December 2014

Indium Telluride Cylinder Fiber Laser

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Abstract

Since the invention of optical fibers, the bandwidth of communication channels has increased by leaps and bounds. Use of optical fibers for communication has been the primary motive in the development of optical fiber technology. Lot of research effort has been put into decreasing losses of these fibers and changing the operational bandwidth according to requirement. With increase in research on optical fibers, the application possibilities have increased. With time, research has curtailed to fiber coatings. A coated fiber has a filament coating between core and cladding. This filament adds a new parameter to the optical fiber.

On coating the fiber with a semiconductor media, the fiber starts to exhibit gain. The gain exhibited is a property of the semiconductor and depends directly on the number of electrons in conduction band and holes in valence band. More the concentration of electron hole pairs better is the optical conductivity of the fiber. When the fiber's gain media satisfies conditions for a lasing action, the output is a laser beam.

A new type of fiber laser is described here. The laser consists of a 25 mm long fiber with an approximatelly 15 nm thick In_2Te_3 semiconductor layer at the glass core glass cladding boundary. The laser mirrors consist of a thick vacuum deposited aluminum layer at one end and a thin semitransparent aluminum layer deposited at the other end of the fiber. The laser is pumped from the side with either light from a Halogen Tungsten incandescent lamp or a blue, power LED. Since both, the gain of the In_2Te_3 semicoductor and aluminum mirrors have a wide bandwidth the output consits of a pedestal from a wavelength of about 455 nm to about 650

nm with several peaks. There is a main peak at 545 nm. The main peak has an amplitude of 16.5 dB above the noise level of - 73 dB.

Indium Telluride Cylinder

Fiber Laser

BY

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A thesis submitted as a partial fulfillment of the

requirement for the degree of

MASTERS OF SCIENCE IN

ELECTRICAL ENGINEERING

At

SYRACUSE UNIVERSITY, SYRACUSE

2014

ACKNOWLEDGEMENT

Immeasurable appreciation and deepest gratitude to the following people for their continuous support and guidance which has helped me make this project possible.

Dr. Phillip Kornreich, research advisor, subject specialist, for his support, guidance, valuable comments, suggestions and provisions that benefitted me in the completing of this project. He shared his knowledge and also helped in analysis of data and its statistical computations. Lastly, for giving immeasurable contribution in finishing this manuscript.

Mr. James Flattery, Lab Manager, for his immeasurable guidance and patience while explaining whole manufacturing process and helping me out at every phase of the project. Without your help the project can't be where it is right now.

Dr. Qi Wang Song, Committee member, for his timely guidance and experienced contribution in completion of this project and also in taking out the time and effort to read the manuscript.

Dr. Carlos Hartmann, Committee member, for taking out the time and effort to read the manuscript.

Dr. Chilukuri Mohan, Department chair of Electrical engineering and Computer Science, for his supports both intellectually and also for providing financial aid required for the purchase of various laboratory equipment required in completing this project.

Dr. Prashanta Gosh, Advisor, for his guidance and support in completition of this project.

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CHAPTER 1

1. Theoretical Backgrounds

1.1. Optical fiber

An optical fiber is generally considered to be made of 3 concentric cylinders, the inner most one is called a core it has the highest optical refractive index. The immediate outer cylinder I called a cladding and have a comparatively lower refractive index (as shown in Fig 1.1). The fiber is then coated with a plastic jacket as a protection for the fiber.

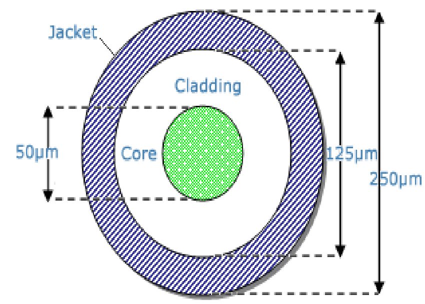

Fig 1.1 Optical fiber cross-section

There are two types of fibers Single mode and Multi-mode. The difference between the two is the diameter of the core. A single mode fiber has a core of 9 microns and a multimode fiber has a diameter of 50-62.5 microns approximately.

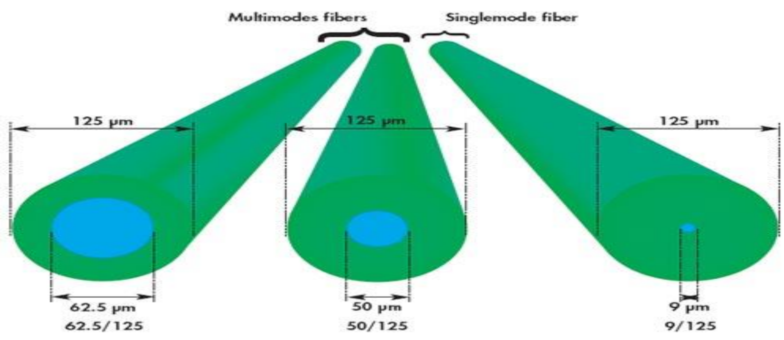

Fig 1.2 Single and Multi mode fibers with varying dimension

1.2 Properties of Light Transmission in a Fiber

1.2.1 Laws of Reflection

Light has very predictable behaviour, if a ray of light can be observed to be approaching and reflecting of a flat mirror. This predictable behaviour is governed by laws called laws of reflection.

1^{st} law of reflection:- the angle of incidence is equal to the angle of reflection of a mirror.

1.2.2 Laws of Refraction

The angle of incidence and the angle of refraction is directly proportional to the ratio of refractive indices.

1.2.3 Total Internal Reflections (TIR)

Light propogates in an optical fiber by the principle of 'Total Internal Reflection' where light gets reflected into optically denser medium whenever it tries to propogate from the core to the cladding due to change in optical refractive index. Critical Angle is an angle of incidnece made when the refraction angle is exactly 90^{o} .

When the angle of incidence is greater than critical angle Total Internal Reflections takes place.

