Fiber Optics
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Lecture – 05
Optical fiber fabrication

In the last lecture we had seen that there can be single mode fibers, multimode fibers. And in these 2 categories we can also have graded index fibers. In a single mode fiber we had seen that in the central region the core region the refractive index is something like 1.45 over 10 micrometer across over a diameter of 10 micron. And beyond that you have a material of different refractive index refractive index something like 1.44 which can extend up to 125 micron diameter.

In multimode fiber the core can be 50 micron diameter and cladding again 125 micron diameter. And you see the refractive index of the core and the cladding are different. So, the material is distributed along such a small dimensions. If you talk about graded index fiber, then even in core itself the refractive index changes with radial position. The question is how to obtain such a structure, how to make such a structure, how to fabricate such a structure on such a small scale of micrometer scale. So, in this lecture we would look into the technology of optical fiber fabrication.

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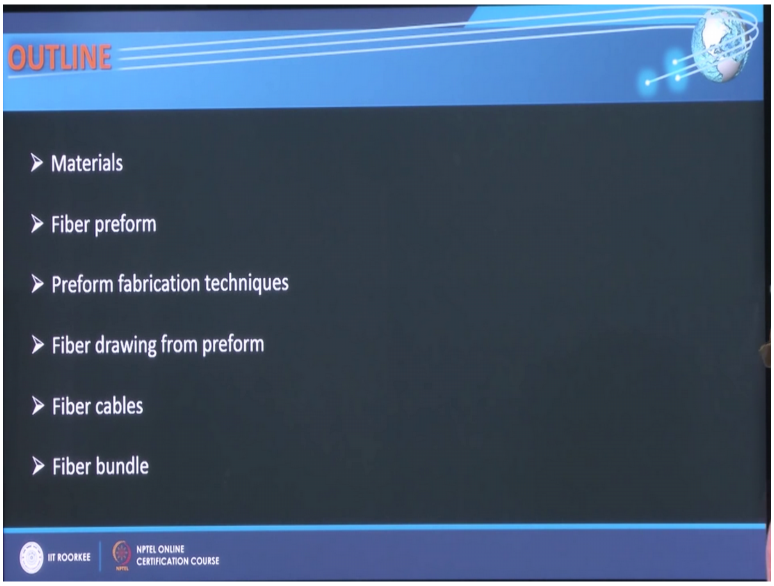

The flow of the lecture is something like this; you will first talk about the materials, which are suitable for making optical fibers. Then we will talk about a structure which is known as fiber preform, which is a blown up version of an optical fiber. Optical fiber cladding diameter is 125 micron and length is kilometres. This is blown up to few centimeters in transverse dimensions and length can be around the meter also. So, first we make this fiber preform. Then what are the techniques for making the preform of fiber, then how do we make fiber out of this perform then fiber cables and fiber bundles.

So, let us first find out what are the requirements for material to make an optical fiber. First thing it should be possible to draw flexible thin kilometers long fiber from the material.

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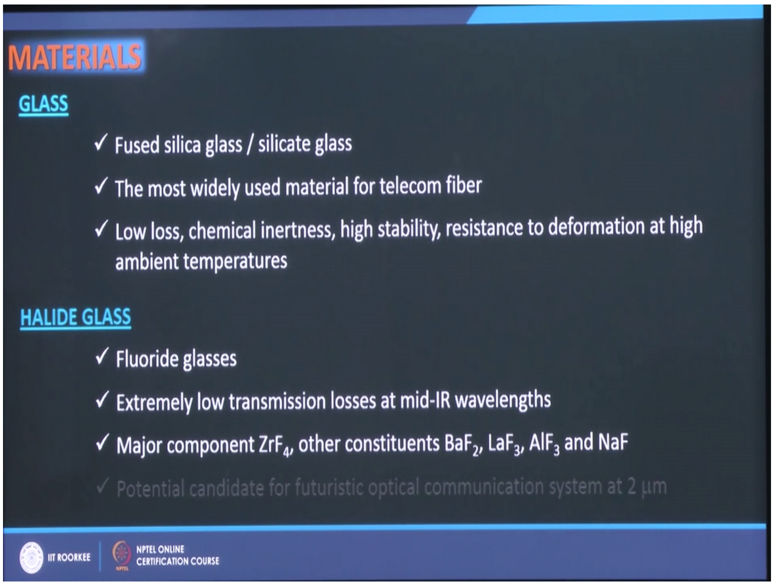

So, our material should be such that we can draw very thin kilometers long fiber out of it. Second thing is since the core in the cladding are of different materials. So, we should have these 2 different materials which are physically compatible. Otherwise there would be deformation in the structure. So, physical compatibility is necessary for core and cladding materials.

So, these materials should be available. Third thing is that since we want to use this fiber primarily for telecommunication purpose. So, the losses of optical fiber should be as small as possible in the wavelength range of interest. So, these are the primary requirements while selecting material for making an optical fiber. What are various materials? First and foremost is fused silica glass or silicate glass. It is the most widely used material for telecom fiber, the advantages and characteristics of this glass is it is low loss it has very small loss. It is chemically inert, highly stable and it is resistance to deformation at high ambient temperatures.

Another type of glass is halide glass. In this category there are mainly fluorite glasses. These glasses have extremely low transmission losses at mid-IR wavelength the major component in this glass is ZrF, 4 and other constituents are BaF 2, LaF 3, AlF 3 and NaF. And this glass is the potential candidate for futuristic telecom fiber, which can work around 2 micrometer wavelength. Then we can also have active glass. What can we do is actually we can dope certain materials rare earth elements into silica glass and out of that we can make active glass.

