Fiber Optics
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Lecture – 29
Optical Fiber Components and Devices- II

In the previous lecture we were discussing the directional coupler. We discussed about the physics and working principle of directional coupler. In this lecture we will continue the discussion we would also look into few more components that can be made using directional coupler. And some other fiber optic components like, polarization controller and fiber gratings. So, what we were discussing that if we have a directional coupler with 2 non identical cores which have modes with propagation constants beta 1 and beta 2.

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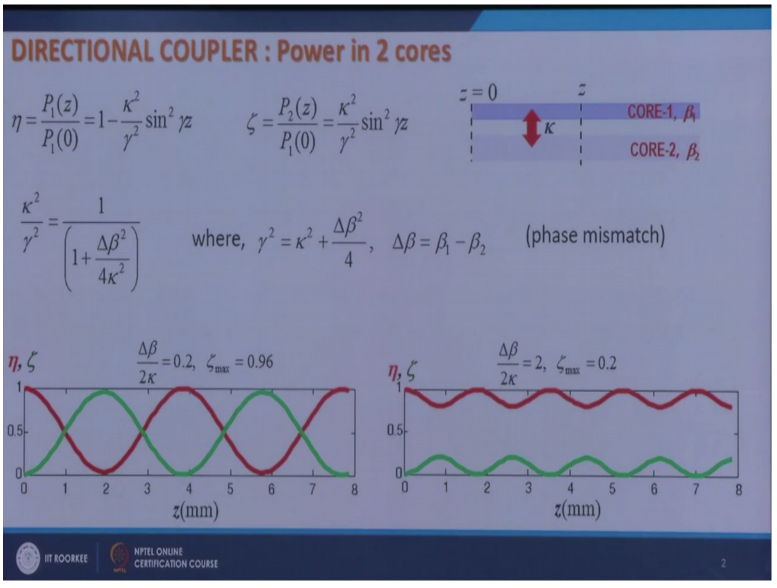

Then the fractional power that is in core 1 is given by 1 minus kappa square over gamma square sin square gamma z. And the fractional power in the core 2 is given by kappa square over gamma square sin square gamma z, where gamma square is equal to kappa square plus delta beta square by 4 and delta beta is nothing but the phase mismatch which is the difference between the propagation constants, beta 1 and beta 2.

But we had seen that if delta beta over kappa is small, then we can have maximum coupling of power from one core to another core this zeta max can be close to 1 and if delta beta is equal to 0 then we can have 100 percent coupling of power from core 1 to core 2. But if this phase mismatch delta beta is substantial then we cannot have 100 percent transfer of power from core 1 to core 2 as shown here. So, for delta beta is over 2 kappa is equal to 2 the maximum power that can be coupled from core 1 to core 2 is 20 percent.

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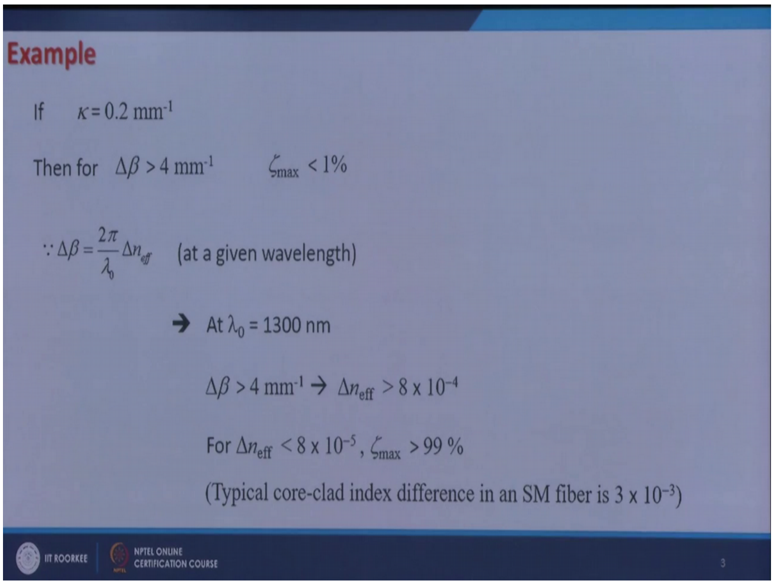

Let us work out an example, yet if we take a typical value of kappa as 0.2 millimeter inwards. Then we find that for delta beta greater than 4 millimeter inwards zeta max would be less than one percent, this calculation is very simple can be done very easily. How much is this delta beta will the, let us work out some numbers and have a feel of delta beta how much this delta beta is. We know that delta beta is equal to k not delta n effective were k not is 2 pi over lambda not.