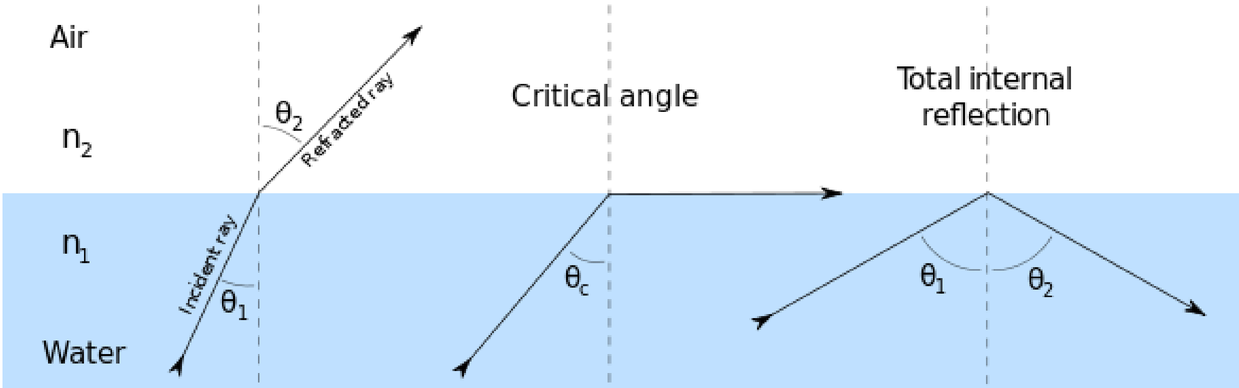

Fig 1.3 :- Refraction of light at the air and water interface

1.2.4 Numerical Apperature (NA)

The maximum angle off incidence which can result in total internal reflection back into the core at the core and cladding interface is called numerical Apperature as shown in Fig 1.4.

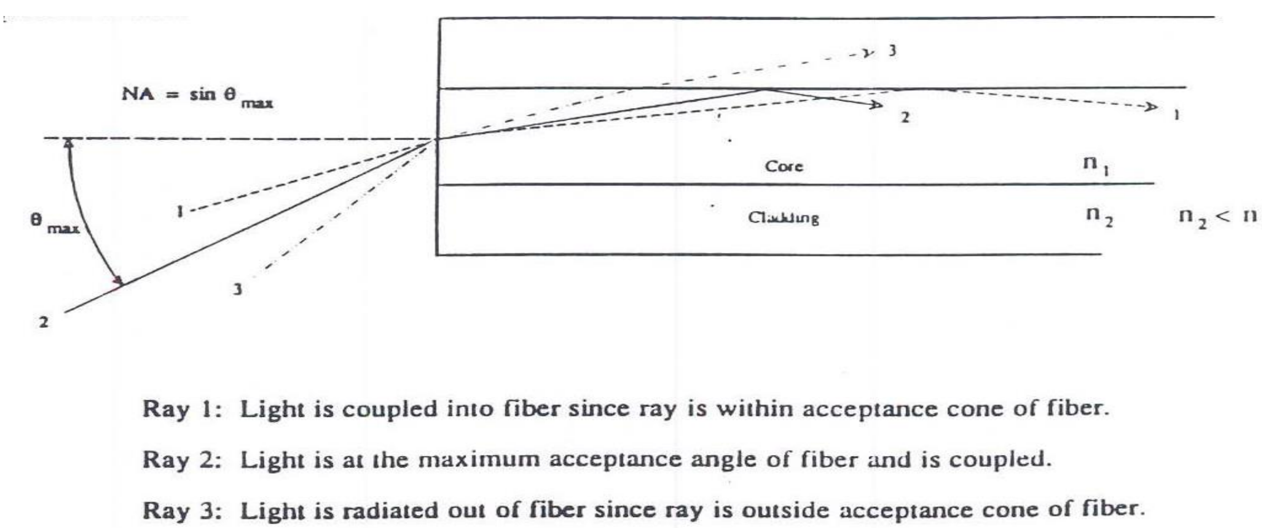

Fig 1.4: transmission of light into a fiber

1.3 Semi-Conductor Laser

In a semi-conductor laser, gain is provided by the semi-conductor medium. The choice of material helps determine the wavelength. Light is generated because of radiative recombination of electrons and holes. In order to generate more light than then that is absorbed population inversion is required which is achieved by pumping with electric field or optic beam. Light is emitted when excited electron recombines with a hole, if this interaction happens on its own it’s called a spontaneous emission and if lead by another photon it’s called stimulated emission. Laser beam is a collection of photons emitted with stimulation, hence to form a laser beam one needs to have most electrons in conduction band and ready to recombine with holes to release photon.

1.4 Fiber Laser (Existing Technology)

Fiber lasers are meant to be lasers which use optical fiber as a gain media, lasers with semiconductor gain media and fiber resonator is also called a fiber laser. Most common fiber lasers have a core doped with rare earth metals like erbium (Er^{3+}), neodymium (Nd^{3+}), ytterbium (Yb^{3+}), thulium (Tm^{3+}), or praseodymium (Pr^{3+}). Most of these fiber lasers are pumped using diodes. The gain media for a fiber laser is very similar to solid state bulk laser except for the effective smaller effective mode area. This leads to quite few changes in properties exhibited like having greater gain from the media but also higher losses through the resonator.

1.4.1 High Power Fiber Laser

The original fiber laser built had an output power of less than few milliwatts, with research this output has been increased to hundreds of watts and even kilowatts in some cases. This potential arises due to greater confinement guiding effect and better surface to volume ratio (it helps in cooling).

1.4.1.1 Double Clad Fibers

Most high power amplifiers and lasers are Double Clad Fibers. A double Clad Fiber has two claddings and a core, the refractive indices of these decreases away from the center as shown in Fig 1.5. These double clad fibers are generally pumped with fiber coupled diode bars or laser diodes. The pump light is launched into the inner cladding in place of the core. A very good beam quality laser light is generated in the core, which can be bettered into a diffraction limited beam by utilizing a single mode glass core. The brightness of the output laser can be orders of magnitude greater than the pump, though the output power somewhat smaller, approximately 50%-80%.