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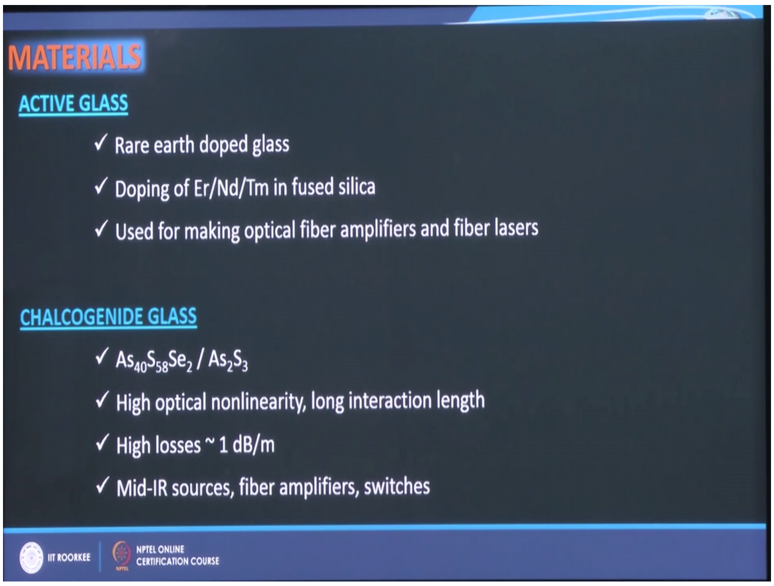

So, doping can be of erbium, neodymium, toliam in fused silica. And these glasses are used for making optical fiber amplifiers and fiber lasers. Then there are soft classes like chalcogenide glass where the core can be made out of As 40 S 58 Se 2 and cladding out of As 2 S 3. They have high optical non-linearity over long interaction length, but they have very high losses. The losses are typically few dB per meter. So, of course, these kind of fibers are not very good for transmission of optical signal as a line fiber transmission line fiber they are not very good, but what can be done using these fibers is we can make light sources in mid-IR wavelength range. We can make fiber amplifiers, and components like switches using this kind of glass.

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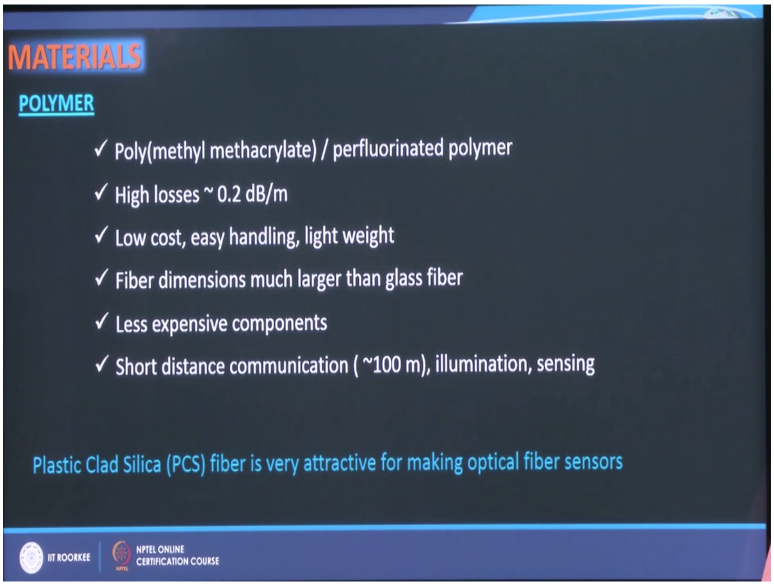

Another widely used material for making optical fiber is polymer plastic. There are 2 widely used polymers one is PMMA poly methyl methacrylate and second is perfluorinated polymer. They have high losses as compared to glass. Glass has now glass has loss of the order of 0.2 dB per kilometer. And plastic or this polymer fiber has loss of the order of 0.2 dB per meter. So, there is orders of the magnitudes difference in the loss, but they are low cost easy handling and lightweight and the dimensions of fiber which you make out of polymer are much larger than the glass fibers. They have less expensive components and they are useful for short distance communication; for example, within a room for example, within a room or communication or illumination incensing.

You can make a fiber which has silica core, but plastic cladding. So, this is known as plastic clad silica fiber popularly known as PCS fiber. It is very attractive for making optical fiber sensors.

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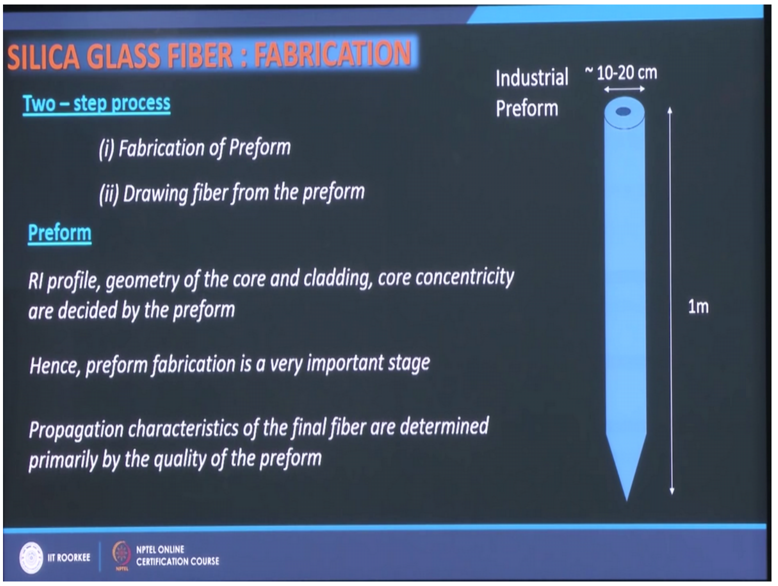

Now, we will concentrate on the fabrication of silica glass fiber and the fabrication of silica glass fiber is a 2 step process. First is fabrication of preform and second is drawing fiber from the preform. In old days people used to make fiber in similar way, they used to heat up the glass and used to throw it and when they throw it then a fiber is drawn out of that.

