Physics of Linear and Non Linear Optical Waveguides
Prof. Samudra Roy
Department of Physics
Indian Institute of Technology, Kharagpur

Module - 04
Fiber optics components
Lecture - 41
Fiber Bragg Grating (FBG)

Hello student to the course of Physics of Linear and Non-Linear Optical Wave Guides. So, today we have lecture number 41. And in this lecture, we will going to start which is called Fiber Bragg Grating. It is a fiber optical Bragg component and very important component and we will going to study from the first principle the how this fiber optic Bragg grating works.

So, we have lecture number 41 today, and we will start a new topic "Fiber Bragg Grating" on in short FBG. So, what is fiber Bragg grating?

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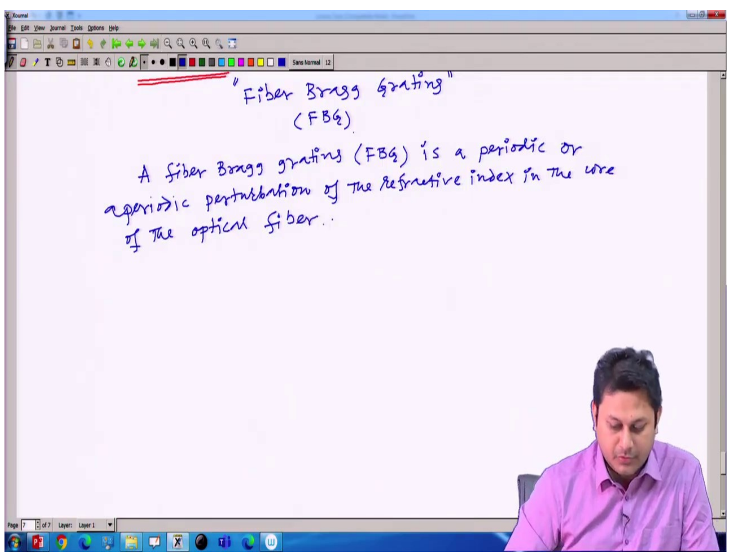

So, a fiber Bragg grating or in short FBG is a periodic or periodic or aperiodic perturbation of the refractive index in the core of the optical fiber. So, I try to draw this. So, what is the meaning of periodic or aperiodic perturbations that we need to understand. So, let me draw quickly the fiber structure.

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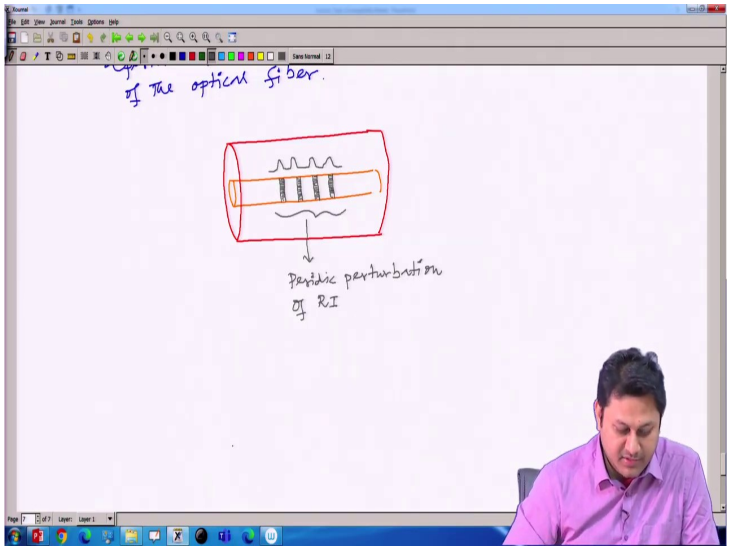

So, in the fiber we have a structure like this. I have a core part and I have a cladding part. In the core part, if I have a periodic variation of the refractive index like this. So, I have a refractive index n 1 of the core and n 2 of the cladding that we know. On top of that I now I am putting some kind of periodic perturbation in the core region along z direction. So, this is a periodic perturbation of refractive index.