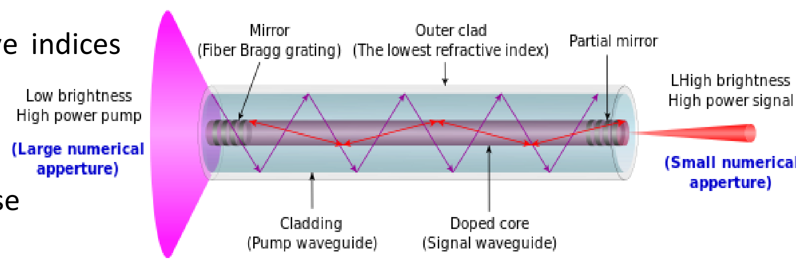

Fig 1.5: Transmission of light in a double clad fiber

For higher output, power core area should be larger to support higher optical intensities. A double clad fiber has a high ratio of cladding to core leading to weak pump absorption. To have a fairly good output beam quality most of the light should be propagate in fundamental mode. Higher modes can be suppressed by coiling the fiber resulting in a better beam quality.

1.4.1.2 Fiber Disc laser

The fiber disc laser has a traverse delivery of pump light. The pump beam is not generally parallel to the active fiber but it is made to have an angle (usually between 10-40 degrees) as shown in Fig 1.6. This helps regulate the shape of the pump beam, providing efficient use of lamp. Typically no mirrors are required as the minute reflection is sufficient to provide efficient operation. As there are no reflective surfaces involved, both the ends of the fiber can be used as an output.

Fig 1.6: Fiber disc laser

1.4.2 Launching Pump Light

1.4.2.1 Direct launch -Pump light is generally launched directly into the cladding at one or both ends of the fiber (shown in Fig 1.7). The process if very simple and doesn't require complex machinery but is a hard process.

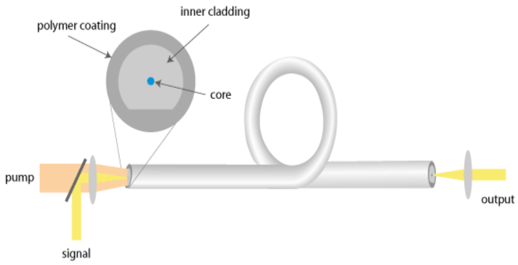

Fig 1.7: Launching of pump light

1.4.2.2 Fiber coupled pump diodes- the pump diode is directly coupled to a fiber in order to deliver light to a place where it is needed. They are also called as a fiber integrated diodes.

1.4.2.3 Un-doped fiber- Light is launched into an un-doped passive fiber which is wound along a doped fiber so as to get transfer of light into the doped fiber.

1.4.2.4 Pump combiner devices- several pump fibers and a single active fiber are fused together for launching the light into an active fiber.

1.4.2.5 Multi-point Injection- light is launched into a fiber from the side of the fiber. Multi point injection has better distribution of heat load.

CHAPTER 2

2.1 Introduction to Project

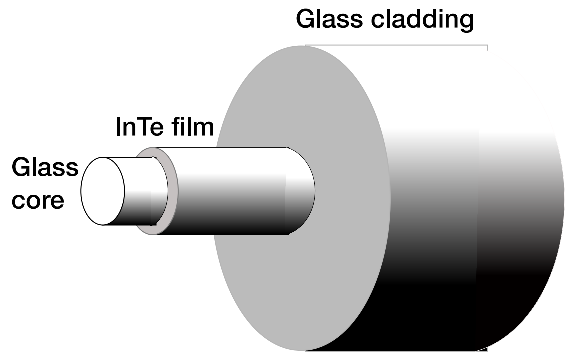

Fig 2.1: Cylinder fiber consisting of a glass core coated with a thin Indium Telluride film and a glass cladding.

We developed a new type of fiber laser. It has an approximately 15 nm thick In_2Te_3 semiconductor layer along the length of the glass core glass cladding boundary, (see Fig 2.1). This **S**emiconductor **C**ylinder **F**iber **L**aser (**SCFL**) has a core diameter of 14.2 µm and an outside diameter of 126 µm. The fiber sections are typically 25 mm long. Both ends of the fiber are polished. Aluminum films are vacuum deposited at both ends to serve as mirrors. A thick aluminum film is deposited at one end and a very thin semi transparent aluminum film is deposited at the other end.

This **S**emiconductor **C**ylinder **F**iber **L**aser (SCFL) has many advantages over conventional fiber lasers. The density of charge carriers per unit length in the semiconductor cylinder is much larger than the concentration of doping atoms per unit length in a doped glass fiber laser. This results in the SCFL that is much shorter than a doped glass fiber laser. The SCFL can be pumped from the side. This eliminates the need for a coupler at the output to separate the signal and pump light. It also eliminates the need for coherent pump light. The pump light must be coherent for it to be coupled axially into a communication fiber core. The semiconductor interacts with a very large bandwidth of light. Therefore, the SCFL can be efficiently pumped with broadband partially coherent light.

The SCFL functions similar to flourescent lights. The white coating in flourescent lamp tubes is a semiconductor. It is energized with UV light at discrete energy levels generated by a gas discharge. The semiconductor coating emits light over a broad band. The SCFL, in its present implementation, also emits light over a wavelength bandwidth from 450 to about 650 nm, see Fig. 2.2.

