioning system and tapered/lensed fiber suitable for characterization of Nano-waveguides. One setup is devoted to medium and large core waveguides or fiber characterization. Vertical mounting for grating coupler alignment are available and can be placed on any setup on request.

The working process is like whenever one wants to measure or work with one optical instrument like optical fibers one will First, should align and position the optomechanical segmented instruments and then can put the optical fibers in order to measure and test on those optomechanical Segments with the help of two magnetic holders. Then for example can couple the optical fibers end to end Therefore in this case the other side of the optical fiber would be visualized with a Camera which is connected to the computer Therefore in this case it is possible also to observe how is the propagation status inside of optical fiber or can use a Photo Detector in order to measure the attenuation losses when its connected to a laser source.

Appendix B:

Technical components tutorial which is used in the laboratory

Optical Fibers:

in this part we will concentrate on the optical fibers

An optical fiber is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair.

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 rates) than electrical cables. Fibers are used instead of metal wires because signals travel along them with less loss; in addition, fibers are immune to electromagnetic interference, a problem from which metal wires suffer excessively. Fibers are also used for illumination and imaging, and are often wrapped in bundles so they may be used to carry light into, or images out of confined spaces, as in the case of a fiber scope. Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers. we have single mode and multi mode optical fibers.

As an assumption a real optical fiber can have a core of 10[um] for a single mode and a core of 50 to 68 [um] for the multi mode while the second layer has a thickness of 125[um]and 250 [um] of thickness for the outer protective (Jacket) at 800 [nm] we had the first generation of semiconductor Optical fibers (GaAs).

that's crystal clear that you are also able to add additional protective Jacket which has 2 to 3 [mm] of thickness.

In a plastic optical fiber which is considered a multi optical fiber we will have 5 million propagation.

K0:nd < beta < K0:nc

we will have different Types of connecting two fibers :

1.Splicer (for permanent) here we will use Fujikura

2.connectors which are Implemented on the heads of two ends of fibers

3.A coupling

we have APC/FC/PC connectors

Note: The FC connector is a fiber-optic connector with a threaded body, which was designed for use in high-vibration environments. It is commonly used with both single-mode optical fiber and polarization-maintaining optical fiber

The two connectors have two different shapes in order to not minimize back reflected light (in this cases we can use angle reflector connectors) in order to perform the Splicing we should remove the polymer protective layer

The instrument which we are going to work with is Fujikura (Pictures are shown in Figure 7 and8) which is a large diameter optical fiber cleaver the fact that you see the light inside the fiber that is changing the shape is because of different modes you have inside the fiber;so you are coupling the light inside the fiber in different modes .

A general cleaving strategy that is employed is known as the scribe-and-tension strategy or the scribe-and-break strategy. This process involves introduction of a crack in the fiber, generally by means of cutting tool made from a material such as diamond, sapphire, or tungsten carbide, followed by the application of tensile stress in the vicinity of the crack.

However, the specific implementations of the cleaving vary and result in cleaves of different Qualities.

Certain implementations may apply the tensile force uniformly across the cross section of the fiber whereas others might bend the fiber around a curved surface causing excessive tensile stress on the outside of the bend. The introduction of the crack in the fiber may also be generated in different ways; the crack may be introduced at a single point on the circumference or it may be generated all along the circumference of the fiber prior to the application of the tensile force.The circumferential introduction of the crack often allows fibers of considerably large diameters to be cleaved while maintaining high quality of the cleave. Cleaving is the process by which an optical fiber is “cut” or precisely broken for termination or splicing. Just like cutting glass plate, fiber is cut by scoring or scratching the surface and applying stress so the glass breaks in a smooth manner along the stress lines created by the scratch. Properly done, the fiber will cleave with a clean surface perpendicular to the length of the fiber, with no protruding glass on either end (called a lip).

A cleaver is a tool that holds the fiber under low tension, scores the surface at the proper location, then applies greater tension until the fiber breaks. Good cleavers are automatic and produce consistent results, irrespective of the operator. The user need only clamp the fiber into the cleaver and operate its controls. Some cleavers are less automated, for example requiring operators to exert force manually for breaking the fiber, making them more dependent on operator technique and therefore less predictable.

Fusion Splicing:

Fusion splicing is the act of joining two optical fibers end-to-end.The goal is to fuse the two fibers together in such a way that light passing through the fibers is not scattered or reflected back by the splice, and so that the splice and the region surrounding it are almost as strong as the intact fiber.