So, this technique is similar to that, but it is of course, much more sophisticated. So, first what is preform? If you talk about optical fiber the cladding is 125 micro meter across. So, if this is the core this is the cladding. So, it should be 125 micron. So, in this 125 micron cladding and 10 micron core you will have to have refractive index variation. Here you have you will have around 1.45 then here you have 1.44 for example, it is not possible to start with something which is on micron scale.

So, what we do we first make a large structure which contains this geometry and reflective index distribution. The dimensions are this is this can go from 10 to 20 centimeter. And the length can be one meter for an industrial perform. And when you draw fiber out of this then this structure is retained over kilometres of lengths. So, and the quality of the fiber now depends upon what is the quality of this perform. In the fiber the refractive index profile geometry of the core and the cladding, core concentricity all are decided by preform itself.

So, preform fabrication is a very important stage. And the propagation characteristics of the final fiber are determined primarily by the quality of preform. So, we should take utmost care while making the preform. How do we fabricate preform? How do we choose materials to make core and the cladding for silica glass fiber itself

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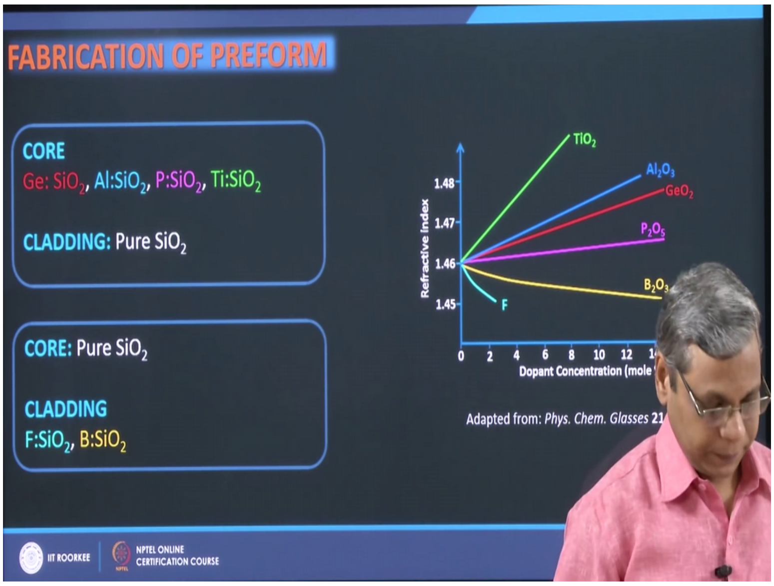

? For the 8 letters look at this plot; where we have drawn refractive index of silica glass as a function of dopant concentration. When we dope when we dope silica glass with different materials then how it is refractive index changes. So, here you can see that this is pure silica at around 1.46 refractive index when you dope it with phosphorous, germanium, aluminium, titanium you increase the refractive index.

While when you dope it with boron or fluorine you decrease the refractive index. We know that for core we need high refractive index and for the cladding we need low refractive index. So, we have different options. One option is that you make cladding out of pure silica since cladding is out of pure silica here 1.46, then core should be using either of these. So, so in core you can either dope germanium or aluminium or phosphorous or titanium to increase the refractive index. And most widely used material is germanium you usually dope germanium to have high refractive index in the core region.

Second possibility is that you use pure silica for core. And cladding you make out of doped silica. So, you can either use fluorine or boron. So, this germanium doped core and pure silica cladding is the most commonly used telecom fiber; however, this kind of fiber where you have pure silica core. And fluorine dope cladding it is used in an environment where there are nuclear or ionizing radiations. Because there germanium does not work, because germanium developed some color centers and then optical radiation is absorbed by those color centers. So, there it is preferred to use pure silica glass fiber, but we will concentrate on telecom fiber in usual environment. So, we will concentrate on germanium dope core and pure silica glass cladding. If you remember that in 60s the major bottleneck in the development of optical fiber communication system was losses in optical fiber.

The losses were of the order of 100 dB per kilometres. And the primary reasons for these losses were impurities in glass. So, if you want to make a fiber which has very small loss then you will have to make glass itself in the laboratory. You start with chemicals make glass from chemicals itself. So, that you do not have any impurities embedded and you do it in a very clean environment. So, this is how glass and doped glass can be made. What you do?

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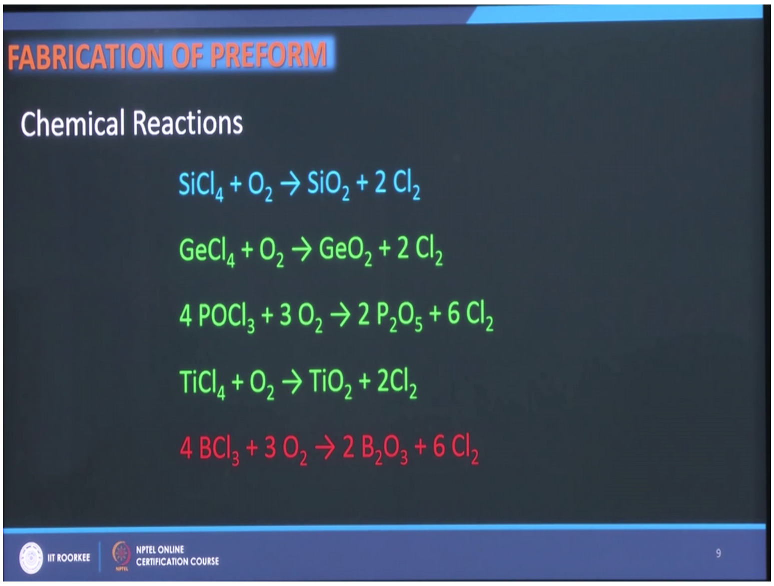

You take SiCl 4 and oxidize it at certain temperature. Then you make silica glass. If you want to make doped glass then along with SiCl 4 you mix a little bit of germanium also in the form of GeCl 4 and then oxidize it. Then you make germania and this would be doped in silica glass.