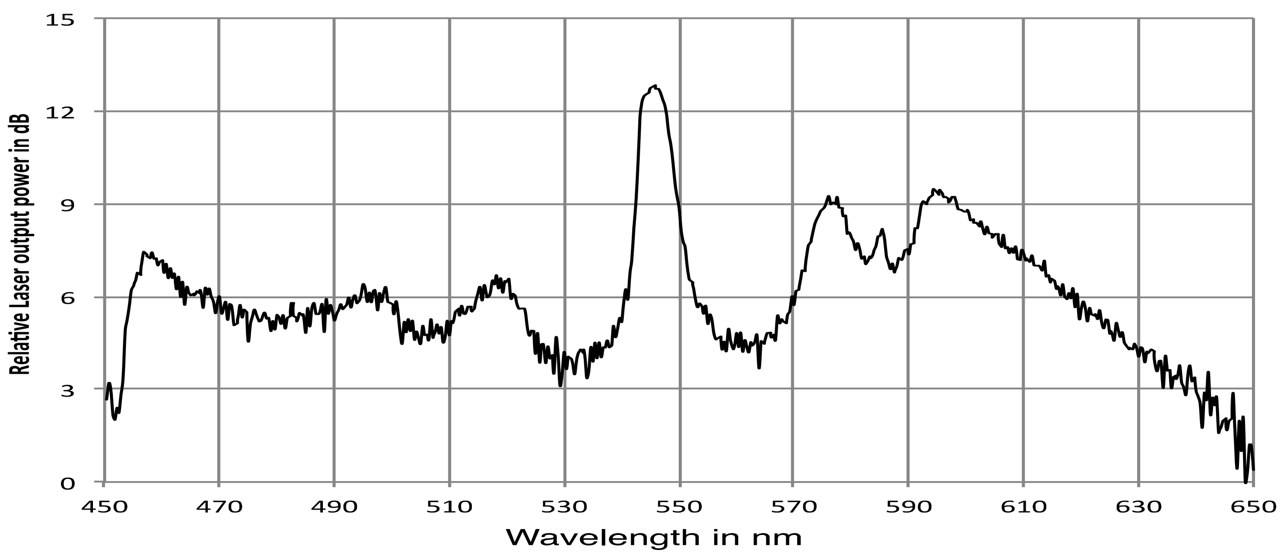

Fig 2.2: Output spectrum of laser. Note the broadband output pedestal from about a wavelength of 455 nm to 650 nm. Also there are a number of peaks besides the main peak at 545 nm. On this scale the noise level is at – 3.78 dB

CHAPTER 3

3. Selection of Materials

3.1 Coating Material

The core can be coated with any material, a metal, nonmetal, an alloy or even a semiconductor. The type of coating gives a generalized change in properties. The effect of the coating on the transmitted light is governed by the availability of electrons in the conduction band of the coating. The properties of the material affect the transmission parameters of the channel.

A semi-conductor normally has very few electrons in the conduction band so has a very high resistance which decreases with raise in temperature. Similarly the resistance drops as the area of cross-section of the semiconductor decreases to the order of microns and nanometers. When the scale is in nanometers the properties of materials change because the cross section has only few molecules worth of width. The approximate width of the coating is around 10-20nm which can be anywhere from 2 to 5 molecule thick.

Indium Telluride is a semiconductor alloy with a melting point of 667^0 C, it has an electron band gap of 1.04 eV between valence and conduction bands. To excite an electron from valence band to conduction band one needs to pump energy onto the semi-conductor layer with a beam of light having wavelength greater than 1.1962µm corresponding to 1.04eV.

On exposure to light electrons get excited and are hence available for conduction. More the electrons in conduction band lower the resistance. So by controlling the luminance on the semiconductor one can control the resistance offered to an optical signal, thereby controlling the very properties of the transmitted signal.

The excited electrons in the conduction band fall back into valence band, the energy is released in form of an optical signal. This process of an electron losing its energy is called spontaneous emission. If a photon initiates the fall back it results in a stimulated emission. In case of a simulated emission the emitted photon matches the photon leading to the emission in all ways possible, resulting in amplification of the input signal.

The spectrum that can be amplified depends on the number of metastable states in the conduction band. Greater the number of states available for electrons, wider range of frequencies can be transmitted. The frequency of the emitted photon depends on the electron jump from conduction to valence band.

Indium Telluride is a semiconductor so it has very few electrons in conduction band with a band gap of 1.04ev which is small enough for easy jumping of electrons to the conduction band. The greater no of metastable states in In_2Te_3 help in obtaining a wider spectrum of amplification.

3.2 Selection of Glass

Glass is manufactured with varying properties both physical and optical by varying the composition of the glass. A low temperature glass has the lowest melting temperature of around 600^0C and higher ones can go as high as 2400^0C.

Important parameters to be considered while selecting the glass are namely the following

1. Refractive index: - The most fundamental principle of optical communication is 'Total Internal Reflection', light must propagate in an optically dense medium and gets reflected back at the interface of dense and rarer medium. The core of an optical fiber is generally designed to have a refractive index greater than that of a cladding.
2. Softening point: - When glass is exposed to high temperatures it softens, this softening temperature is generally way below the melting point. The softening temperature is important as that's the temperature at which glass is soft and is collapsed to form a sealed capsule from which fiber is extracted. Softening point is also the temperature at which fiber is pulled in a fiber tower.
3. Annealing temperature: Annealing is a process of cooling down a heated material slowly so that the shape and structure of the material can be altered without breaking it. If one heats and cools down anything rapidly it turns brittle. Glass is brittle by nature making it hard to change shape and structure of it. So to draw a fiber out one may have to cool it down really slowly to turn it into ductile material. Increasing the ductility of the glass helps us in pulling a fiber. For the capsule to be annealed properly one needs to select similar core and cladding such that, both anneal at the same temperature range.

The melting point of In_2Te_3 shortlists the options of glass one can use. The melting point of In_2Te_3 is 670^0C which can be interpreted as the temperature range for the softening point of the glass used. On observing all the glasses available in the market and at the laboratory I selected 7052 for cladding and 7056 as a core made by Corning.

Glass	Refractive Index	Softening Point (^0C)	Annealing Temperature(^0C)	Thermal Expansion(^0C)	Strain Point (^0C)
7052	1.484	712	484	47.0	440
7056	1.486	718	512	51.5	472

Table: 3.1:- The glass selected and its properties.