So, if I fix a wavelength let us say 1300 nanometer, then delta beta is 2 pi over lambda not times delta n effective and for delta beta is equal to 4 millimeter inverse if I calculate delta n effective from here, then it will come out to be 8 into 10 to the power minus 4 which means that which means that if delta n effective is larger than 8 into 10 to the power minus 4, than the coupling of power from core 1 to core 2 would be less than one percent. How large this? Is how large this delta n effective is, you can compare it with core cladding index difference in single mod fiber which is 3 into 10 to the power minus 3.

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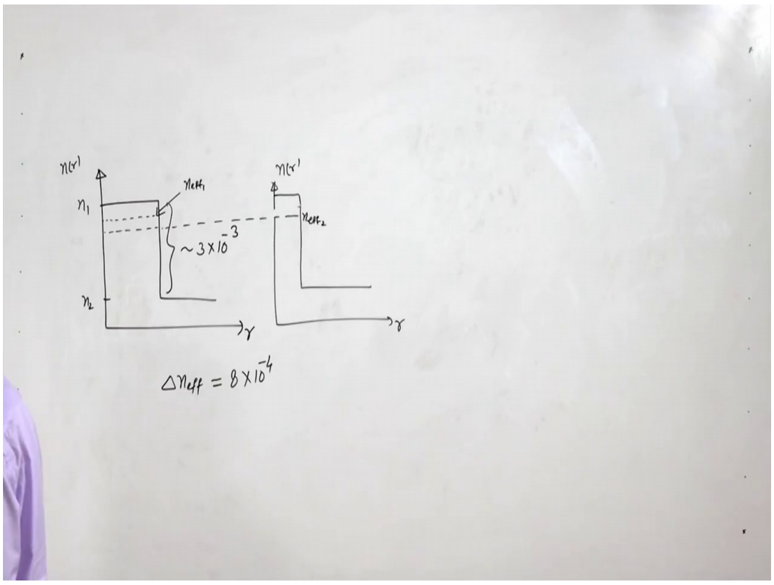

So, if you have a single mode fiber, if I draw the refractive index profile r and this is n r this is n 1 this is n 2. So, this difference is typically 3 into 10 to the power minus 3. And here delta n effective which is the difference between the propagation constants of 2 modes of 2 different wave guides or 2 different fibers delta n effective is typically 8 into 10 to the power minus 4. If it is greater than 8 into 10 to the power minus 4 then there would be coupling of power which is less than one percent.

So, if you compare it let us say there is another fiber like this r n r. So, these are 2 non identical fibers. So, this is delta n effective 2 sorry, this is n effective 2 and this is n effective 1. So, if you compare these 2 the difference should be much smaller. And if you calculate the value for maximum coupling of power for example, say for more than 99 percent coupling of power then this delta n effective should be less than 8 into 10 to the power minus 5.

Now, we can use this directional coupler for multiplexers and de multiplexers also. Here we utilize the fact that the coupling coefficients kappa are wavelength dependent.

