Physics of Linear and Non-Linear Optical Waveguides
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Module - 02
Basic Fiber Optics
Lecture - 07
Cutoff Wavelength, Fiber Characteristics

Hello, student to the course of Physics of Linear and Non-Linear Optical Waveguides. Today, we have lecture 7 and today, we plan to cover the concept of Cutoff Wavelength and then try to understand few very important characteristics of an optical fiber or some wave guide. So, let me quickly start with whatever we have done in the last class.

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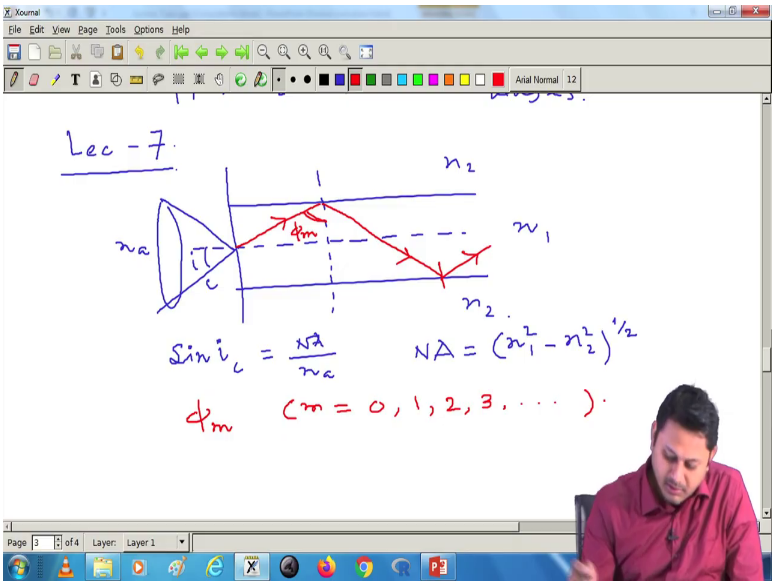

So, today we have lecture 7. So, in the last class, we find that if we have a fiber structure like this wave guide structure like this n 1 refractive index here, n 2 here, n 2 here. We already find out for this kind of structure what is the critical angle and acceptance angle. And, acceptance angle for meridional ray is sin i c is equal to N a divided by n a, where n a is a refractive index this is the axis where n a was the refractive index outside of the waveguide.

And, this big N A which you call numerical aperture is n 1 square minus n 2 square whole to the power half that was the value. For skew ray there was another factor cos alpha here. Now, this is my acceptance angle i c this is my i c, this is a range of my acceptance angle.

All the rays that should fall inside this cone should pass through in principle, but we can we find that if some ray is falling in which is falling like this can only propagate when some interference condition is there. So, that means, this angle we calculated that this angle phi is a function of m, where m is some integer value.

So, that means, it is not that all the rays will going to allow, there are certain rays that can pass through in the fiber. So, that is why, it is a discrete we call it discrete ray. So, phi m that depends on some m value; so, m can be 0, 1, 2, 3 like this.

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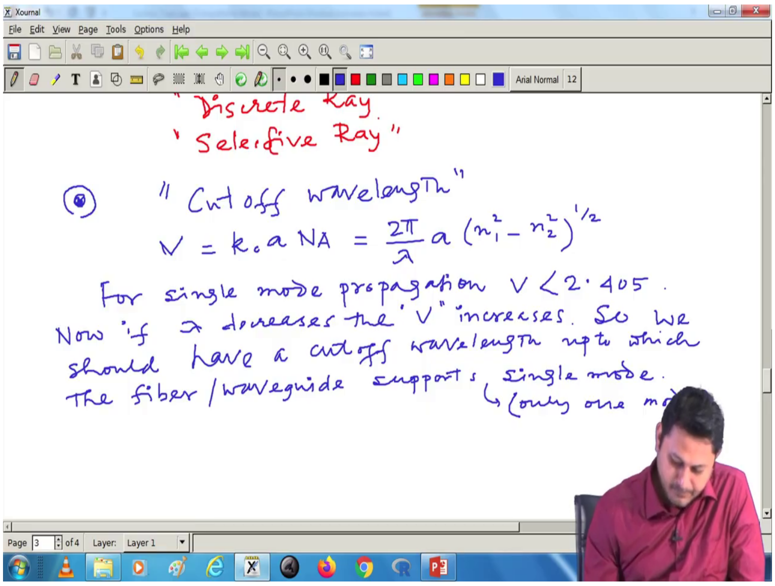

So, we have the concept of discrete ray. Not all the ray, but there will be some selective or some selective ray. So, few selective rays are allowed to pass, not all the rays. Today, we will going to also define another important concept, another important term for waveguide system and that is called the cut off wavelength.