CHAPTER 4

4. Equipment and Machinery

4.1. Material Deposition: - there are many ways of depositing materials on a glass rod depending on the type of material.

1. Thermal Evaporator: - it uses an electric resistance heater to melt the material involved by passing a very high current through it. It is done in high vacuum both to allow vapors to reach substrate without reacting with or curbing and getting scattered due to gas molecules in the chamber it also reduces the incorporation of impurities in the chamber.

2. Sputtering: - plasma is used to knock few atoms from the target. In case of sputtering the target stays at room temperature. Sputtering has one of the greatest flexibility in terms of deposition rates. It is also the best method of deposition for compounds and alloys where each individual component has different evaporation rates.

3. Pulsed laser depositions: - pulses of laser are used to vaporize target material which converts the target material into plasma state, the material turns into gaseous state by the time it reaches the substrate.

Although there are many ways of thin film deposition our laboratory has only thermal evaporator restricting selection. Lab has two different forms of evaporators

1. Metal deposition: - The metal deposition the core of the fiber is exposed and is rotated at constant speed so that deposition takes place in uniform manner. High electric current is passed through resulting in evaporation of the material (In_2Te_3).

The disadvantage of this method is that the chamber is very large and the core is exposed to atmosphere for few seconds before it's sealed. This exposure leads to imperfection in the composition of the coating, as nonmetals and semiconductors which react easily with the atmosphere.

Advantages:-

- Only core inside vacuum chamber, making coating process easy and controllable.
- Better control on the amount of material vaporizing and gradually getting deposited on core.
- Easier and safer working machinery

Disadvantages:-

- The core needs to be bought out of vacuum and exposed to atmosphere where contaminants affect the purity of the coating.
- The equipment is very large and expensive
- It consumes a lot of energy to complete its functions.

2. Semiconductor deposition: - in a semiconductor deposition material is placed at sealed bottom of the cladding and core is then pushed through. Hereafter vacuum is created within the cladding. On achieving required vacuum the semiconductor at the end of the tube is heated. Glass being an insulator for heat ensures that part exposed to heater is hot and the rest of the core is still cold and the material gets deposited on the core. On

repeating the process at appropriate speed all the material gradually gets deposited on the core. Once all the material is deposited a flame gun is fired from multiple directions little after the end of the core, this collapses the cladding sealing the pressure between core and the cladding. Then just separate the sealed capsule from the rest of the cladding.

Advantages:-

- Smaller equipment hence faster pumping mechanism.
- Lower energy consumption and low costs.
- As both core and cladding are in the system there is no possibility of coatings exposure to external factors.
- Better purity in the coating

Disadvantages:-

- No control over deposition over core or cladding. If coating happens over cladding the fiber cannot be made with such a sample.
- Heating mechanism is a moving a furnace which has a variable thermal profile.
- It has too many controllable variables in the coating procedure making it really tough to manage. The heating furnace is movable the speed of linear motion should be moved so as to allow time to burn enough material and also give enough time to cool it down to let it deposit.
- The three variables that affect the thickness of the coating are namely the vacuum pump pulling out air, the temperature profile of the furnace and finally the linear motion of the furnace itself.

4.2 Collapsing Furnace

The collapsing furnace is a two stage furnace both of which are set at different temperatures. The system has a sealed chamber which is to holds capsule. The capsule is placed in a metal boat which is first filled with lead to an appropriate level. Once the lead is cooled down the capsule is placed on it and clipped. Once the sealed the chamber is moved into each of the furnaces in a pattern to collapse the capsule. The chamber is connected to air gas and to a vent, the pressure inside is controlled through these tubes connected to the chamber.

4.3 Redraw Tower

The core in any fiber is a solid rod, whose thickness is an important variable for consideration. After the glass types for core and cladding are selected one needs to find the available diameters in the stockpile. We need to select the core and cladding in such a way that there is a 0.1-0.2 difference between the outer diameter of the core and the inner diameter of the cladding. If a corresponding diametric core isn't available in the laboratory one may have to redraw from a thicker core. The wires controlling the motion of the furnace and the weights help control how much one should extend an existing fiber. The volume of the glass rod stays constant so on elongation of the rod to twice its original length the diameter decreases by root of 2. So by controlling the extension of the rod one can control the thickness of the final product. It's a very important part of the equipment to get both the rod in the appropriate dimension.

4.4 Fiber Tower

A fiber tower is similar to redraw tower with a small variation it doesn't stop at only elongating in place it keeps drawing and the extracted fiber is than wound together. The collapsed capsule hangs from the top into a furnace and the other end hangs some weights. The temperature profile in the furnace has a peak heating point which results in the highest temperature point of the collapsed capsule. This point is where the capsule elongates until its diameter comes down to 125um which is the industrial standard for an optical fiber. Once the diameter comes down to 125um one needs to keep moving the collapsed un-pulled capsule down at a slow rate, this increases the thickness at the point of highest temperature, so is called a feed, as it feeds glass to the fiber drawing system. The feed increases the thickness of the fiber drawn; higher speed means a gradual increase in the thickness of the fiber come out. Similarly there is a motor that constantly pulls on one end of the fiber the force being applied. This force also controls the thickness of the fiber, more the force lesser the diameter. Controlling the temperature feed and the pulling force controls the whole fiber draw process.

4.5 Optical Source

Once fiber is drawn to measure the properties of the fiber one needs to transmit light through the fiber and measure the impact of passing it through the fiber. There are various types of sources available, lasers, different types of bulbs and CFTs. All the sources have a different operating frequency ranges. For the application of this project we need a wide spectrum source. This optical source can be used as a pump source.

4.6 Spectrum Analyzer

A spectrum measures the amplitude of the input signal over a frequency or wavelength range. For the spectrum analyzer to work for optical wavelengths it needs to have a working range of 300-1200nm. The spectrum analyzer in the laboratory is ANDO AQ-1425, it has a wavelength range of 380nm to 1600nm, which covers very little of ultraviolet, whole of visible and some of infrared radiation. It can detect signals as low as -80dB for a narrow bandwidth of not more than 200nm.