So, refractive index is changing here periodically. So, here the refractive index is high, here low, here refractive index is high, low, here again high, low, high, low, something like that. So, there is a variation of the refractive index, periodic variation of the refractive index in the core region. So, this is roughly the structure of Bragg grating. So, this periodic variation of the refractive index of the core along z direction is called this entire system is called the Bragg grating, fiber Bragg grating.

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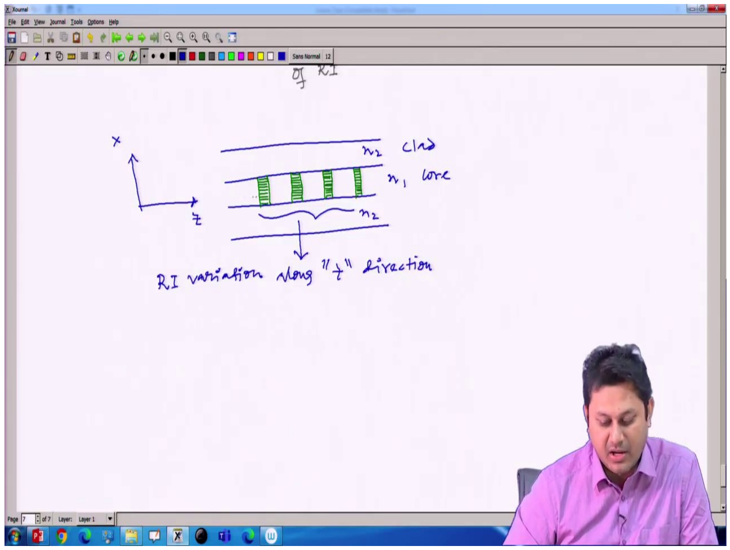

So, if I draw a straight forward simple two-dimensional figure, so this is the cross sectional view. So, I am having this. And I am having this perturbations here with certain periods. The same figure I am drawing, but in two-dimension and in the rest of the lectures, I will draw this two-dimensional figure, so that now you can realize in three-dimension what is the structure and two-dimension how it is changing.

So, I have refractive index n 2 here for cladding, n 2 here for cladding and n 1 here for core, but on top of that I have a periodic variation. So, the coordinate is like this, this is z, and this is x, this is clad and this is core. And this portion there is a variation, and this variation is along z direction. RI variation along z direction. So, refractive index is now vary periodically and this variation is along the z direction, that means, along the direction of the propagation.

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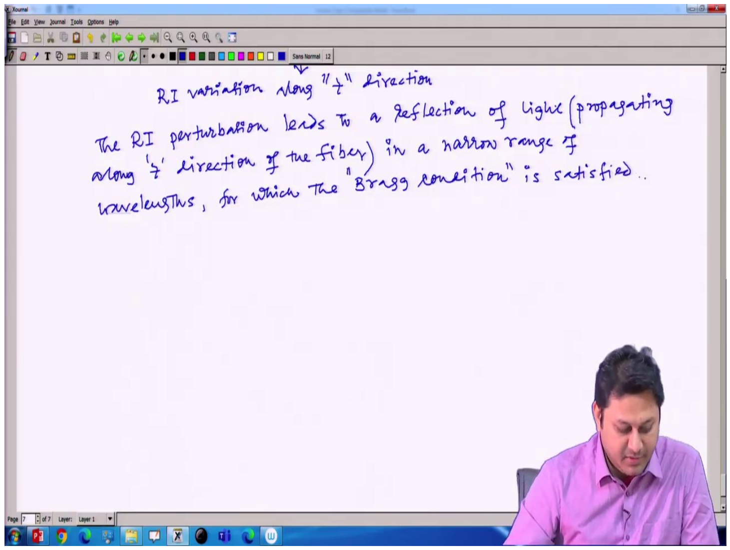

So, what happened? The refractive index, so what happened? The refractive index perturbation whatever the perturbation I put here, the refractive index perturbation on RI perturbation leads to leads to a reflection of light propagating along say z direction of the fiber. So, this light is propagating along z direction of the fiber.