We already defined the V parameter. So, let me remind you V parameter was a parameter of a given wave guide which is defined like k 0 a N A or 2 pi by lambda multiplied by a n 1 square minus n 2 square whole to the power half. That is my cut off wavelength, that is my V parameter, sorry.

So, cut off wavelength from this V parameter we can define something called cut off wavelength. So, let me write it what is the meaning of cut off wavelength in words then I am going to discuss this. For single mode propagation we know for single mode propagation V is less than some value 2.405. This value is a value one can calculate that, there is a method of calculation of that. So, we need to understand what is mode and then we will going to discuss about this more this we know.

Now, if lambda decreases then V the V parameter increases that we will also discuss that if lambda decreases because lambda is sitting here in denominator if this decreases, then the value of the V will automatically increases if a and other parameter n 1 and n 2 are fixed. So, we should have a cut off wavelength up to which the fiber or the waveguide supports single mode only one mode or single mode.

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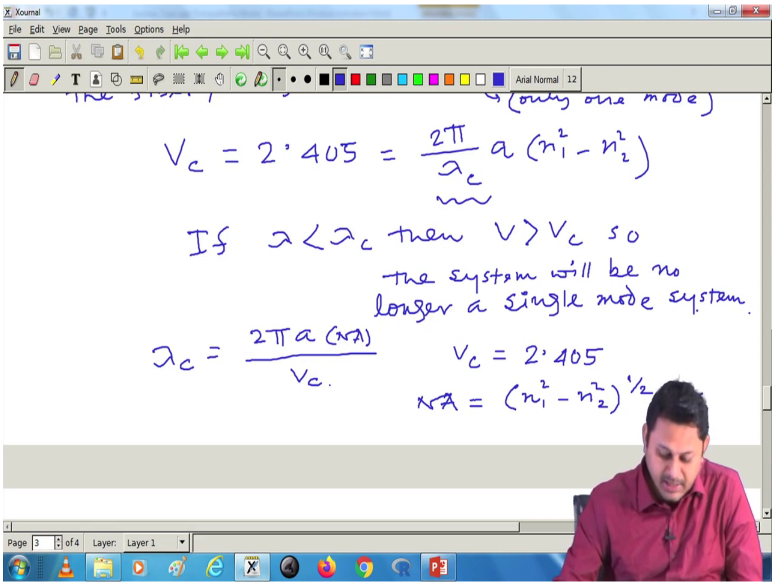

So, naturally there is a restriction of lambda as well because if I put the expression V c which is the critical value of the V as 2.405 then this should be equal to the value of lambda c a and n 1 square minus n 2 square. So, this is the value of the lambda c for which I can have the single mode propagation.

If I now increase if decrease the lambda c, then what happened? If lambda is less than lambda c, then V will be greater than V c and there will be so, the system will be no the system will be no longer a single mode system; that means, more than one mode can propagate.

So, with this restriction we can clearly find out what is the value of lambda c. So, lambda c is simply 2 pi a N A divided by V c, where V c equal to that critical value for which the system behave like a single mode fiber. So, once we know the value of V c once you know the value of n 1.

So, N A again every time you need to remember whenever I write N A it is n 1 square minus n 2 square whole to the power half. So, whenever I write this N A this is the value. So, lambda c one can calculate for a given waveguide. So, once the waveguide is given; that means, A is known N A is known.

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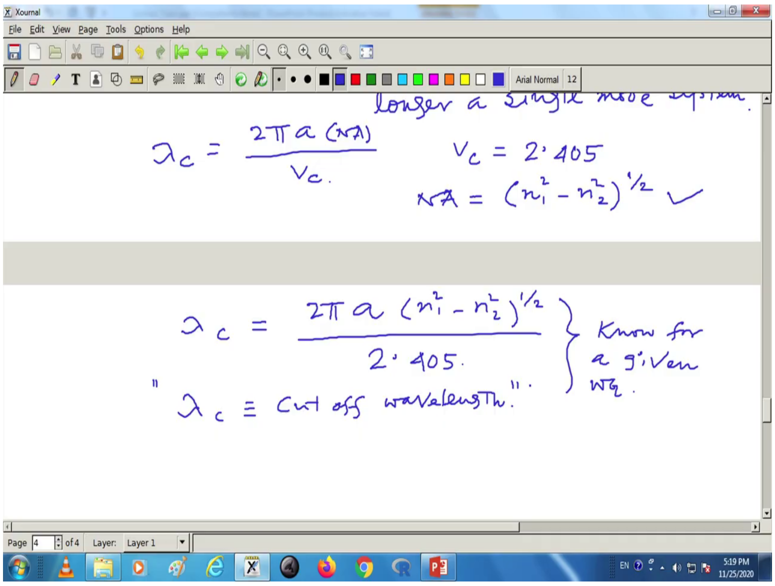

So, readily I know what should be the value of lambda c. So, lambda c if I want to calculate is simply 2 pi a which will be given, then n 1 square minus n 2 square this is the; this is the geometrical parameter of the wave guide divided by V c and in place of V c I can write simply 2.405.