CHAPTER 5

5. Manufacturing Process

To make the fiber there are many ways but with the available equipment one can only make a fiber using the rod and tube method. This method is only useful for laboratory purposes as this process is tedious and really long, even the accuracy of the end product is not upto the industrial standards. The cheap cost is what makes this process attractive for research purposes.

5.1 Cleaning Process

Glasses are manufactured in bulk and are handled by different people by the time it's used. Its cut, taped, chipped at many places leading to a lot of deformities and hence, it needs to be cleaned. For the best cleaning results of not only getting rid of dust and dirt particles but one needs to make hydrophilic or hydrophobic surfaces so as to get better sticking properties of the glass, depending upon the type of the coating.

Basic cleaning

Basic cleaning involves cleaning a rod and cladding with the following in order

- Soap and water
- Acetone
- Alcohol
- Distilled water

Specialized cleaning

- Removes Metals

  1 :1 :6

  HCl:H202:H2O

- Removes Oxides

  1 : 50

  HF : Water

- Makes a hydrophilic surface

  3 : 1

  H2SO4 : H2O2

The glass rod and cladding both are made to go through all the cleaning process and then dried by blowing air gas which is basically nitrogen gas.

5.2. Material Deposition

5.2.1 Metal Deposition:

- Place In_2Te_3 on a boat connecting the two electrical terminals of the evaporator. And place new glass slides below it and all along the sides so as to cover as much surface area as possible till the rod.
- Once the rod has been placed into the holder check for any openings or leaks.
- Close the bell jar and foreline followed by opening the roughing
- If foreline drops below 10^{-3} close roughing and open foreline, keep doing this till we have roughing and foreline at 10^{-3}
- When both are at 10^{-3} close roughing, open foreline followed by opening hi-vac.
- Start the Hi-Vac pump and after few seconds start emiss

- On achieving a pressure <10 $^{-6}$ on emiss start the evaporator and the motor holding the rod
- Slowly increase the current flowing through the boat till you see the inside surfaces covering the material turn black. Keep increasing the current till one see's a very bright light from the center of this darkened setup. Then suddenly pump up the current and decrease it gradually.
- Let the setup cool down for a few minutes, close the hi-vac valve and open the vent valve increasing the pressure inside the bell jar back to atmospheric pressure.
- Once atmospheric pressure is achieved open the bell jar and transfer the coated rod into a sealed cladding.
- Create vacuum within the cladding and seal off the other end.

5.2.2 Semiconductor Deposition

- Seal one end of a cladding at one end and push In_2Te_3 powder to the bottom.
- Insert the core rod and the whole setup into semiconductor vacuum machine.
- Seal it properly and start main pump.
- On achieving 10 $^{-3}$ torr start the hi-vac pump to reach 10 $^{-6}$ torr.
- Now start the furnace which slowly moves towards the vacuum machine while heating more and more of the glass cladding.
- The material In_2Te_3 is at the bottom of the cladding so it gets heated up first and evaporates.

- Glass being an insulator doesn't conduct heat so other parts are still cold and indium telluride deposits itself on the core.
- As the furnace heats up more and more of the glass cladding the farther away parts of core get coated with In_2Te_3.
- Once complete coat is achieved one has to seal the open end of cladding with a flame gun.

5.3 Collapsing furnace

Collapsing furnace consist of two different furnaces Z1 and Z2, a pressure sealed chamber and a boat.

- We start collapsing by filling the boat with lead
- Place the sealed capsule in the boat and fix it in its position so it can only move in lateral direction and it doesn't touch the ends of the boat.
- Place the boat in the chamber and seal it.
- Start both furnaces Z1 and Z2. Z1 is set at 450^{o}c and Z2 at 700^{o}c.
- Push chamber into Z1 and wait for the temperature of chamber to reach Z1 it takes about 30 minutes.
- Now move the chamber into Z2 and allow it to raise to 700^{o}c
- On reaching 700^{o}c start applying pressure into the sealed chamber. The high external pressure added with low internal pressure at such a high temperature leads to collapsing of the capsule.

- Remove the external pressure, turn of the furnaces and let it cool down while the baffles of the furnace are still closed. Baffles help slowing down the cooling process.
- Slow cooling results in annealing of the glass

5.4 Fiber Draw Tower

- Attach handles to both ends of the capsule.
- Hand the capsule in the furnace such that the middle point of the furnace is slightly above the lower joint.
- Set temperature to about 800oc
- Hang weights at the lower end, as soon as the temperature of the furnace reaches required temperature the weight starts to come down.
- Once the weights reach the floor, break the handle pull the fiber into the rotor which pulls the fiber at constant speed.
- Start the feed which drops the capsule down.
- Measure the thickness of the fiber and get it down to 125 microns.
- Continue pulling as long as possible.

CHAPTER 6

6. Observations

6.1 Fiber Cross-section

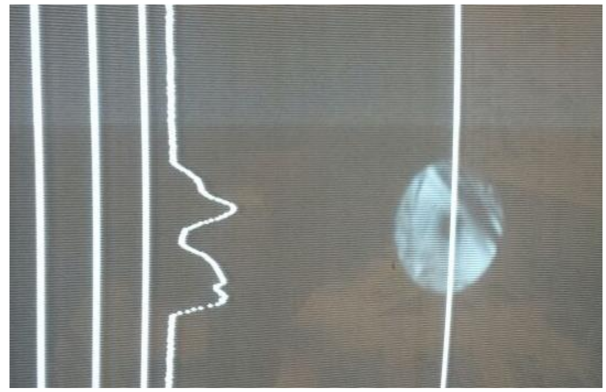

Fig 6.1: Fiber cross section and light intensity plot.

Fiber is observed under a microscope after being pulled. This helps noting the position and thickness of core, coating and the fiber itself.

The image shows a dark central spot indicating no light is passing through the center of the fiber, and all the optical energy is being transmitted by the coating and the cladding.