Similarly, you can use phosphorus titanium or and boron or fluorine. So, these are some chemical reactions which are used while making glass and doped glass. So, what is the process what are different processes to make the preform. Well you start with these chemicals depending upon your choice of doping. And then you have 2 roots one is flame hydrolysis another is chemical vapor deposition.

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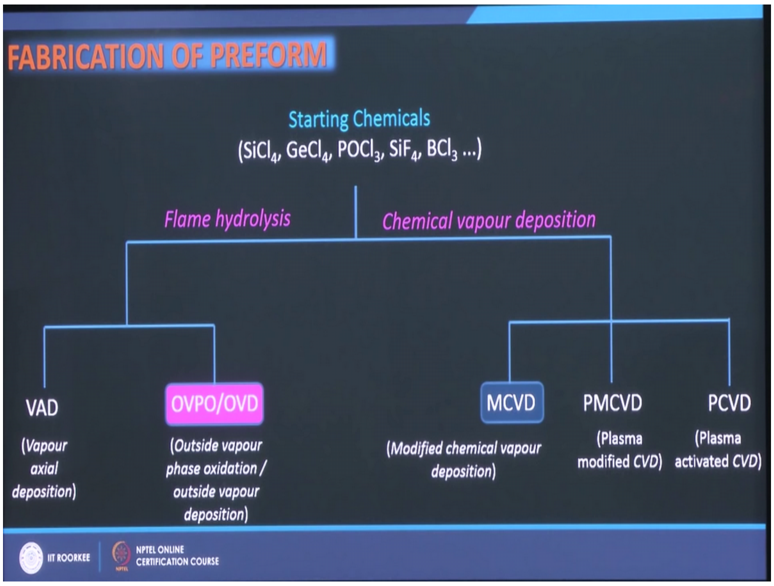

In flame hydrolysis technique, you can have either vapor axial deposition VAD or you can have outside vapor phase oxidation or outside vapor deposition popularly known as OVPO or OVD technique.

In chemical vapor deposition route you can have 3 possible techniques. One is MCVD modified chemical vapor deposition. Another is plasma modified CVD or PMCVD or plasma activated CVD or PCVD. Out of these techniques the 2 most popular are OVD and MCVD. So, in this lecture we will understand these 2 techniques of making fiber preform. So, let us first look at MCVD technique. This method as developed by bell laboratories. What is done here?

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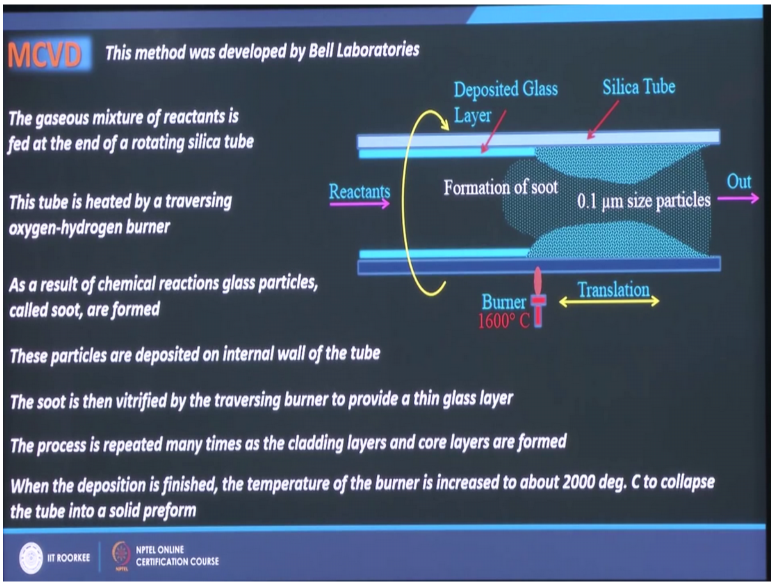

You take a tube of silica glass and you flow reactants into this tube you want to make silica glass cladding. So, you flow in SiCl 4 in oxygen environment and heat it up. How do you heat it up? Well you use a burner which is kept at around 1600 degree centigrade and this burner translates in this direction horizontal direction. And simultaneously this tube is rotated.

So, burner translates and tube is rotated So that it can cover the whole area surface area of this tube. So, when the reactants are flow flown into this tube and they are heated. Then as a result of chemical reactions the glass particles are formed, since it is inside vapor deposition. So, first you deposit cladding layers inside this tube. So, initially you just put SiCl 4 here in oxygen environment heat it up oxidize it. When you do that then initially glass particles are formed. These glass particles have typical size of around one micrometer sorry 0.1 micrometer. And these particles are called soot, these particles are deposited on the internal wall of the tube. And then this burner translates this tube at 1600 degree centigrade. Then these particles are vitrified and form a thin glass layer.

So, you keep on depositing cladding layer by layer. And when you think that you are done with depositing enough clear cladding layers which are required to have certain thickness of cladding. Then you start depositing core layers, for core layers you need to dope germania. So, along with SiCl 4 you start now flowing required amount of GeCl 4 also. So, you now deposit germanium doped silicon layers on top of cladding layers and when you are done with depositing core layers. Then you stop when the deposition is finished then you increase the temperature of burner to about 2000 degree centigrade and collapse the tube into solid perform, when you increase the temperature to such a high value 2000 degree centigrade. Then this tube is collapsed and from hollow tube you get a solid. And this solid rod has in the center the core layers and outside the cladding layers and this is called preform.