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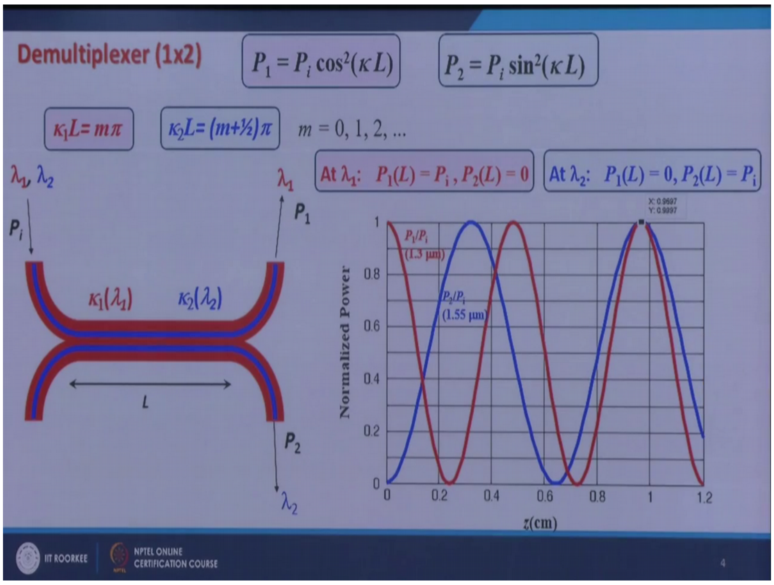

So, if we send 2 wavelengths lambda 1 and lambda 2, through this device then what will happen. Let us say at lambda 1 the coupling coefficient is kappa 1, and at wavelength lambda 2 the coupling coefficient is kappa 2. We know that for phase matched case let us consider phase matched case for convenience P 1 is equal to P I cosine square kappa L this is the power in core 1, and P 2 is P I sin square kappa L power in core 2.

Now, now if I choose this length L such that kappa 1 times L is equal to m pi, and kappa 2 times L is equal to m plus half pi, remember that kappa 1 is the coupling coefficient at lambda 1 kappa 2 is the coupling coefficient at lambda 2. In such a case at lambda 1 at wavelength lambda 1 P 1 L would be equal to P I because kappa L is equal to m pi. And P 2 L would be 0 because kappa 2 L sorry, kappa 1 L is equal to m pi, So P 2 would be 0.

So, this would be P 1 and this would be P I and this would be 0 at lambda 1. At lambda 2 at lambda 2 since kappa 2 L is equal to m plus half pi. So, this will give you P 2 is equal to P I and this one will give you P 1 is equal to 0 at length z is equal to L. Which means that, which means that lambda 1 will come out from this core and lambda 2 will come out of this core.

If I plot normalized power that is: P 1 over P I or P 2 over P I as a function of z then how it varies? P 1 over P I would vary like this and P 2 over P I would vary like this. So, what I find that at this value of z, I have power in core 1 at lambda 1 is equal to P I and power in core 2 at lambda 2 is equal to P I. So, lambda 1 will come out from this port and lambda 2 will come out form this port. So, this is how I can choose the coupling length, multiplex de multiplexing length for such a coupler.

So, what I am able to do with the help of this? I am able to separate out 2 wavelengths into 2 different fibers. So, this works as wavelength de multiplexer. In the same device if I now launch lambda 1 from here and lambda 2 from here, then for a given length L which we can find from the previous slide itself for that length L itself both the wavelengths will come out from a single fiber. So, I can multiplex 2 wavelengths together. So, these kinds of couplers are known as WDM coupler, because they are used in WDM systems.

Let us know look at some practical parameters of a directional coupler. A directional coupler is a 4 port device and we can name the ports like this. This is the input port this is through put port, this is cross port or coupled port and this is reflection port.