The outer cladding dimensions were calculated to be 127 microns, the coating thickness varied from 21.2 to 24 microns for different samples. The core came out as 27-30 microns.

6.2 Measurement of Lasing Properties

6.2.1 Fiber with air mirror or no mirror

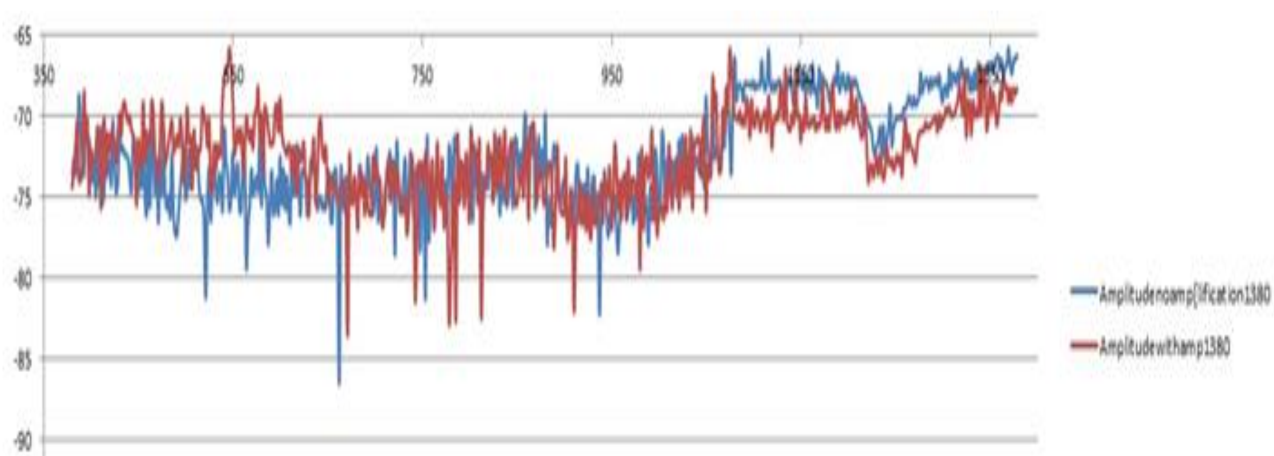

Fig 6.2: Graph obtained at the spectrum analyzer with and without a pump

Amplification is observed at 450nm to 650nm with a central peak at around 550nm. The gain for the peak is around 10dB and for other frequencies it's around 5 dB.

6.2.2 With silver paint at one end

On painting silver at one end to act as a mirror the gain observed is way more substancial.

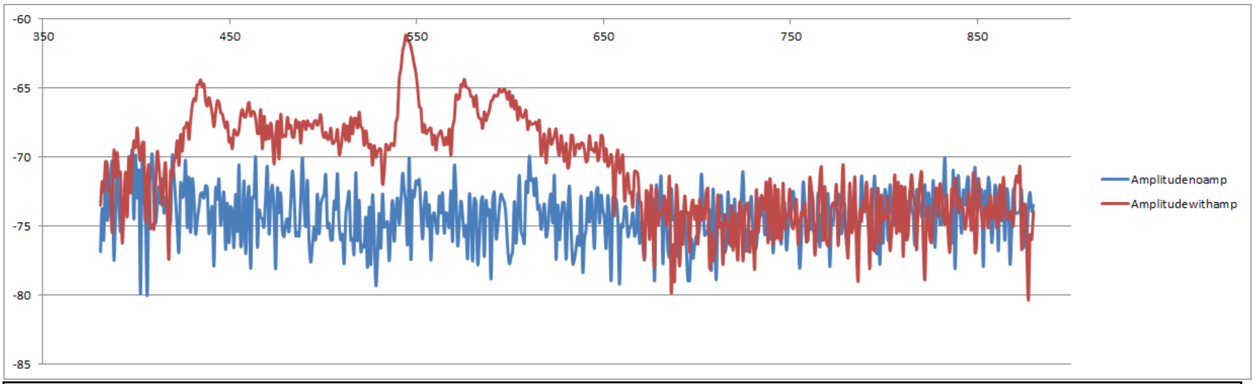

Fig 6.3: Graph obtained at spectrum analyzer with and without a pump for a fiber painted silver at

From the graph one can infer than gain region starts at 428.4nm and extends to 660.8nm

Main Peak:

Wavelength:	543.5nm
Width:	9.3385nm
Level:	12.404 dB above noise level
Noise level:	-73.752 dB

Other peaks	433.455 nm
	460.07 nm

574.459 nm

596.764 nm

Plato 428.416 nm to 660.792 nm

2.891 eV to 1.876 eV

From the Plato we can infer the Fermi energy of In_2Te_3 fiber is approximately 2.891eV and energy gap is calculated to be 1.876eV.

6.2.3 With aluminum on both ends of fiber

Aluminum is deposited on both ends one being thicker that the other. The thinner end is inserted into the spectrum analyzer. This end is partially reflective and partially transitive.