And reflection of what? The RI perturbation leads to a reflection of light in a narrow range of, narrow range of wavelengths, for which the “Bragg condition” is satisfied. So, for this kind of structure, so what is the Bragg condition? So, let me write in down first.

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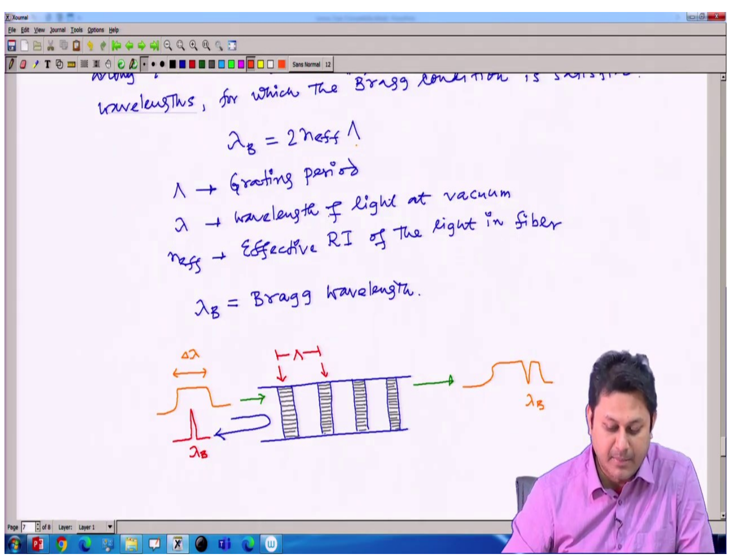

So, which wavelength will going to reflect back? It is lambda B equal to 2n effective we will going to prove that and big lambda, where this big lambda is the grating period and lambda is a wavelength of light at vacuum.

An n effective, the effective, refractive index of the light in the fiber. So, whatever the wavelength we have lambda in the vacuum for that particular wavelength what is the refractive index, it will going to experience inside the fiber is defined by n effective. So, n effective is the effective refractive index of the light in fiber. And lambda B is a Bragg wavelength. This is a Bragg wavelength. This is the wavelength that will going to reflect.

So, let us understand this once again in a more clear perception that we have a periodic structure like this here. This is a periodic variation inside the core. I highlighted this part. Periodic variation means there is a change of refractive index, and this change is periodic.

This darker part means we have higher refractive index, then the rarer part. So, this darker part, this lines suggest we have the refractive index here large. So, what is lambda here? From here to here, if I measure the distance this is a period and this period is my lambda. This is the lambda period of the grating.

Now, what happened? I launch a light having a range of wavelength. So, there is a bandwidth of the light. So, I launch a light. So, I have a bandwidth, say some delta lambda. And in this particular bandwidth there is a specific lambda which is following a very sharp lambda say lambda B. Even though it is having some kind of width, but that is much much less compared to the light that is launched here the bandwidth of the light that is launch here.

So, these things will going to reflect back. So, this is in this things is going inside, suppose I launch it here it is going inside and something is coming back, behave like a it behave like a reflection. So, this reflection is nothing but a particular wavelength is reflecting out.

And in the output what happened? So, in the this is the output, what happened? I am going to have this similar with only thing is this particular lambda will going to miss. So, I launch; so, this is my lambda B. So, from the entire spectra this lambda B will going to miss because this lambda is reflected out from this structure.

So, this is the principle of fiber working the rough working strategy of the fiber Bragg grating. And why it is so useful? Because it is very sensitive, this reflected wavelength is very sensitive to the value lambda. From the expression on it is already mentioned that lambda B is equal to 2 n effective multiplied by lambda.

So, that means, if somehow I change, somebody if somehow change this lambda big lambda that is the period of the grating then what happened instead of having lambda B we can have a new lambda, lambda B because the condition Bragg condition will going to change.