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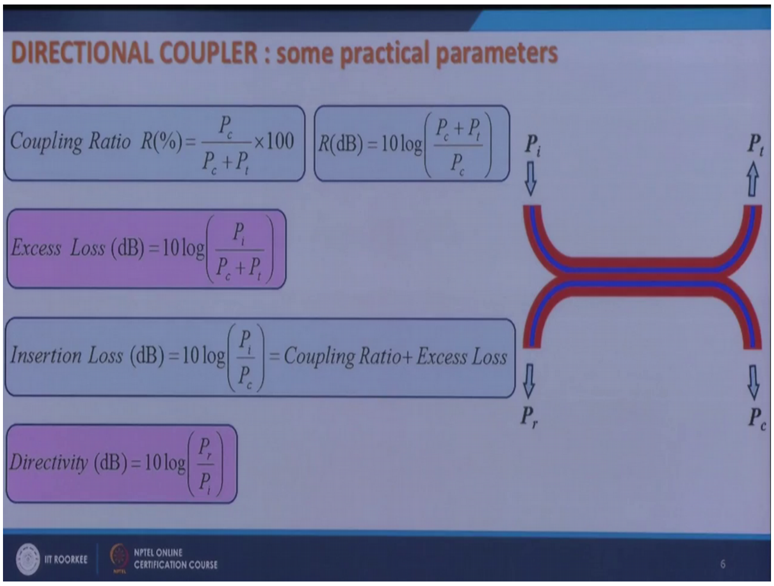

And important parameter is coupling ratio, coupling ratio in percent can be defined as power in the cross port divided by the power in cross port plus through put port. So, power in cross port divided by total output power, times 100 this is in percent. So, this is coupling ratio in percent in dB I can define it as 10 log P c plus P t over P c.

Then I can also define the excess loss, as 10 log P I over P c plus P t, which basically tells you that how much loss this device will introduce. What is the inherent loss in this?

Because not all the power is coming out whatever power you are inputting; so not all the power is coming out. Then we have insertion loss, insertion loss is for a coupler or switch. So, it is defined as 10 log P I over P c, which is nothing but summation of coupling ratio plus excess loss. Then another important parameter of a directional coupler is the directivity which is defined as 10 log P r over P I. It is how it is the measure of how much power comes back we want that all the power should go in one direction in the forward direction.

So, this defines how much power comes back. So, larger the power comes back poor is the directivity of the coupler. So, for a good directional coupler I should have low insertion loss and high directivity.

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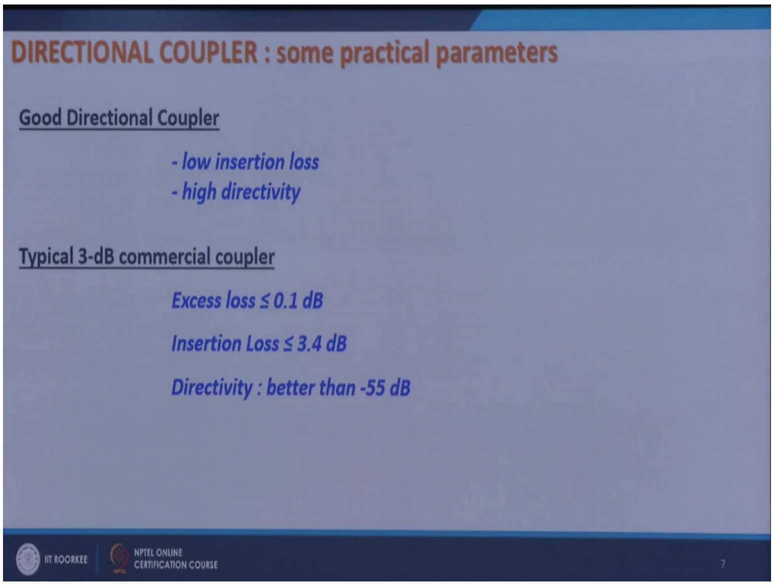

For a typical 3 dB commercial coupler excess loss is less than or equal to 0.1 dB. Insertion loss says about 3.4 dB or less and directivity is better than minus 55 db.

So now I can go into some other fiber optic component. So, apart from this directional coupler, another important component is polarization controller. We sometimes need to control the polarization state in the fiber. And for that we require this polarization controller. This polarization controller is based on bending effect in the fiber. So, we will discuss that how bending of a fiber can control the polarization state of the light which goes through the fiber.