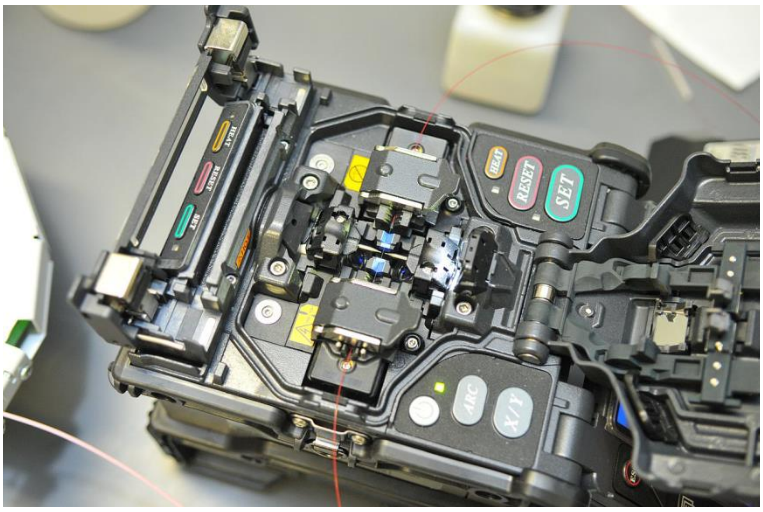

Figure B.1 :Optical Fiber Splicer Machine

The source of heat is usually an electric arc, but can also be a laser, or a gas flame, or a tungsten filament through which current is passed.

Laser Diode:

A laser diode, (LD), injection laser diode (ILD), or diode laser is a semiconductor device similar to a light-emitting diode in which a laser beam is created at the diode's junction. Laser diodes can directly convert electrical energy into light. Driven by voltage, the doped p-n-transition allows for recombination of an electron with a hole. Due to the drop of the electron from a higher energy level to a lower one, radiation, in the form of an emitted photon is generated. This is spontaneous emission. Stimulated emission can be produced when the process is continued and further generate light with the same phase, coherence and wavelength. We will start the fallowing process :we will apply the current and Temperature to the Laser Diode we will measure the Output power with Power meter . as we know the optical fiber has a fundamental mode HE11 but since it have a circular shape so by changing the shape of fiber by stretching we will have also other modes that will change the dBm shown on the power meter. LP:In electrodynamics, linear polarization or plane polarization of electromagnetic radiation is a confinement of the electric field vector or magnetic field vector to a

given plane along the direction of propagation. See polarization and plane of polarization for more information.
The orientation of a linearly polarized electromagnetic wave is defined by the direction of the electric field vector. For example, if the electric field vector is vertical (alternately up and down as the wave travels) the radiation is said to be vertically polarized.
The point is that for Weakly guided modes you can write only LP modes you will need a Tune able filter to fabricate the Optical spectrum analyzer like Fabry Perot .
The higher the reflective the narrower the filter you will have !
by increasing the Temperature the beam filter will be also disappeared .So it is Important to control the Temperature of Laser . Increasing the Temperature Usually it means that we will have also the Power Losses !

Optical Spectrum Analyzer:A spectrum analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals. The input signal that a spectrum analyzer measures is electrical; however, spectral compositions of other signals, such as acoustic pressure waves and optical light waves, can be considered through the use of an appropriate transducer. Optical spectrum analyzers also exist, which use direct optical techniques such as a monochromator to make measurements.

By analyzing the spectra of electrical signals, dominant frequency, power, distortion, harmonics, bandwidth, and other spectral components of a signal can be observed that are not easily detectable in time domain wave forms. These parameters are useful in the characterization of electronic devices, such as wireless transmitters.

Coupled mode theory (CMT): is a perturbational approach for analyzing the coupling of vibrational systems (mechanical, optical, electrical, etc.) in space or in time. Coupled mode theory allows a wide range of devices and systems to be modeled as one or more coupled resonators. In optics, such systems include laser cavities, photonic crystal slabs, metamaterials, and ring resonators.
E(x;y) = A1.e1(x).exp(-jbeta1.z)+A3.e3(x).exp(-jbeta3.z)

Erbium Doped Fiber
Erbium-Doped Fiber Amplifier (EDFA) is an optical amplifier used in the C-band and L-band, where

the loss of telecom optical fibers becomes lowest in the entire optical telecommunication wavelength bands. Invented in 1987 [1], an EDFA is now most commonly used to compensate the loss of an optical fiber in long-distance optical communication. Another important characteristic is that EDFA can amplify multiple optical signals simultaneously, and thus can be easily combined with WDM Technology.

