Physics of Linear and Non-Linear Optical Waveguides
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Module - 05
Nonlinear Fiber Optics
Lecture - 51
Optical Kerr Effect (Contd.)

Hello student, to the course of Physics of Linear and Non-Linear optical waveguide. So, today we have lecture number 51 and in the last lecture, we started Optical Kerr Effect. So, we will going to continue in this class also, the calculation for Optical Kerr Effect.

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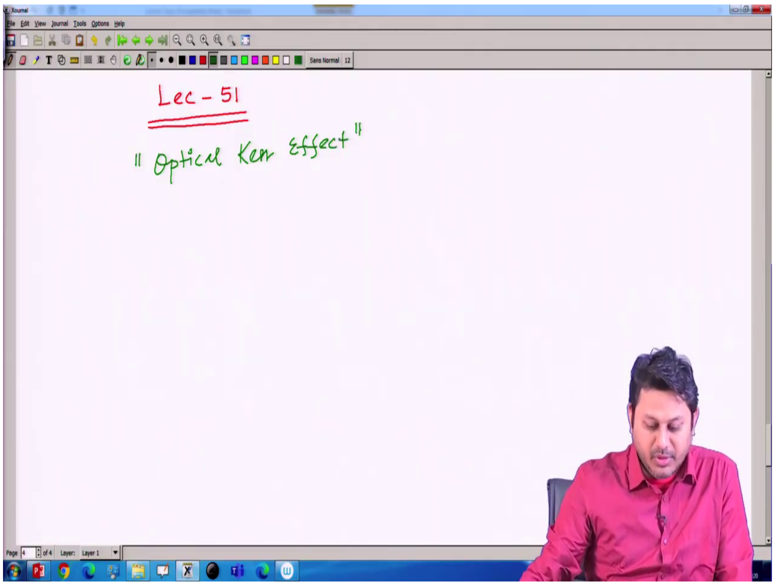

So, if you remember in the last class. So, we are dealing with optical Kerr effect.

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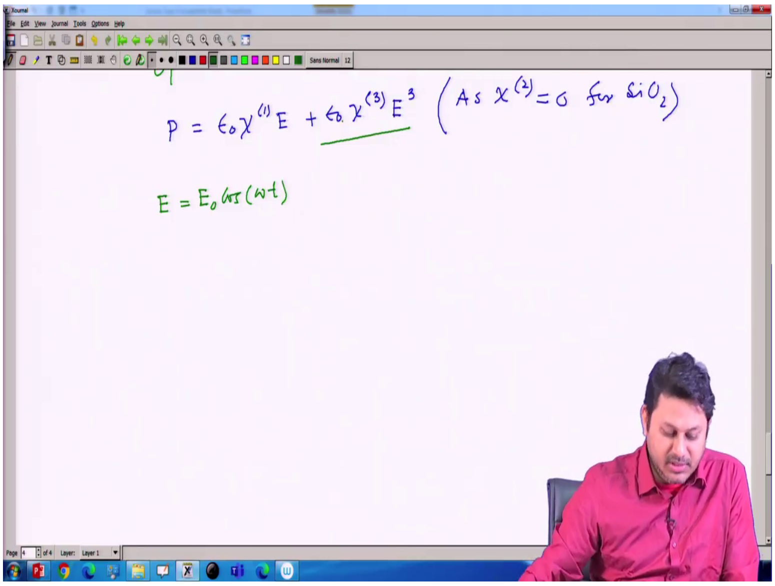

So, in optical Kerr effect; what we try to understand is this. So, P in fiber I can write in this form as chi 2 is 0 for silica. Silica is a centrosymmetric molecule. So, for centrosymmetric molecule, we mentioned that chi 2 is 0. So, since chi 2 is 0, we can say that my P is this quantity. I am not going to take the more higher order term I only take the first higher order term which is this one related to chi 3.

After that we introduce our electric field as this. So, next we introduce the electric field E as E 0 cos of omega t. And these things we put here in this equation.