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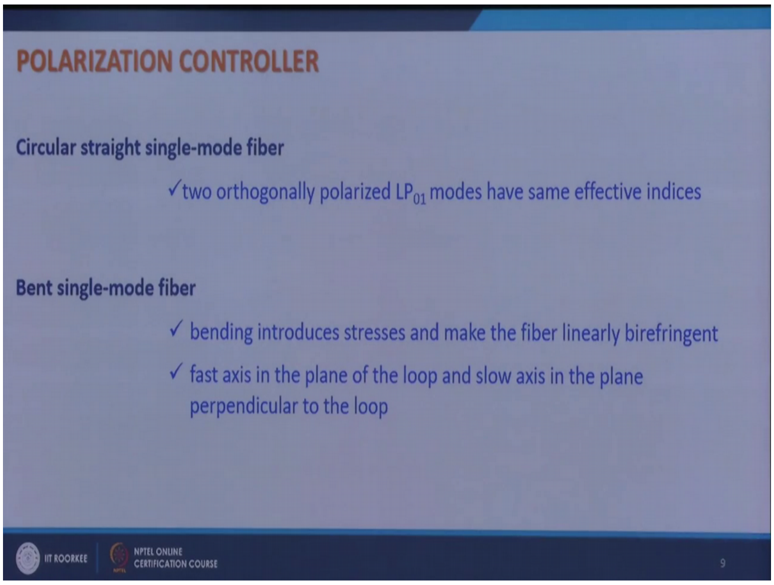

If I have a circular straight single mode fiber, circular straight single mode fiber, since it is single mode fiber. So, and I am always working in weekly guiding approximation. So, the modes are L P modes. So, in a single mode fiber I have L P 0 1 mode. And this mode has 2 orthogonal polarizations. And these 2 orthogonally polarized modes have same effective index. Because it is a weekly guiding fiber, but if I bend this fiber. Then bending introduces a stresses in the fiber, and this makes the fiber linearly birefringent, which means that which means that now this polarization will travel with different velocity and this polarization will travel with different velocity.

That is this polarization will see different refractive index of the fiber as compared to this polarization. And what happens is that the fast axis in the plane of the loop and slow access in the plane perpendicular to the loop. So, so if I have a fiber which goes like this if I make a loop like this in the fiber.

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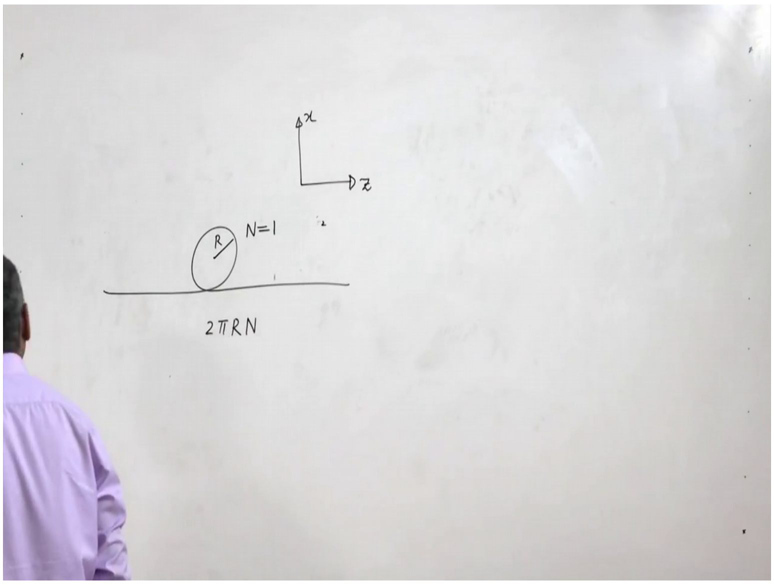

And this is z direction and this is x direction then this axis is the fast axis, which is in the plane of the loop and this axis is slow axis which is perpendicular to the loop ok.