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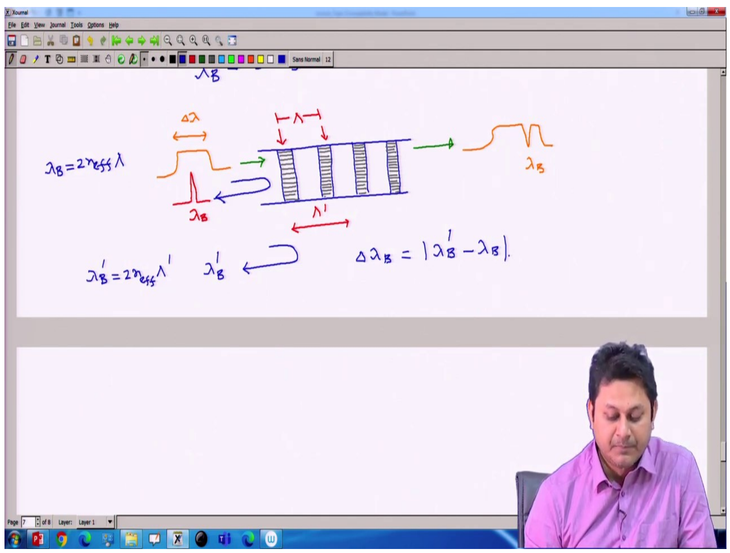

So, if I, if I extend the fiber, if I just put some kind of stretch over the fiber, then this lambda, this big lambda can now be stretched and I can have lambda prime. If it is stretched, then what happened? Now, I can have a new lambda B. So, now I can have lambda B prime.

In the previous case, the condition lambda B equal to 2n effective lambda was satisfied. And in this case lambda B prime is equal to 2n effective, n effective will not be affected that much lambda prime will satisfy. So, from these variation of lambda B, one can have. So, this lambda B prime this delta lambda B rather, which is say mod of lambda P prime minus lambda B, so the change from the change of this variation of the reflected wavelength one can estimate many things.

For example, one can estimate what is the stretch that is put to this fiber which can be used as a stretch sensor. If the fiber is heated then what happened that because of the heating this fiber will going to be expanded. And if it is expanded, this lambda which is the period of this Bragg grating will also going to be expanded. And previously whatever the lambda it is reflecting now it will going to reflect different lambda B.

So, I can measure what is the change and based on that I can calibrate and find what temperature is given to the fiber. So, that it behave a very sensitive sensor. Many research is going on many people are working in this field. But in this lecture, as I mentioned I try to understand from the very basic principle what is the working theory of this kind of structure.

Well, after having a very rough knowledge of how these things is working, the next thing we will going to understand the fabrication procedure.

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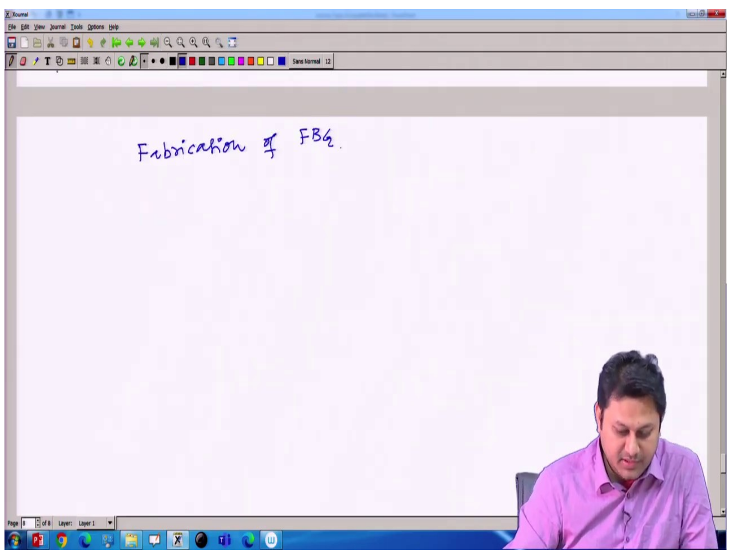

So, the fabrication procedure, so the fabrication of FBG. So, in the fabrication procedure of the FBG. So, essentially in the FBG what we try to do? We try to damage the refractive index permanently inside the core. So, let me draw first the schematic picture how these things is done, then I will going to explain.