So, all the values are known for a given wave guide and if these values are known we can calculate for the given wave guide what is lambda c and lambda c we called is at cut off wavelength. So, I can calculate the cut off wavelength if the condition if the geometrical parameter of the waveguide is given and also V c is applied ok.

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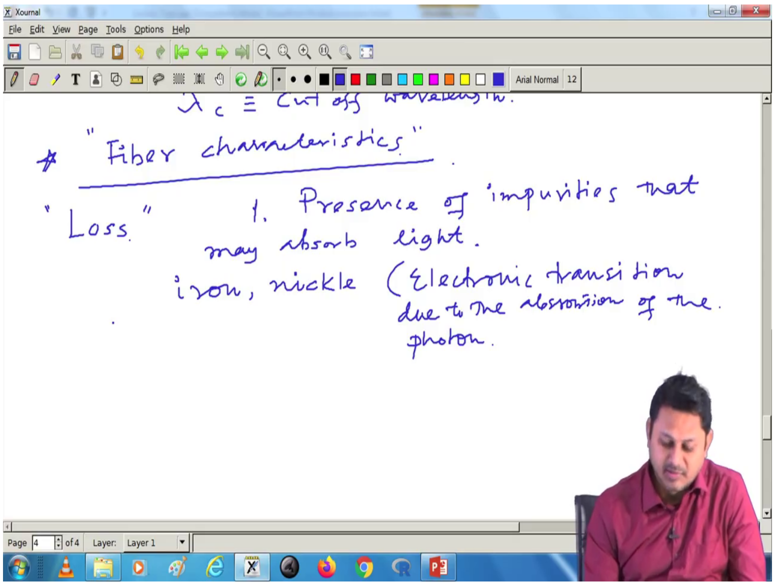

Now, the next thing we like to discuss few things about the fiber characteristics; so, basic few basic characteristics of the fiber. So, fiber, so, few basic fiber characteristics. So, the first thing we will going to learn about the loss. This is a very very important parameter, important property or important phenomena that happens in the fiber.

So, definitely when some wave in the wave guide when the light is propagating it will not going to propagate to a very very long distance due to some losses and which is quite natural in the nature. In fiber also we have certain losses and I can list out few of them. One is presence of impurity; because of the presence of impurity what happened? That may absorb that may absorb light and it goes to.

So, there are certain impurities that may present in the material of the waveguide and due to the presence of this impurity what happened? They will going to absorb certain amount of light and because of because the fact they are absorbing the light we will going to have a certain amount of loss. So, which kind of material are normally present as a impurity? These are like iron, nickel, etcetera. So, they so, when they absorb so, what happened?

So, I also note that. So, there should be some kind of electronic transition due to the absorption of the photon. So, what happened? So, this material going to absorb the photon and there will be electronic transition and eventually, we will going to have a loss in this system which is where the light is propagating.

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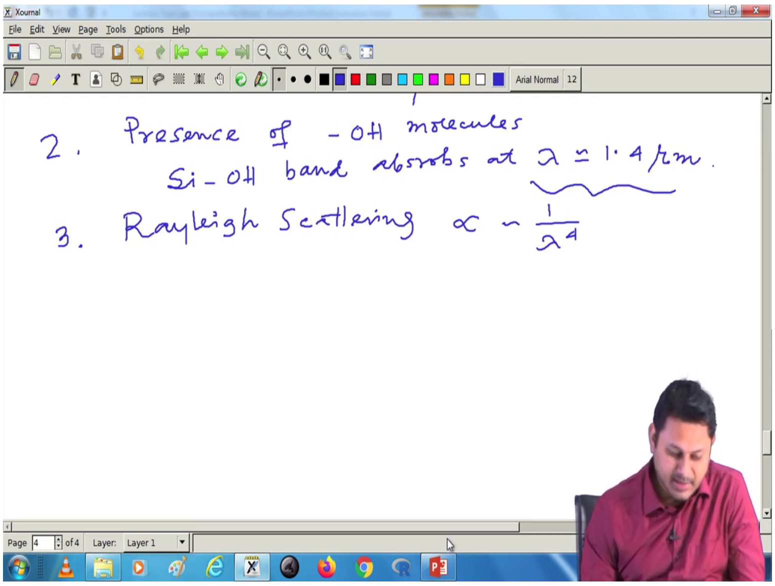

Next thing specially for fiber specially for fiber which is made of silica the presence of the presence of OH molecules moisture. So, Si-OH band what happened due to the presence of OH molecules as an impurity, so, Si-OH band absorbs at absorbs light actually at lambda equal to null equal to 1.4 micrometer.