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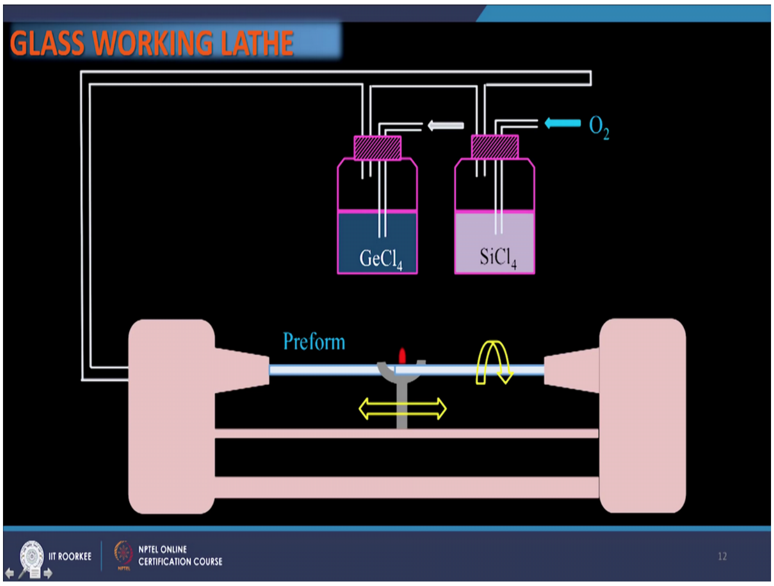

So, in this way you can make preform. This is done on a glass working lathe. Typical lathe looks like this, where you have this silica tube and these chemicals SiCl 4 and GeCl 4 in oxygen environment are flown in from here. This is the burner which translates this tube rotates. In this way you can make perform on this glass working lathe. I have a small video of making this glass preform using MCVD technique and which is routinely done at central glass and ceramic research institute which is a csi or lab in kolkata. So, I have a video from there which shows a glass working late.

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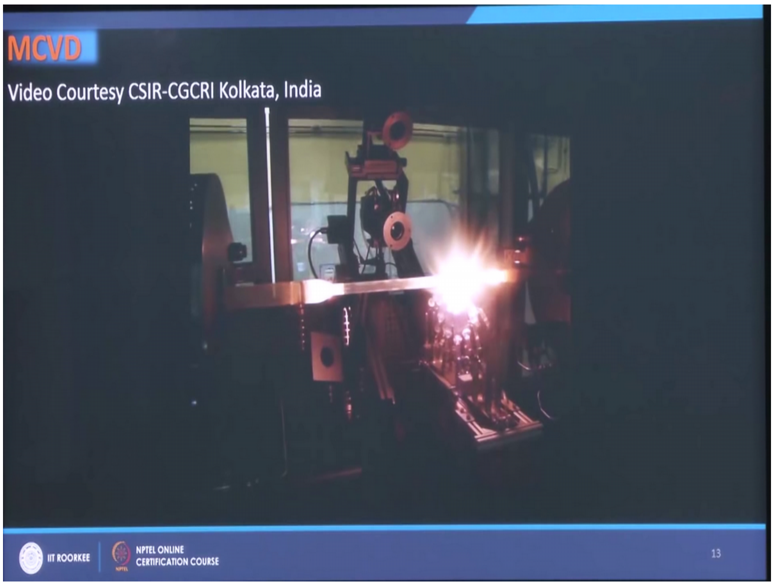

So, this is glass working lathe you can see that this tube is rotating. And this burner is translating this burner is quartz burner which can withstand very high temperature. From here the gases are flown in and this burner translates this tube. So, it every pass you deposit a layer of glass inside the tube. And the tube the burner is on only in one direction when it when it translates from this direction to this direction then only the burner is on it does not do like this it goes in this direction, then you switch off the burner translate it to this end and then again switch it on ok.

So, this is how it works. Everything is well monitored you monitored it using camera. You always monitor the temperature very carefully and this is a fully automated machine to make the fiber preform. So, you can see that as soon as it will reach this end the burner will go back and then it will start again. So, it is now about to reach here at this end of the tube. Now you put down the flame and then retrace it back to the input end, here you go. So, you go back to this end and then again started. So, in this way you deposit glass layer by layer.

Then there is outside vapor deposition OVD technique, which has been exclusively used by cordoning since 1970s.

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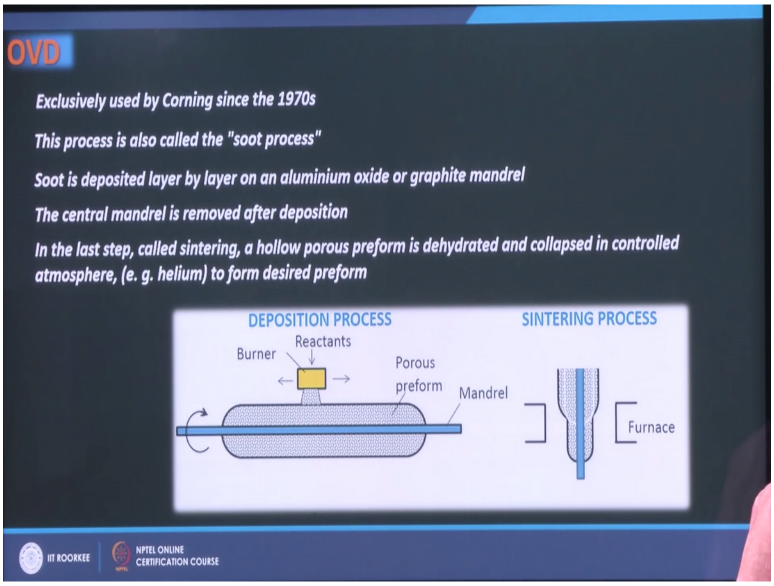

You remember that corning glass works was the first company which produced a fiber with very low loss in 1970 the fiber they produced had a loss of 16 dB per kilometer. And that marked the revolution in optical fiber communication actually. So, again this process is also called soot process. Here what you have? You have a central mandrel which is made of aluminium oxide or graphite. And you flow in the reactants from here and heat it up there is a burner which translates this mandrel is rotated. So, you cover the whole area.