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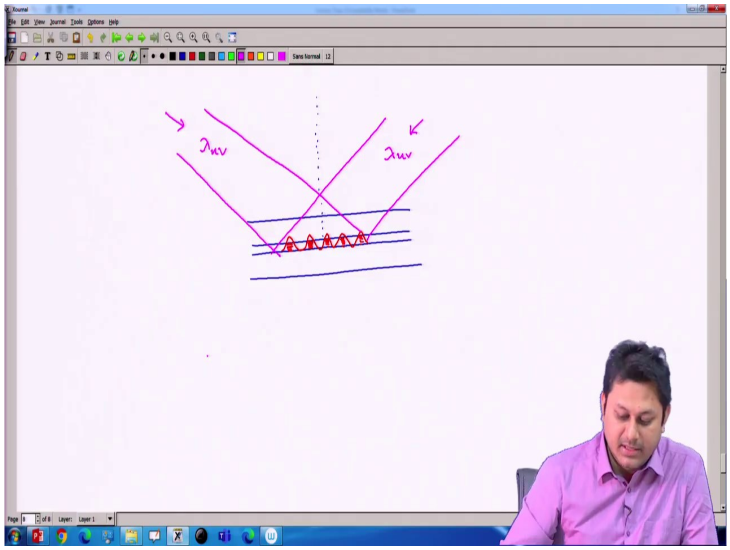

So, suppose this is the fiber and this is the core part of this fiber, this is the core part of this fiber. So, the fiber is placed in a in a in a field in a in a UV radiation, two lights, UV light is now allowed to fall over the fiber. And when these two light is falling over the fiber there should be some kind of interference of these two lights and because of that we can have some kind of interference pattern here. So, let me draw this interference.

So, interference pattern means I have a bright light and then like that. So, I have interference pattern here. And this, because of this interference pattern I have a maximum light here and it will going to expose this part. So, this part there will be a permanent damage of refractive index. Again, this part will be permanently damaged, the refractive index will going to change permanently, this part also, this part also, this part also.

So, I launch, as I mentioned I launch two UV light. So, suppose it is launched like this and this and the light is like this and this. So, UV light are coming, two UV source is coming, so that they can interfere here in the core region. So, this is lambda UV, lambda UV that is falling over the fiber.

And in the core region, it is a there is interference it will create an interference pattern in the core region. And when they will fall, they will form interference pattern here there is a permanent damage in the core region. We can have a periodic perturbation of the refractive index.

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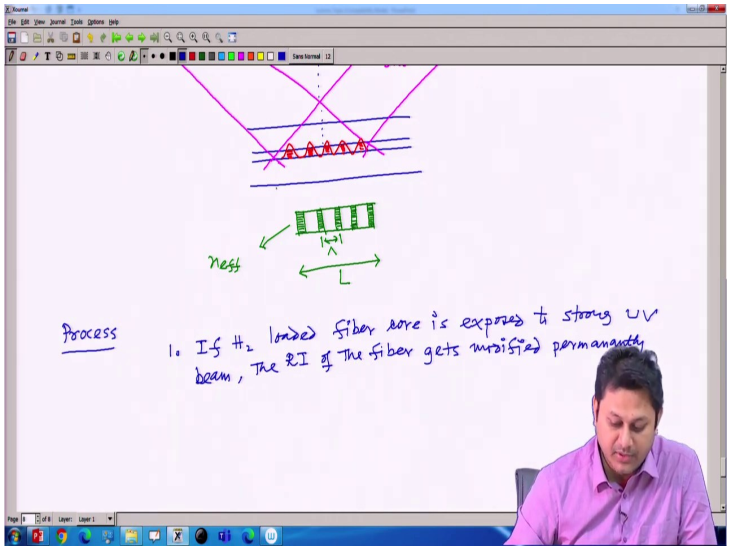

So, if I draw here only the core region, so this will come like this. Variation of the refractive index, the permanent damage of the refractive index here in the core region and I will going to have a grating structure. This is roughly the grating structure.