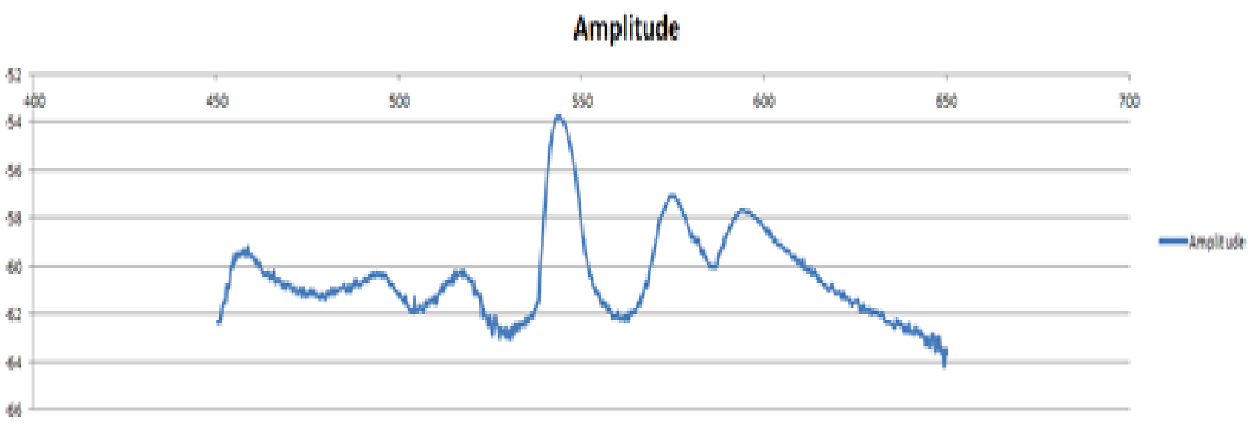

Fig6.4: Output spectrum of laser with aluminum coated at both ends.

With reflective surfaces on both ends are present there is a significant increase in output power. The peak is obtained at 544nm with a maximum value of -53.8db. This peak value is way higher than previously recorded values with and without mirrors.

A metal deposition on both ends gives us an overall gain of approximately 20dB.

Main Peak:

Wavelength: 544.5nm

Width: 9.3385nm

Level: ~20 dB above noise level

Noise level: -73.752 dB

Other peaks 574.459 nm

596.764 nm

Plato 428.416 nm to 660.792 nm

2.891 eV to 1.876 eV

6.2.3.1 Transmission properties of aluminium

As shown in fig 5.5 the thin aluminum coat results in a drop of 2db while for the thick coat the drop varies at around 10-12db.

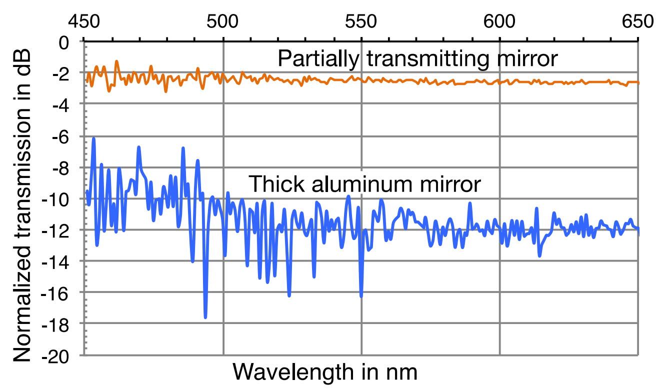

Fig 6.5: Normalized transmission through the aluminum coatings.

2db of the thin coat corresponds to a reflection of 36%.

12db reflection corresponds to a reflection of 93.75%.

5.2.3.2 Power Relation

As shown in Fig5.6 the relative output power and pump power are proportional to each other. There also exists a threshold value for the pump power below which lasing doesn't occur.

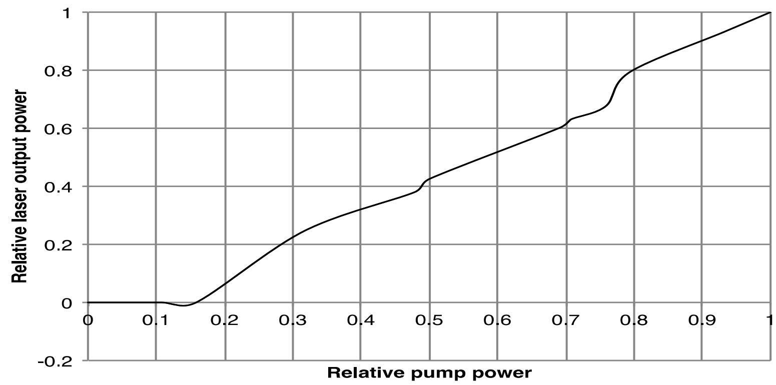

Fig 6.6: Laser characteristic. Laser output power is directly proportional to pump power

The gain, with gain coefficient , in the SCFL is produced by the pump light induced charge carrier inversion in the In_2Te_3 semiconductor. The gain coefficient λ_{Thresh} at the threshold can be determined from the fact that the round trip gain of the device has to be equal to one at the threshold.

$$R_1R_2\exp\left[2\left(\gamma_{Thresh} - \alpha\right)L\right] = 1 \qquad (1)$$

Where R_1 and R_2 are the reflection coefficients of the mirrors, λ_{Thresh} is the gain coefficient at threshold, λ is the absorption coefficient, and L is the length of the fiber. The sum of the reflection coefficient R and the transmission coefficient T must be equal to one.

$$R + T = 1 \qquad (2)$$

Solving for the gain coefficient at threshold:

$$\gamma_{Thresh} = \alpha - \frac{1}{2L}\ln\left(R_1R_2\right) \qquad (3)$$

The transmission coefficients T_1 and T_2 can be determined from Fig.5.5. The transmission coefficients and thus the reflection coefficients at a wavelength of 550 nm are:

$T_1 = 0.5754$ $R_1 = 0.4246$

$T_2 = 0.0631$ $R_2 = 0.9369$

Thus for the 25 mm long SCFL the threshold gain coefficient is:

$$\gamma_{Thresh} = \alpha + 18.4375 \text{ per m} \quad (4)$$

Recall that the SCF section oscillated during the attempt to measure is gain. Thus the absorption coefficient ? is difficult to measure with our equipment.

CONCLUSION

The devices described here were individually fabricated. To date (5 October 2014) 25 In_2Te_3 SCFL have been fabricated and tested. All exhibited similar properties. One can fabricate many SCFL at the same time. One can enclose about 20 or more SCF at a time in a potting compound. This structure can then be cut to size and polished on both sides. Multi-layer dielectric mirrors can be deposited on this multi-fiber structure. Next, the potting compound can be dissolved to separate the individual lasers.

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  Dec 2012
  players and comparative description of the different types of Optical Coherence Tomography machines available in the market
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  April 2013
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