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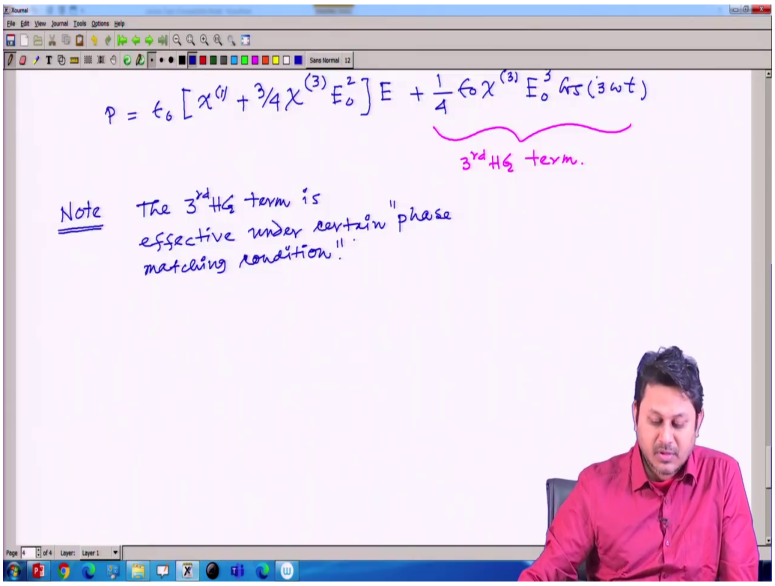

And after doing some calculation, we find that P can be written in this form epsilon 0 chi i plus 3 by 4 chi 3; 3 by 4 chi 3 then, E 0 square E then, 1 by 4 epsilon 0 chi 3 then, E 0 cube cos of 3 omega t and we mentioned that this is a 3rd harmonic generation term; this is a 3rd harmonic generation term.

So, these are 3rd harmonic generation terms. So, normally we will also mentioned in the last class. So, let me write what we discussed in the last class. So, note; the 3rd harmonic generation term is effective; is effective under certain "phase matching condition". I am not going to discuss detail what is the phase matching condition, because this is entirely a topic related to non-linear optics.

But here we are not study the hardcore non-linear optics, rather we just use certain results that is coming out in the non-linear optics and how it is meaningful in the waveguides when we launch then, electric field which is very very high in intensity that we are going to discuss.

So, only the phenomena will be discussed in detail, but not the hardcore non-linear optics topic, where this phase matching and all these things will be discussed in detail. So, this is not the scope to discuss the phase matching condition in detail. So, for the time being you should know that this things that I launch a.

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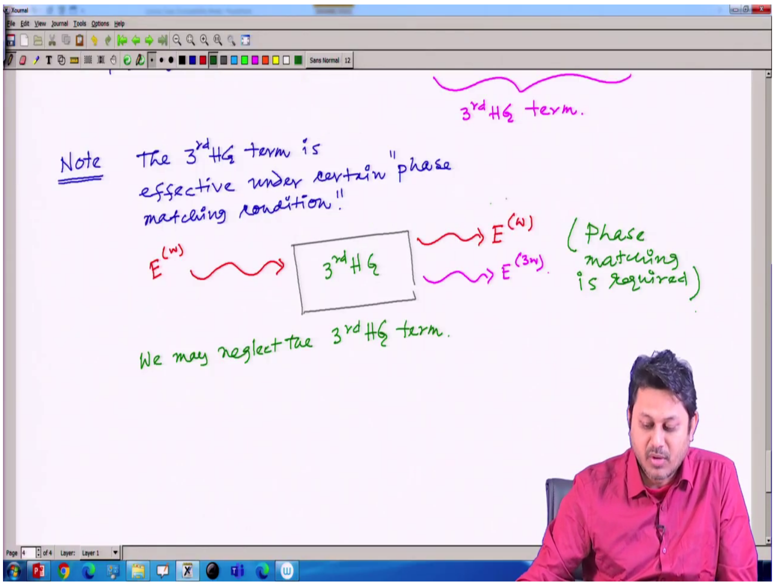

So, what is the system here? So, last day we draw this figure. So, I have a system and I launch a light like this which is E omega, and in the output, I am having E omega and also another light say, E 3 omega. So, this is called the 3rd harmonic; this process is called the 3rd harmonic generation. So, this is essentially the 3rd harmonic generation process.