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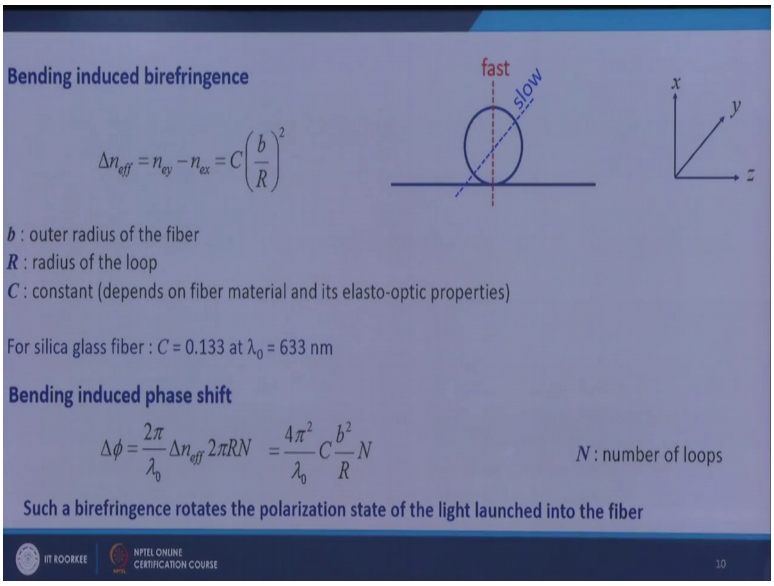

So, here it is. So, if I have this kind of situation. So, the loop is in a exact plane. So, your x axis is the fast axis and y axis is the slow axis. So, there is birefringence introduced in the fiber. And the difference between the effective indices of y polarized and x polarized mode would know be given by delta n effective is equal to n e y minus n e x. And this is dependent on this depends on this birefringence depends upon, what is the overall diameter of the fiber what is the cladding diameter what is the thickness of the fiber and what is the bending radius? So, it is given by c times b square over r square where b is the outer radius of the fiber and r is the radius of the loop. And it is it is intuitive because this birefringence is produced by stresses induced in the fiber by bending.

So, if the fiber is thicker. So, if you bend it if you bend a thicker fiber then the stress is introduced would be more, a thin fiber would be very flexible thin fiber would be very flexible. So, is stress is introduce would not be very large. So, the birefringence would be smaller in thinner fiber as compared to in thicker fiber then radius of the loop if the radius of the loop is large.

So, bending is very soft it is not very strong bending then birefringence would be smaller. And if you give it a very tight bend that is radius of curvature is very small then birefringence introduced was would be large. Typically for silica glass fiber this c; which is the constant which depends upon the material of the fiber and elasto optic properties of the fiber material. So, for silica glass fiber this is given by c is equal to 0.133 typical value is 0.133 for silica glass fiber, at wavelength 633 nanometer.

Now, since there is a birefringence introduced in the fiber. So, this polarization is travelling with different velocity as compared to this polarization. Now if at the input end of the fiber you excite both the modes simultaneously, both the polarization simultaneously. Then as they will propagate in the fiber of phase shift would be accumulated between them. As they propagate in the fiber a phase shift would be accumulated between them, and the state of polarization at any value of z inside the fiber can now be found out by super posing these 2 polarizations with the accumulated phase shift. So, so you can find out the state of polarization at any distance z. And so, since there is a phase shift accumulated. So, this polarization state will slowly rotate ok.

So, let us say after one loop if I have one loop of radius r here capital r and number of loops, let us say n is equal to 1 n is the number of loops, then how much length does it take? Does it travel when it goes through this loop? So, the length would be 2 pi r times n and if n is equal to 1 then it is 2 pi r. So, for so, this is 2 pi r for n is equal to 1 and for n number of loops this distance would be 2 pi r n. So, what would be the phase shift accumulated if there are n number of loops? So, phase shift would be 2 pi over lambda not times delta n effective times the length. Total length in the loops which is 2 pi r n, if I now put the expression for delta n effective from here then it would be 4 pi square over lambda not times c times b square over r times n.

Now, since delta 5 is equal to this. So, I can now have a particular radius or the number of loops, to introduce a particular value of phase shift. Let us say I take n is equal to 1, and then I calculate what would be the radius of the loop to introduce a phase shift of pi. Or what is the radius of the loop to introduce a phase shift of pi by 2. And I know I know that a phase shift of pi by 2 corresponds a quarter wave plate, if I talk about bulk optics.