So, from here to here this value is lambda, the period of the grating. And I have n effective here, the effective refractive index will be there because of this perturbation. And in the cladding region the n 2 is there and this is the grating length, the entire length is called the grating length L.

So, the process wise, so the 1st if H 2 loaded fiber core is exposed to strong UV beam, the refractive index of the fiber gets modified permanently. So, I expose, if somebody expose this the fiber which is H 2 loaded, so the photo if it is H 2 loaded, then this process will be much more efficient and now I am going to expose this over this UV strong UV light.

And when it is exposed to the strong UV light interference pattern will generate here and as a result there will be permanent damage of refractive index. That will eventually produce the grating structure.

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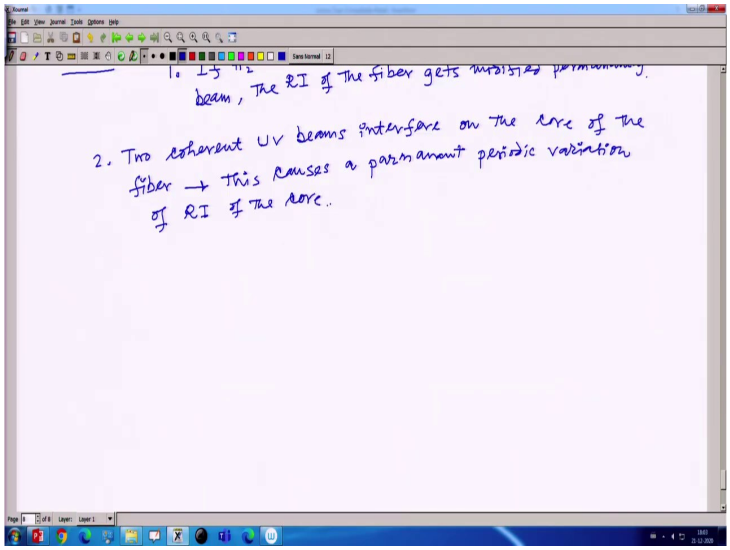

So, in this in the 2nd process, what happened? Two coherent UV beam, UV beams interfere on the core of the fiber. This causes as I mentioned a permanent periodic variation of RI of the core.

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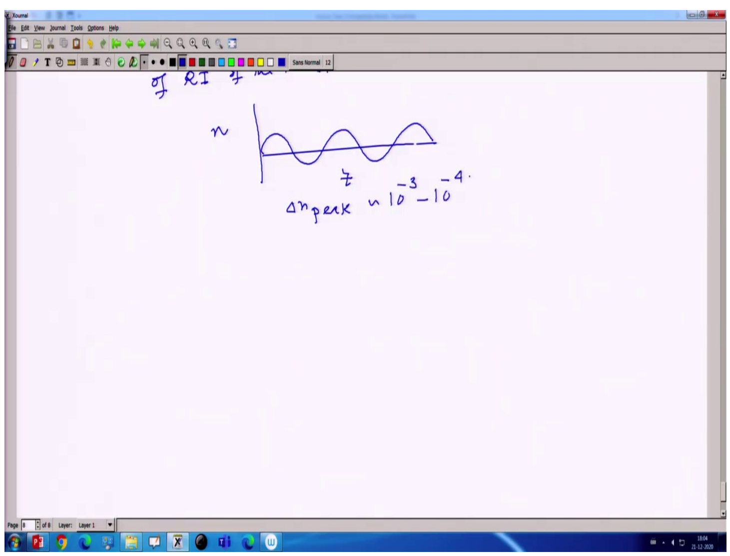

So, there is a periodic variation of the core, there is a permanent periodic variation of the core. So, there is a periodic kind of variation refractive index variation of the core as a function of z because of this interference pattern. I already explained that in this figure.