So, as a as a result of the chemical reactions again the soot is first formed. And the soot is deposited on this mandrel layer by layer, but it is not verified here. It is in the form of soot itself particles and particle over particle then this preform is a porous preform. Then what you will have to do after making this preform we will have to remove it from here the mandrel you remove and then you sinter it. You sinter this hollow porous perform in a furnace you dehydrate it and collapse it into a solid preform in a highly controlled atmosphere, usually helium atmosphere. So, that is how you make preform from OVD technology.

Once you have made the preform then you will have to draw fiber out of it. And it is done in a fiber draw tower which is as high as a 3 storey building; on top of that you have a furnace.

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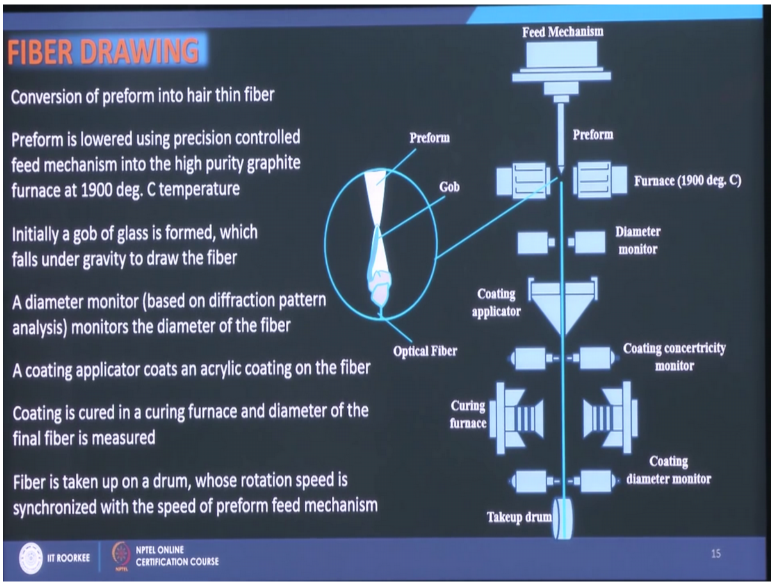

Which is kept at around 1900 degree centigrade, and you lower the preform using a precise feed mechanism into this furnace, very slowly you lower this preform into this. Initially what happens is when it starts melting a gob of glass is formed here and this gob of glass falls under gravity when it falls under gravity it pulls the fiber down. And this fiber now goes through various stages. Here the diameter monitor where the diameter is monitored using diffraction technique using a laser. Then you coat this fiber with an acrylic coating. Here you monitor the concentricity of the coating, here you cure the coating either you can have a coating which can be cured thermally. So, you have curing furnace. Some coatings can be cured by UV then you will have some UV lamp assembly here ok.

Finally you monitor the diameter of the final fiber and then you take it up on a drum. And the speed of the drum which is the take up drum and the speed of lowering feed mechanism of this preform are synchronized to have a final overall diameter of the fiber. So, this is how it is done.

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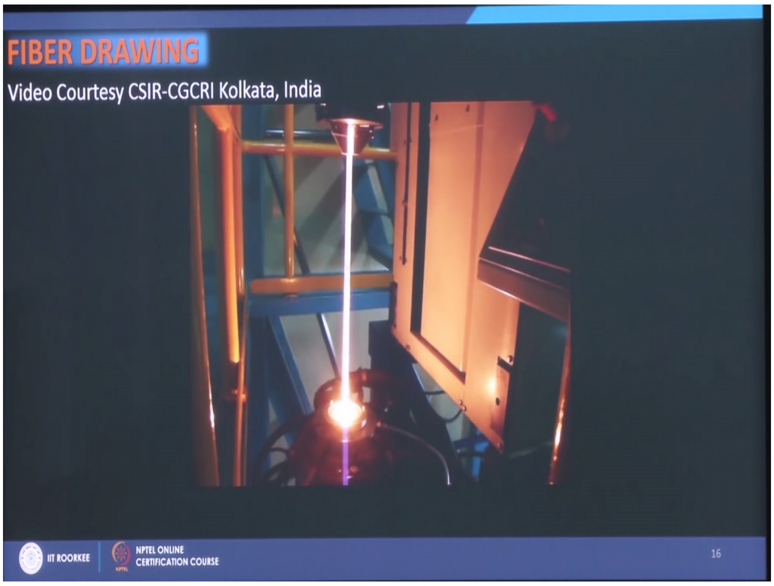

And again I have a small video which shows this fiber drawing at CGC RI kolkata. So, so you can see that this is the fiber preform into a furnace.

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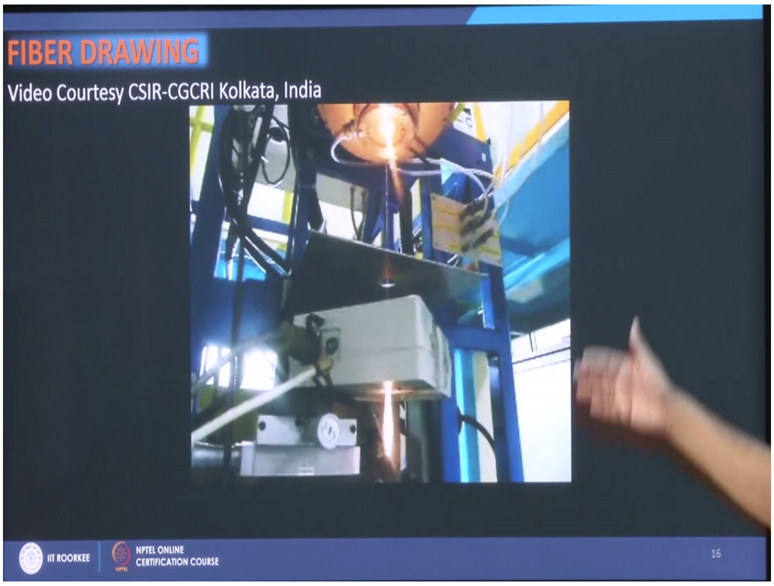

And you will see initially this gob of glass is formed and this is the fiber coming out and then it goes through various stages ok.