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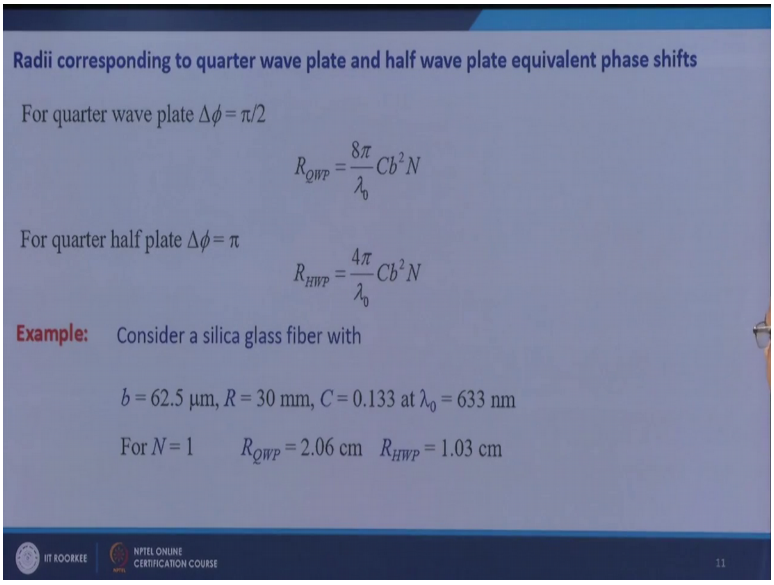

In bulk optics if I have birefringent crystals then out of these crystals I can make quarter wave plate half wave plate. Quarter wave plate means apart difference of lambda by 4 or phase shift of pi by 2.

So, I can immediately find out the radius corresponding to quarter wave plate, if I put delta phi is equal to pi here. And find out correspondingly the radius. So, this radius comes out to be 8 pi over lambda naught, times c times b square times n. For n number of loops, for half wave plate I am sorry. There is a typographical error here. For half wave plate this quarter should not be there delta phi is equal to pi and the corresponding radius is given by r h w P is equal to 4 pi over lambda naught times c times b square times n. What are typical values of these radii, if I consider a silica glass fiber with b is equal to 62.5 micrometer which is the standard cladding radius. And I give it a bend give it a bend of about 3 centimeter radius.

And I consider let us say c approximately equal to 0.133 at lambda not is equal to 633 nanometer, then for n is equal to 1 if I consider n is equal to 1 then the radius of quarter wave plate would be about 2 centimeter. Radius corresponding to radius of the loop corresponding to quarter wave plate is about 2 centimeter. And the radius of the loop corresponding half wave plate is about 1 centimeter ok.

So, this much a loop of this band radius will introduce a phase shift of pi by 2 or part difference of lambda by 4. And a loop of this band radius will introduce a phase shift of pi or part difference of pi, part difference of lambda by 2.

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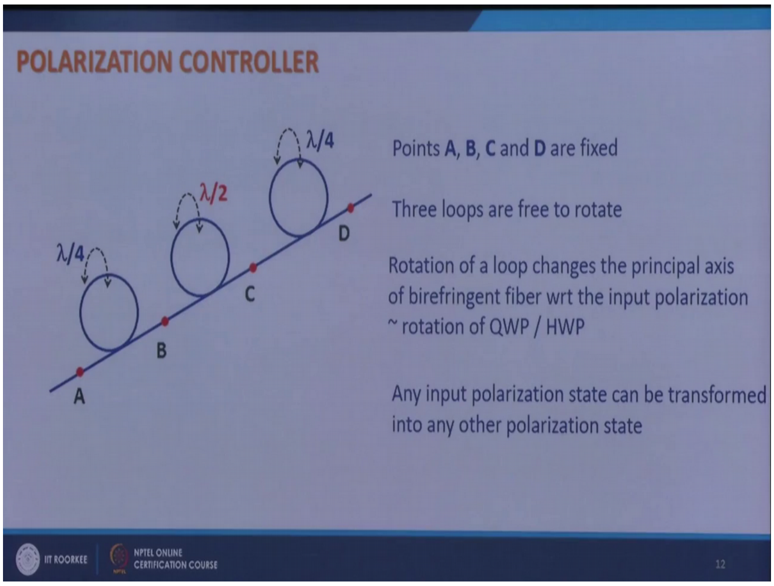