Normally, these the peak the change delta n peak is normally of the order of 10 to the power of minus 3 to 10 to the power of minus 4. This is roughly the order.

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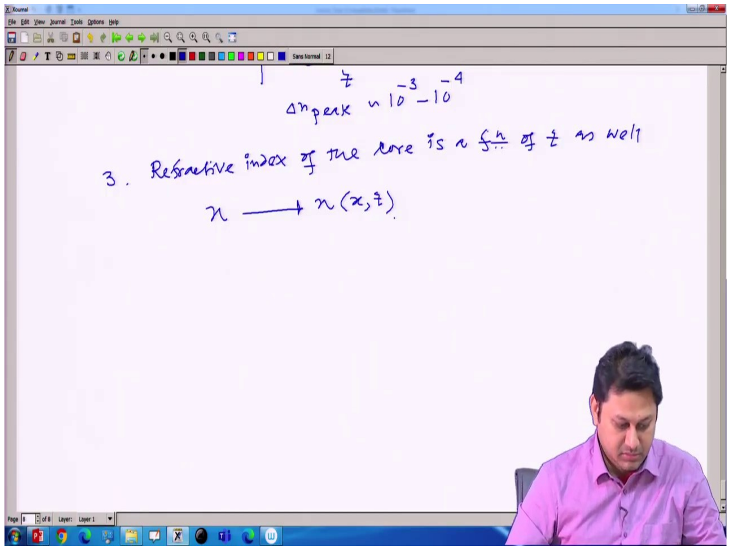

Next, what happened? The refractive, now the refractive index of the core is a function of z as well. That is important. So far we are dealing with refractive index as a function of x, but now this refractive index will be a function of x as well as z. So, that will give something extra in the couple mode theory.

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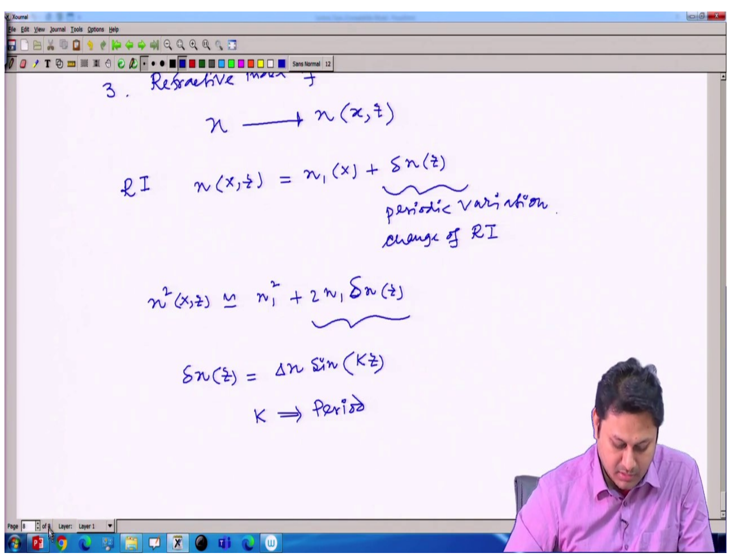

So, refractive index is changing over z, so that is why it will be a function of z. So, refractive index n which is a function of x, z can be write in this form, n 1 which is a function of x plus additional modification due to this permanent damage. So, this basically take care of the periodic variation. So, this is related to the periodic variation. Due to the periodic variation of the core part I can write an additional part delta n to the mean value. So, this is basically the change of RI, periodic change of RI.

Now, if I took n square, n square which is a function of x, z I can nearly write it as n 1 square plus 2n 1 delta n z. I can have a higher order term of delta, but this period this variation is too small, so that is why I can neglect. So, this is the variation I am having in terms of n square.