So, if I have a OH band then this OH band will going to absorb. So, there is some vibrational energy associated with this Si and OH bond. So, there is a few frequencies are there and these frequencies are matching with this resonance frequency and that is why it should have some vibrational band.

So, lambda around lambda equal to 1.4 at that wavelength range it will going to absorb the light and we will going to have a peak the absorption peak there especially this is specially for the optical fiber. So, we have to be very careful in making the core of the optical fiber and lot of efforts are there to make these to remove these OH molecules, so that we should have the absorption the OH molecules absorption loss.

Another example of the loss is say the Rayleigh scattering and we know that in Rayleigh scattering, we have the absorption scattering loss of the order of 1 by lambda to the power 4; if lambda is very very small then we have large amount of scattering. So, when electromagnetic wave is propagating for small wavelengths it can experience the Rayleigh scattering inside the medium. So, there are few very very well known examples apart from that there are other issues also through which one can expect losses. So, for example, bending loss.

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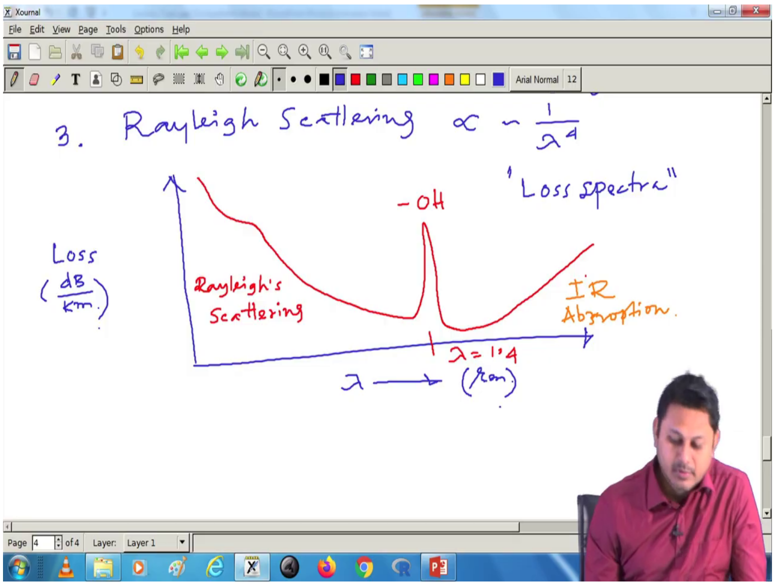

So, I will come this. So, before that I like to show very a very hand drawn picture of the loss curve that one can have for fiber. So, in Y-axis if I plot loss which has a unit dB per kilometer; this is a very very special unit normally used in all fiber optics communication systems. And, if I plot lambda in this direction say in micrometer unit then the loss curve or attenuation curve is typically like this a very rough drawing. For better drawing you can search internet or you can find in the book as well.

So, we have as I mentioned we have a peak here and this peak is around lambda equal to 1.4, where this is due to the loss of this OH molecule. So, which basically have a vibrational energy, a vibrational transition here absorb the light here and we have a peak. This portion this lower lambda portion is for Rayleigh scattering and this higher part higher also you can see the loss is increasing here.

And, at some point here there is a minimum loss in this side also if I go to the lower wavelength we have a higher loss if I go to the higher wavelength also it seems that losses are increases and this loss is due to the IR absorption is due to the IR absorption. So, we have a very very narrow window here in this region near very close to 1.4, where we have the minimum loss and obviously, for a transmission system we required a region where the characteristics loss should be very very small.

And, this these are the few losses which always be there. It will be very difficult to remove. Apart from that another kind of loss one can expect. So, this is a loss picture what I draw here is loss spectra for fiber loss as a function of wavelength.