So, with the help of this with the combination of these loops: I can virtually obtain any polarization state, how? Well, I take a fiber and make loops like this. Let us say the radius of the loops are such that or radii of the loops are such that this loop introduces a part difference of lambda by 4. So, this is the quarter wave plate this is equivalent to half wave half wave plate and this is again quarter wave plate.

Now, let me fix these points A B C and D. So, these points are fixed. And now these loops these loops can be rotated. So, so if you have this fiber and there is a loop here then this loop can be rotated like this. This loop can be rotated, this loop can also be rotated, this loop can also be rotated. What do I achieve by rotating these loops? You see that if this is the loop, then I have certain principle axis, I have this is the fast axis this is the slow axis. When I change the rotation if I rotate it if I change the orientation of this loop the fast axis is this and slow axis is this. So, basically what I am doing? I am changing the principle axis of this of the loop. It means that it is equivalent to rotation of your half wave plates or quarter wave plate in bulk optics.

So, by rotating these loops I am virtually creating different orientations of half wave plates and quarter wave plate. And so, the phase shift introduced now would be different, I can control the phase shift that can be introduced. So, with the combination of these and different rotations I can I can convert any input polarization state into any other polarization state. So, this comes out to be very, very efficient device in terms of polarization controller. The only thing is that since we are giving tight bends here and bending always introduces loss. So, this kind of device would introduce certain losses in the system.

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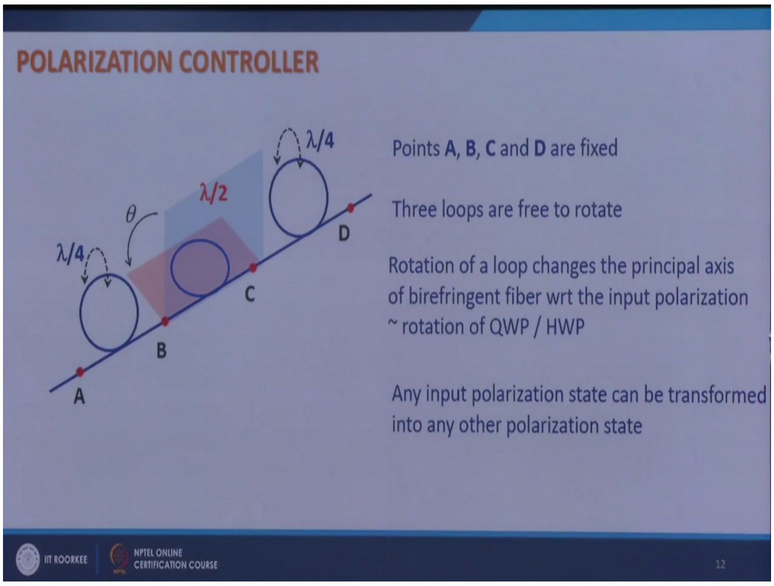

So, this is how this is how I can rotate for example, this and obtains any polarization state. So, in the in this lecture we had seen how directional couplers can be directional couplers can be used as multiplexers and de multiplexers. We had seen in this section how we can make a power splitters how we can make switches using directional coupler. We had also seen that with the help of introducing certain loops in the fiber we can make polarization controllers. These polarization controllers are commercially available also.

In the next few lectures we will study some other components based on optical fiber. And these components involve gratings in the core of the fiber, what you can do? You can in the core of the fiber you can introduce periodic refractive index modulation, and this periodic refractive index modulation can alter the spectrum of the light, which you pass through this fiber. So, with the help of this we can make several components we can have applications of these components in different devices; in telecom devices, as well as in sensing devices.

So, we will study these fiber gratings in the next lecture.

Thank you.