So, delta n, now I put delta n which is a function of z and I now assign is a periodic variation. And this periodic variation I write delta n over sine K z. Now, K here is related to period which is related to the period of this variation.

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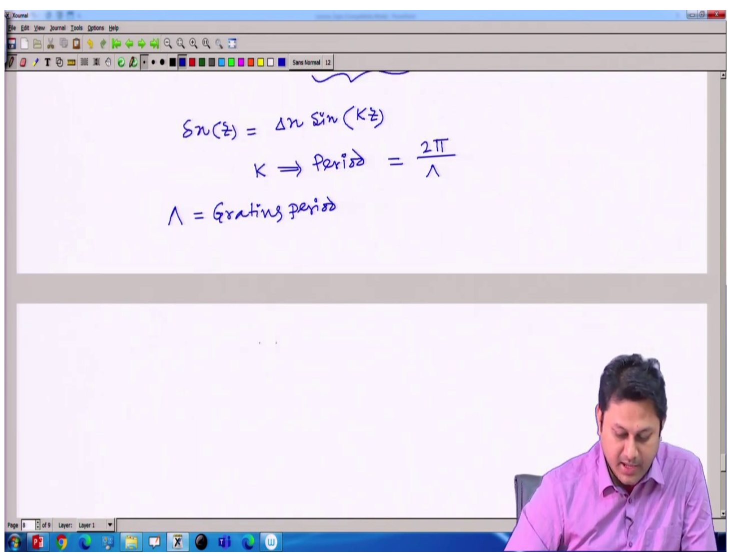

So, I can write this as 2 pi, which is related to the period is equal to 2 pi divided by lambda, where lambda is the grating period.

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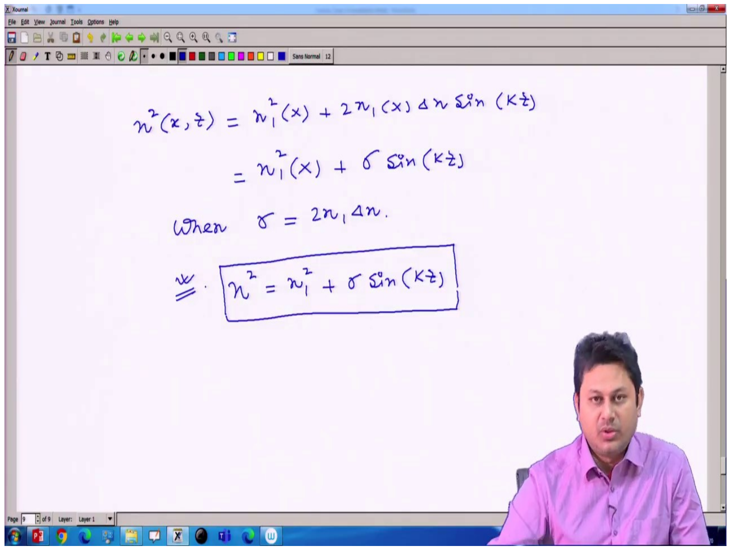

So, if I write all this whatever the definition now I write, with the whatever the definition I used based on that I can write n square which is a function of x, z is equal to n 1 square this is a function of x plus 2 n 1 which is a function of x. Then, delta n sine of K z or n 1 x square plus this entire term I write sigma, sigma of sine K, z. I will going to use this expression of n square in the calculation. So, that is why I just define this. So, when sigma is equal to 2 of n 1 delta n.

So, eventually I have n square equal to n 1 square plus sigma sine K z. So, this is the expression I will going to use in my couple mode theory in the next class. And we defined all the values here one by one, what is the meaning of delta n, what is the meaning of big delta n, etcetera.

And this is basically the expression find out, and this expression tells us how the refractive index will going to vary in the core region because of the presence of this grating, which is eventually the modification of the refractive index, periodic modification of the refractive index.

So, with this note, I would like to conclude today's class. In the next class, we will study more about the Bragg grating and do all the calculations. So, thank you for your attention. And see you in the next class.