But it is not easy to extract the energy from this fundamental wave and generate another wave which is now, vibrating as a frequency 3 omega. So, certain phase matching condition is required to happen this to make this happen. So, this phase matching condition is not easy.

So, normally that is why we can neglect this term; whatever the term we have here, if we neglect this term so, phase matching is required here, it will not happen naturally. So, some phase matching is required. So, we are not bothering about this phase matching condition etcetera. So, simply we ignore this.

So, if we ignore. So, the 3rd harmonic generation; the 3rd harmonic generation term is effective under certain phase matching condition. So, normally we do not have the 3rd harmonic generation phase matching condition so, we can we may neglect the 3rd harmonic generation term. Simply, we just neglect, because there is a phase matching condition required to happen. So, normally this phase matching condition is not there so, that is why we can ignore that.

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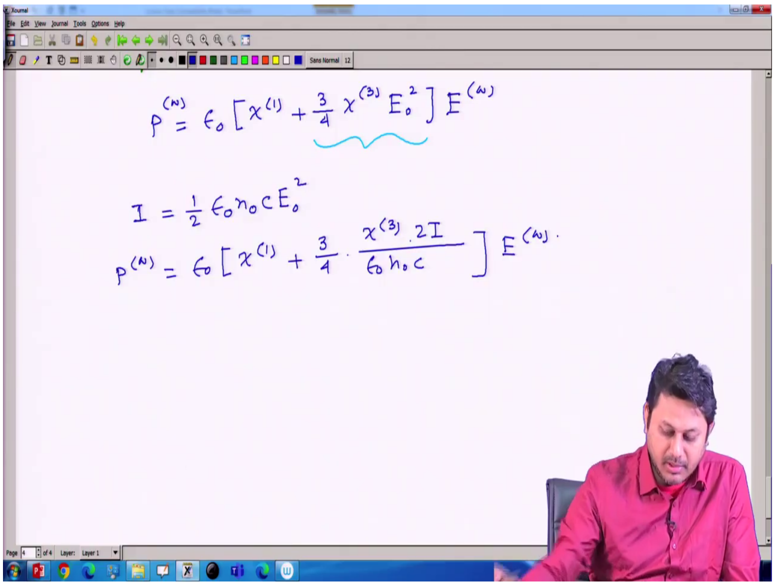

So, then what happened I can write the P in this way. So, my P here, the non-linear polarization term will be added to the P. So, I have the term P as which is a frequency of omega. In the right-hand side, all the frequency all the terms is having the frequency omega. So, I have chi 1 plus 3 by 4 chi 3 E 0 square then this E omega.

So, P omega is a term that is vibrating with the frequency omega that is the input frequency so; that means, I have some additional term here, which is interesting and some additional term here, which is now, changing the refractive index, because this term is related to chi I is relate chi 1 is related to refractive index now I am having an additional term that is effecting this chi 1.

So, we should expect that some sort of change of refractive index may happen, because of the presence of this chi 3. So, that we will going to calculate. So, we know I; which is intensity can be related in terms of electric amplitude of the electric field, there is a relation and this relation is simply this we derive this relation earlier. So, this is the relation between the intensity and the electric field E 0. So, what I do I just replace this E 0 in terms of intensity.

So, P which is vibrating as a frequency omega is equal to epsilon 0 then, chi 1 plus 3 by 4 then, chi 3 E square I will going to replace as 2 of I divided by epsilon 0 n 0 c and I have E omega here.