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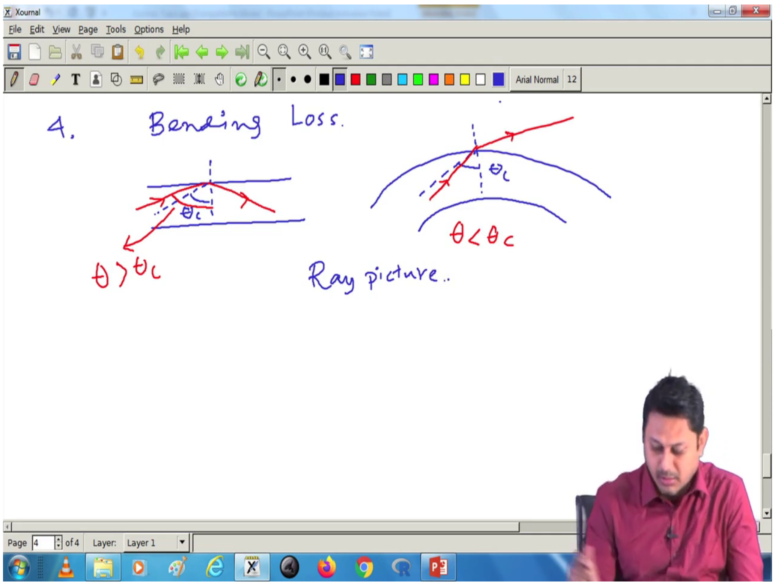

Now, I can have another kind of loss which is important in fiber optics communication and which is called bending loss. If I bend optical fiber so, this is the fiber for state fiber and we know for state fiber already in the Ray picture we find that if this is my critical angle, if I launch something greater than the critical angle then it will be reflected back like this.

So, this is the structure for straight fiber and this angle is theta c is a critical angle and I launch something. So, total internal reflection will take place here. Now, if I bend the fiber so, there is a possibility. So, if I bend the fiber like this so, there is a possibility that whatever the critical angle I have. So, the Ray now will not going to follow this condition. So, here if this angle is theta this big angle is theta which is greater than theta c.

Now, the same theta can be the same theta I launch in a similar way, but here this theta can be less than theta c and light can leak through due to the bending. This is Ray picture. In the Ray picture I can understand qualitatively how one can have the bending loss.

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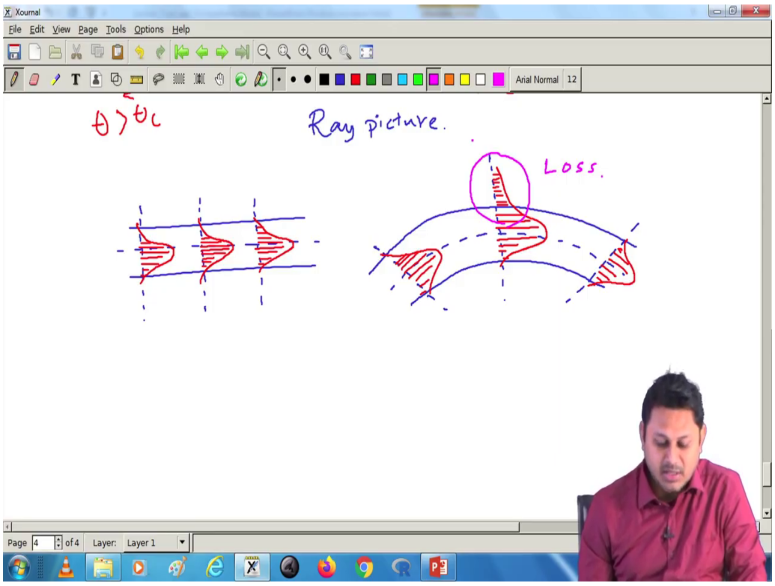

However, also the mode picture is there. So, we will going to learn that. So, when the light is propagating it is associated with something called mode the distribution. So, this distribution if I draw it should be like this. So, very much confined the mode is very much confined.

So, we can see the mode if I set this region so, the mode is very much confined inside the system and it is propagating through it is propagating through like this. I can have another. So, the mode is propagating without any problem. So, everything is inside the system.

Now, if I bend this, if I bend this like the previous case if I bend this. So, the distribution of the mode will be affected by this bend radius and now, instead of having this we can have a more distribution like this and if I set this it should be like this. In this straight region by the way, I can have less leaky part.

So, this is the part which is leaking. So, here we can see a region this is loss. Due to the bend, what happened? Some portion of the energy is leaking through the fiber and due to that one can expect some kind of loss and this is due to the this is the consequence if I bend a fiber.

Well, with this note I like to conclude today's class. So, today we learn qualitatively the concept of losses. Before that also we learnt something called the cut off wavelength, how to calculate the cut off wavelength etcetera. In the next class, we will continue with the loss and try to find out the units that is being used to calculate the loss.

So, thank you for your attention. So, see you in the next class.