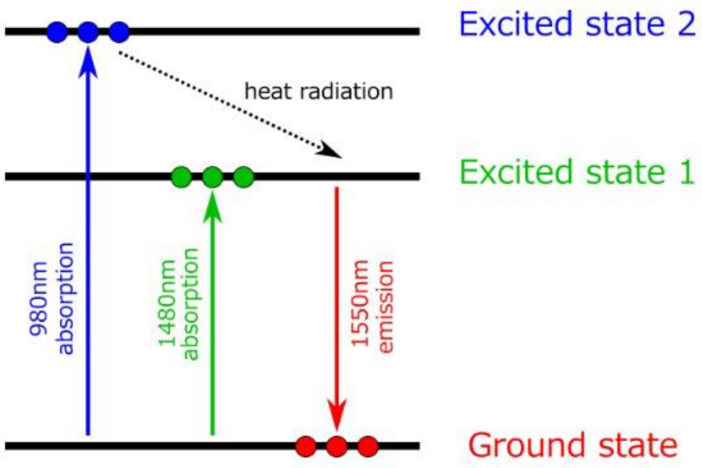

Figure B.2 :Energy diagram of Er

When an EDFA is pumped at 1480 nm, Er ion doped in the fiber absorbs the pump light and is excited to an excited state (Excited state 1 in Figure 3). When sufficient pump power is launched to the fiber and population inversion is created between the ground state and Excited state 1, amplification by stimulated emission takes place at around 1550 nm. When an EDFA is pumped at 980 nm, Er ion absorbs the pump light and is excited to another excited state (Excited state 2 in Figure 10). The lifetime of the Excited state 2 is relatively short, and as a result, the Er ion is immediately relaxed to the Excited state 1 by radiating heat (i.e. no photon emission). This relaxation process creates a population inversion between the ground level and Excited state 1, and amplification takes place at around 1550 nm.

Appendix C:

Some Further Applications :

LIDAR has many different applications which we can name as :Topography, Space, Transportation and Robots ; For automotive applications(mainly ADAS), an impulse length of about 30 ns is commonly used.

on the other hand, are currently large and expensive systems but increasingly used in the autonomous vehicle applications (See Figure 1.2D). For example, the Google self-driving car has mounted and utilized a LIDAR senor on its roof. Current implementations have improved range substantially from 20 meter up to 200 meter which has turned cars into machines capable of mapping their surroundings with high resolution as well. Current LIDAR sensors work well in all light conditions, but start failing in snow, fog, rain, and dust particles in the air. At present, despite the fact that LIDAR is a superior technology, there is universal agreement that the technology is currently too expensive for wide deployment. However, the difference in price between LIDAR and other sensors could become negligible as the technology evolves. Quanergy system promises to release a solid-state LIDAR in the next couple of years that will be less than $100, bringing costs in line with cameras or radars while offering better perceptive ability

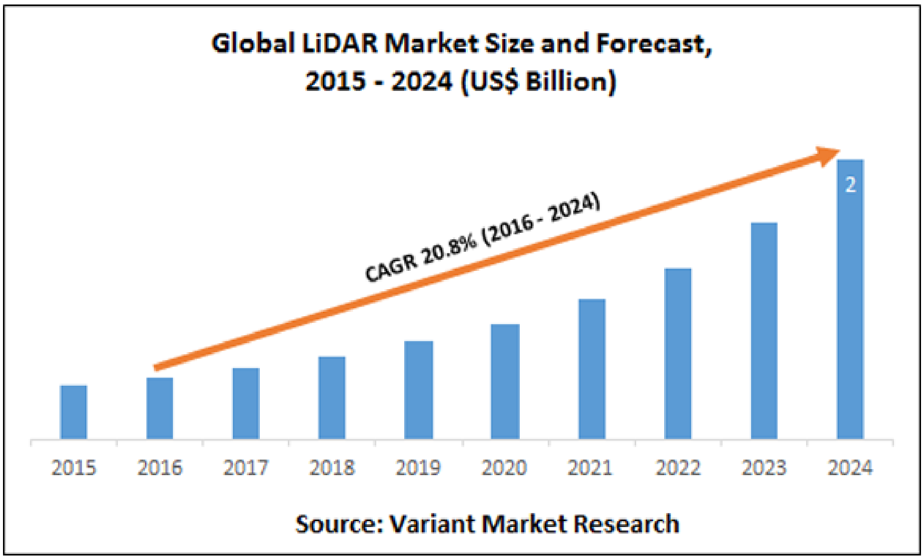

Figure c.1: Market prediction report for Lidar regardless of different applications

According to this research report [16] as is show in the above figure it has been expected to reach $1636 million by 2024 for the CAGR which stands for compound annual growth rate until 2024.

Therefore, we are able to find a strong need of both industry and research based on this high-tech topic.