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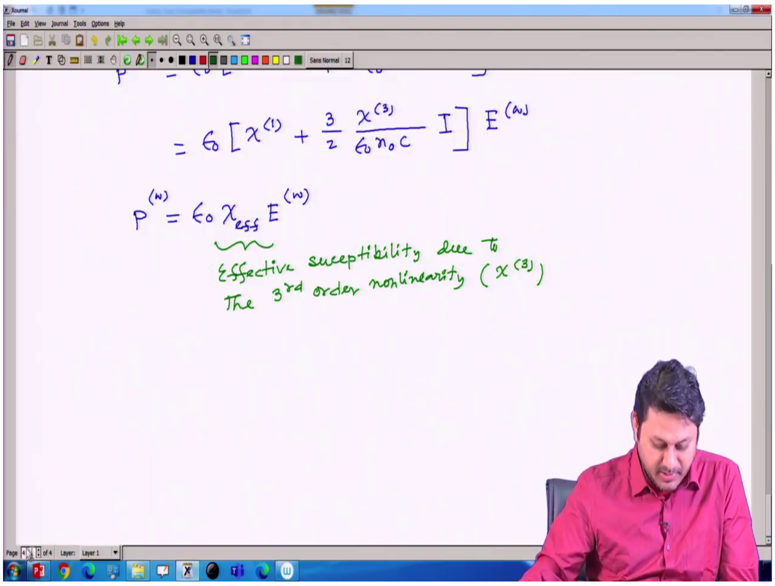

Then, what I do? I just rearrange this term and I have E 0 chi i plus 3 by 2 chi 3 divided by epsilon 0 n 0 c and then, intensity I and E omega. I can write this entire equation as P is equal to epsilon 0. And I write this term which is in the bracket as chi effective some chi effective and then, E, which is having the same frequency omega.

So, the chi effective is this is the effective susceptibility due to the 3rd order non-linearity which is represented by chi 3. So, because of the chi 3 the presence of chi 3 now, my susceptibility is modified. And if I now write what is the modified susceptibility, I will get something before that.

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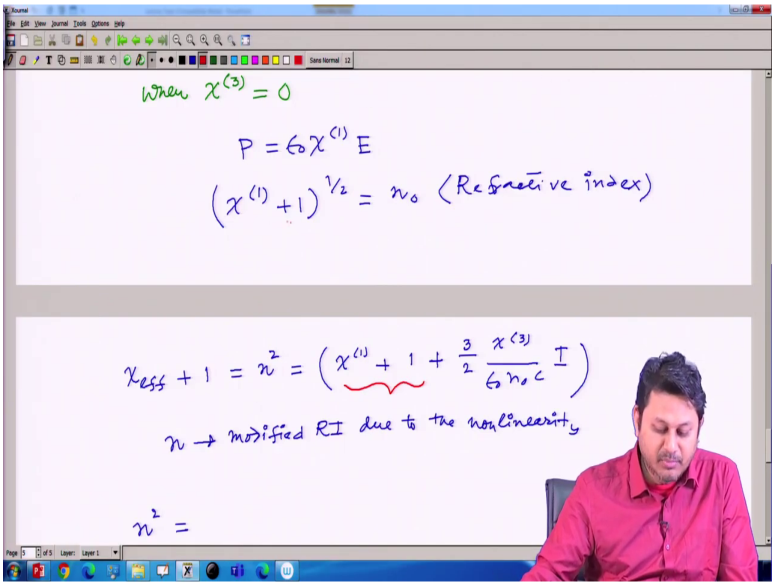

So, in absence of non-linearity so, when chi 3 is equal to 0, there was no non-linearity. I can simply write my P as epsilon 0 then, chi 1 and then E and from that I can write that chi 1 plus 1 whole to the power half; that was the refractive index of the system that was the refractive index of the system.