So, this is the fibre coming out this is the diameter monitor, this is again you can see the fibre coming down and this is the take up drum.

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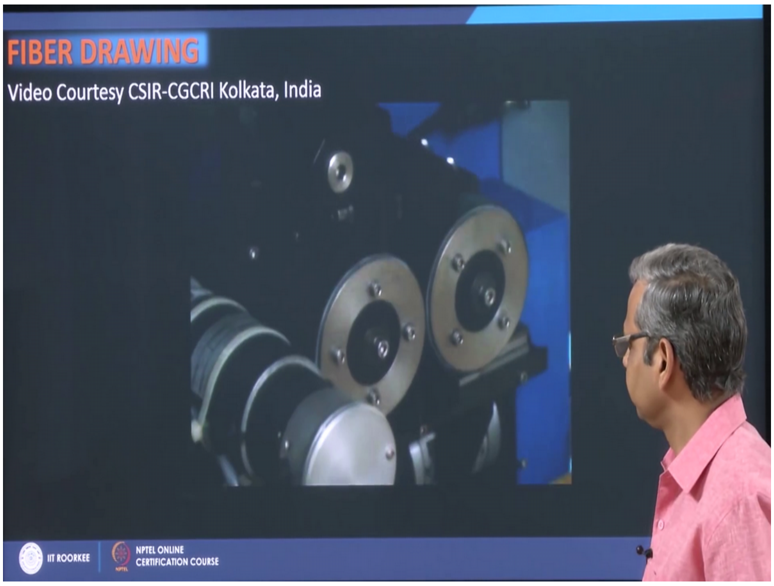

So, when fiber comes out of the draft hour it looks like this, which has got a core cladding and acrylic coating then it can be put in the form of cables. So, what you will have to do?

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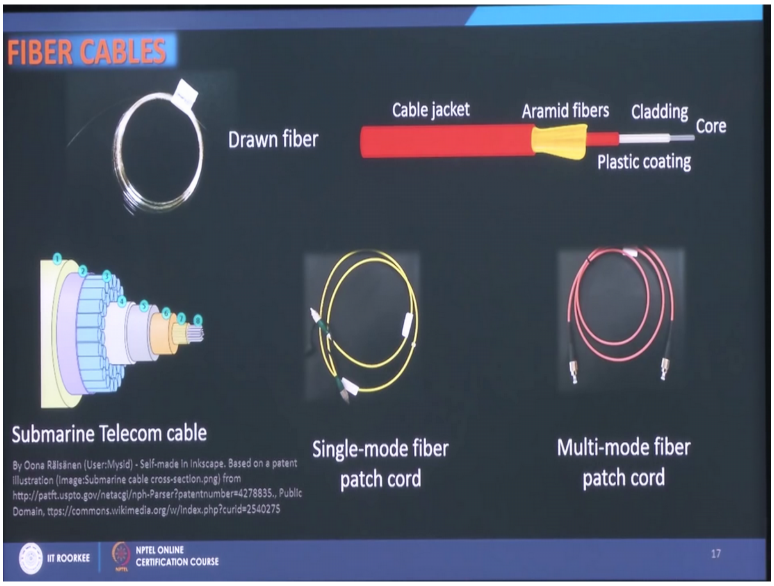

So, this is the fiber then you put it into a jacket you put a jacket on to this fiber and in between you put some cushioning using aramid fibers popularly known material of this is Kevlar. Using this you can now either make submarine telecom cable or you can make patch cords.

This is a typical telecom cable this is a single mode fiber patch cord whose color is kept yellow. And this is multimode fiber patch cord whose color is kept orange this is color coding. This is a typical fiber cable which you put on seabed.

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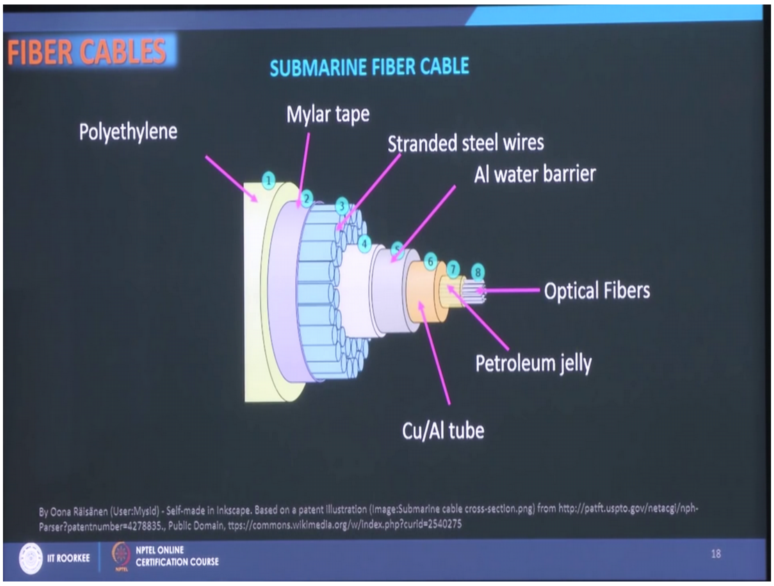

So, it has got these optical fibers then to remove friction between them you put some petroleum jelly, then you house them into copper or aluminum tube. Then you put a water barrier made of aluminium then you give strength to these fibers by using stranded steel wires. So, the these are used as re reinforcing elements then you have Mylar tape and then ultimately they are housed in a polythene jacket.

So, this is a typical submarine fiber cable. You can also make bundle sort of these fibers by putting or several fibers together you can assemble these. Fibers in 2 fashions one is when they are not aligned in a proper fashion there jumbled up the relative positions of the fiber that input and output ends are not the same.