Now, what happened that, because of the presence of chi 3, I now have additional term and that is why my susceptibility is now modified. So, I have effective susceptibility. So, if I write down the effective susceptibility in this way, I can write that psi effective chi effective plus 1 is equal to n square which is equal to the quantity chi 1 plus 1 plus 3 by 2 chi 3 divided by epsilon 0 n 0 c multiplied by the intensity I; that was the structure we have.

So, in here, is the modified refractive index due to the non-linearity. So, n is the modified refractive index due to the non-linearity. So, non-linearity modify the refractive index; that is the most important outcome we find here. So, n square now, can be written as. So, mind it I have a term here, chi 1 plus 1. So, from here, I can write chi 1 plus 1 is simply n 0 square.

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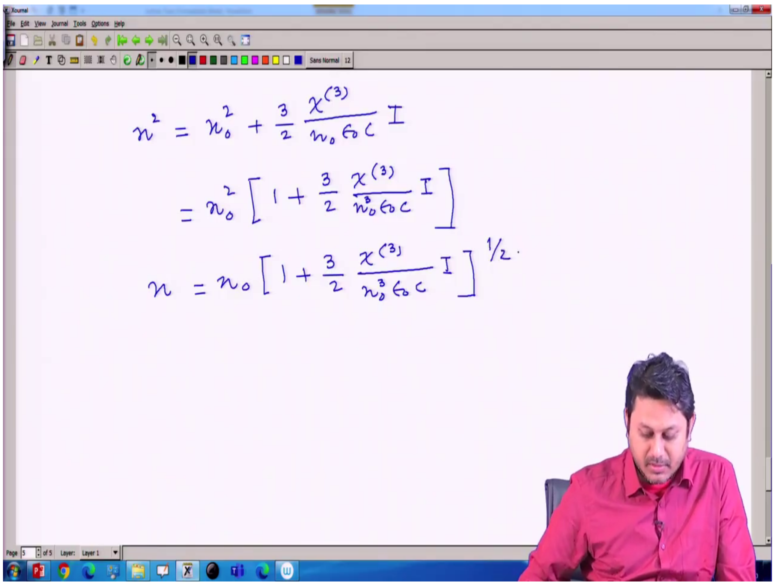

So, n square is simply n 0 square plus 3 by 2 chi 3 the old term which we had divided by n 0 epsilon 0 then, c and then, I; that was the term now, I am having. So, I can write it in a this in a way like that 1 plus 3 by 2 chi 3 divided by n 0 epsilon 0. So, n 0 cube, because I am taking n 0 common so, it should be n 0 cube epsilon 0 c and multiplied by I.

Now, from here, I can write my n as this n 0 and then, 1 plus 3 by 2 chi 3 n 0 cube epsilon 0 3 epsilon 0 c I whole to the power half. So, this is the value of n. Now, I will make a series expansion, because chi 3 is normally very very small.

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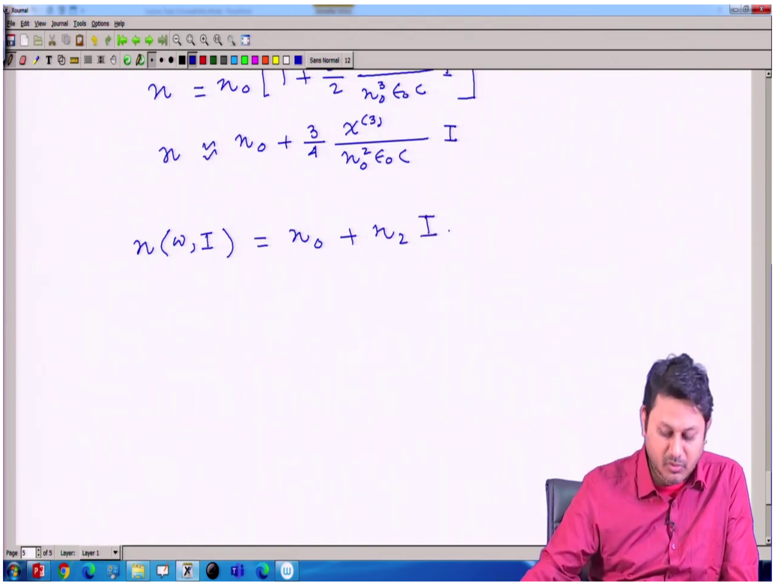