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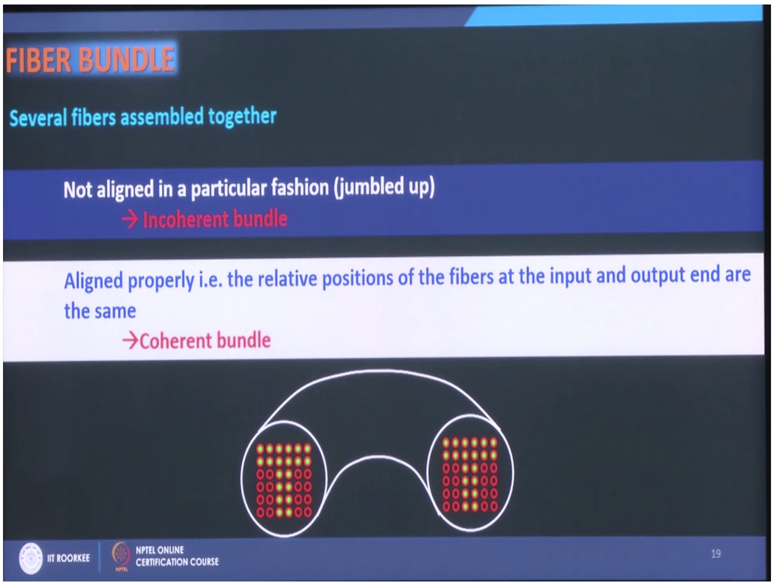

Then it is incoherent bundle, but when the relative positions of the fibers at the input and output ends are the same then it is coherent bundle. Coherent bundle can be used for image transmission like this. So, if you light up these fibers at the input end. So, at the output end also these fibers are lathe up and you can transmit the image.

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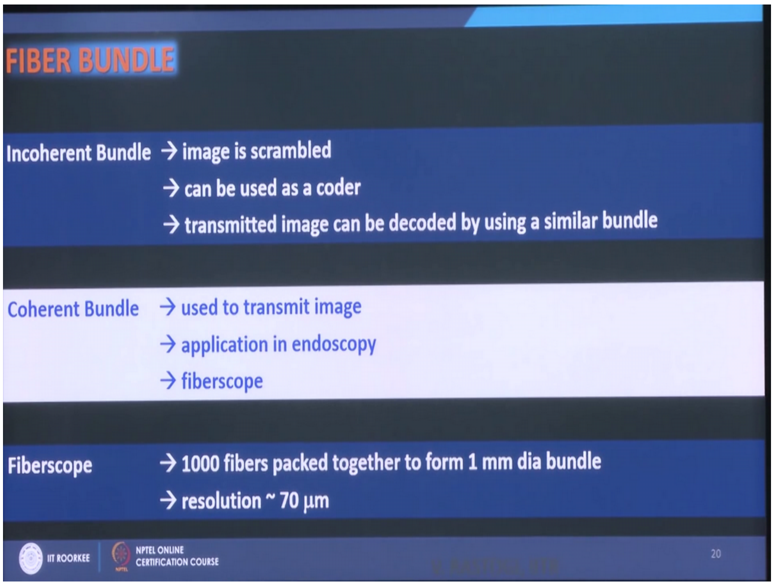

In an incoherent bundle since the relative positions of the fibers are not the same at the input and output end. So, the image is scrambled.

So, it can be used as a coder. So, if you send an image through this incoherent bundle and you use the similar or same incoherent bundle at the output end then you can get back the image. So, transmitted image can be decoded by a similar bundle. So, coherent bundle can be used to transmit image. And it is applications are like an endoscopy or to make fiber scope. And the typical fiber scope can have 1000 fibers packed together to form a one millimeter diameter bundle. And it is resolution can be something like 70 micrometer.

So, what we have learnt in this lecture is that glass and polymers are 2 widely used materials for making optical fibers for diversified applications. Glass fiber is most suitable for telecom applications fabrication of fiber is a 2 step process first you make a preform and then you draw fiber out of it.

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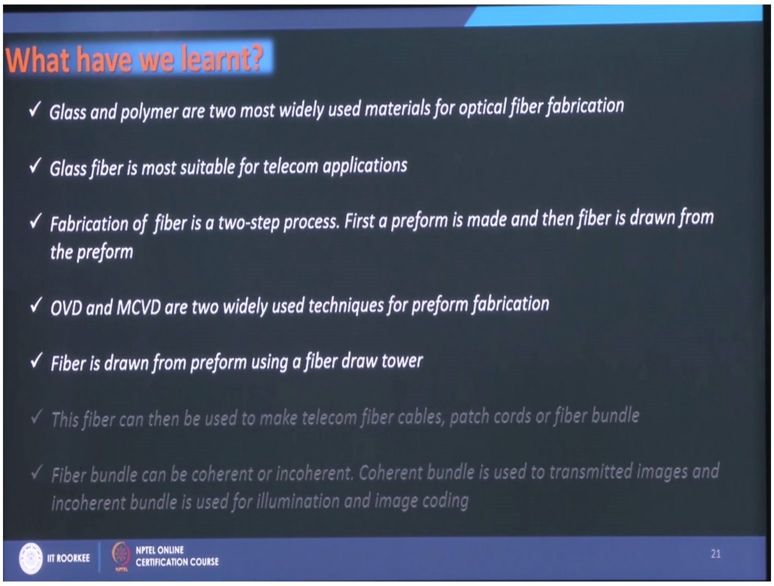

OVD and MCVD are the 2 most widely used techniques for making fiber perform. Fiber is drawn from preformed using a fiber draw tower. And this fiber then can be used to make telecom fiber cables, patch cords or fiber bundles. Fiber bundle can be incoherent or coherent bundle is used to transmit images. And incoherent bundle is used for illumination and image coding.

Thank you.