So, if I make a series expansion it should be n is nearly equal to n 0 plus 3 by 4 then, chi 3 divided by n 0 square, because one 0 will cancel out c and then, I. This expression I can write as n which is normally a function of omega now, become a function of intensity like I, is equal to n 0 plus n 2 I. This n 2 is called the Kerr coefficient.

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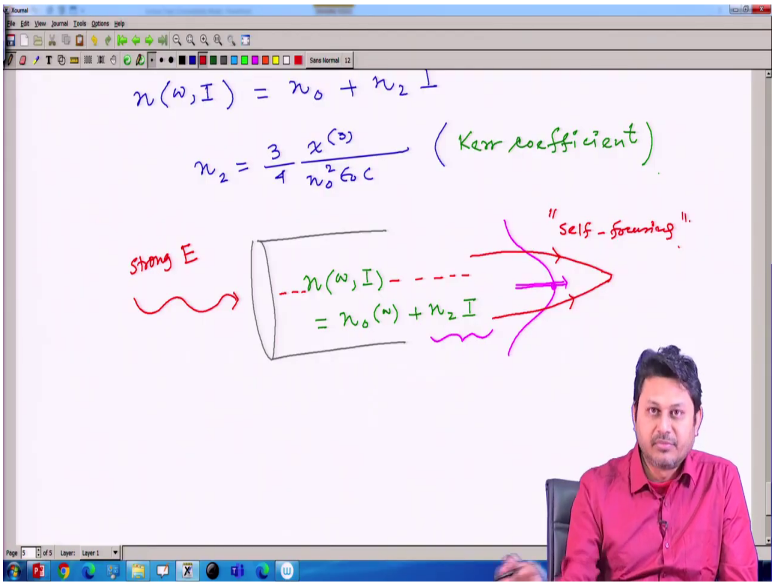

So, n 2 here is 3 by 4 chi 3 whole divided by n 0 square epsilon 0 c. So, this is called the Kerr co-efficient. So, here, we can see that the refractive index now, modified by the input electric field itself. So, if I have a waveguide or a say, fiber structure like this and if I launch a very strong electric field then, what happened the refractive index of this system.

The refractive index which was initially, a function of omega now, became a function of intensity as well so; that means, there will be a modification of the refractive index. The electric field that is going to propagate inside this system will now, see a different refractive index and this refractive index is simply n 0, which is a function of omega.

So, this is the refractive index without any non-linearity plus the additional term into I. So, if the intensity is very very high related to this electric field so this electric field will going to going to experience this additional part. And now, this intensity interestingly is a function of time as well as space.

So, when the electric field is moving in the system. So, since the intensity is not same in this region. So, normally it is a Gaussian kind of shape the intensity is now, a Gaussian kind of shape. So, the pulse will going to experience a high intensity. The electric field is going to experience a high intensity here, in this region and low intensity here. So, refractive index will also modify in this this fashion.

So, this effect is called the Kerr effect and since, the refractive index is modified in this this way what happens is when the electric when the light is propagating here so, it will going to experience an electric refractive index high. So, it will propagate in this way. This is called the self-focusing this is called the self-focusing.

So, right we will going to focus, because the value of refractive index is high here, in the region in this in this region which is the axis of the fiber, because the intensity is distributed in this way. This is called the self-focusing; this is called a self-focusing. Well, I can estimate that what is the value of the self-focusing etcetera. So, let us try to find out what is the unit of this Kerr co-efficient first.

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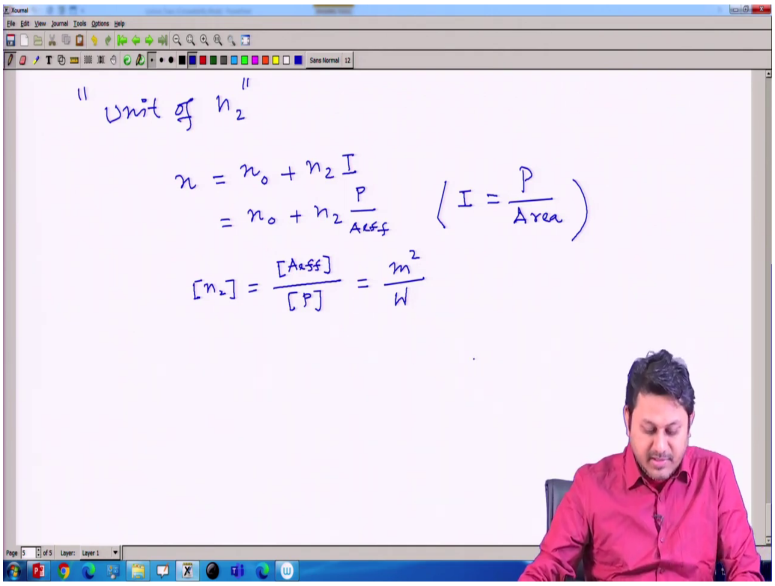

Unit of n 2, so, n I write this as n 0 plus n 2 I; I is a intensity. So, I can write it as n 0 plus n 2 in terms of power, it should be power divided by the effective area. As intensity can be represented as power divided by area a effective is a effective area. So, refractive index is a dimensionless quantity. So, from here, I can say that n 2 the unit of n 2 should be the unit of effective area divided by the effective (Refer Time: 23:05) the power of the system.

So, essentially it is meter square divided by Watt; that is the standard unit of n 2 one can have. Well, let us try to now, find out the estimate estimated value to realize the value.

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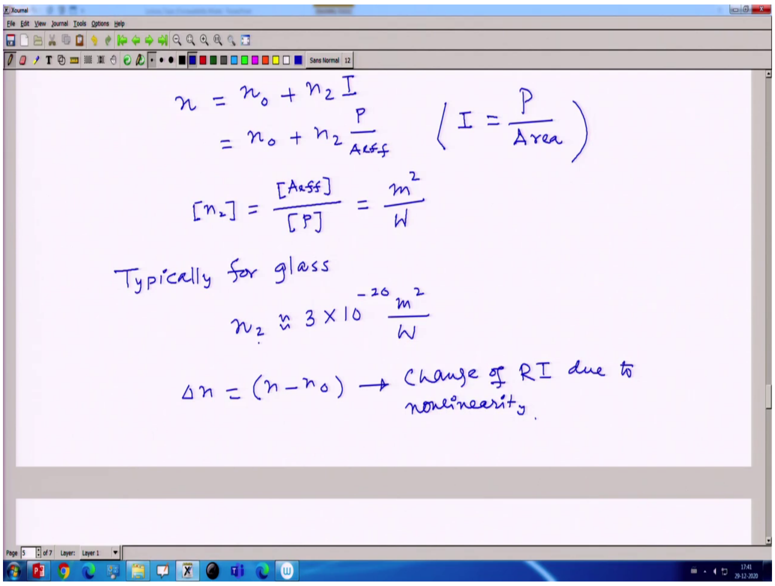

So, typical; so typically, for glass; that means, the silica the n 2 is of the order of 3 into 10 to the power of minus 20 meter square plus by Watt, which is very very small which is very very small. So, if I want to find out what should be the change, because of the non-linearity, it should be delta n will be simply equal to n minus n 0, which is the change of R I due to non-linearity.

So, this change is very very small I can see, because of the value of this n 2. Since, the value of the n 2 is very very small normally this change is very small. So, let us estimate what should be the value of n delta n?

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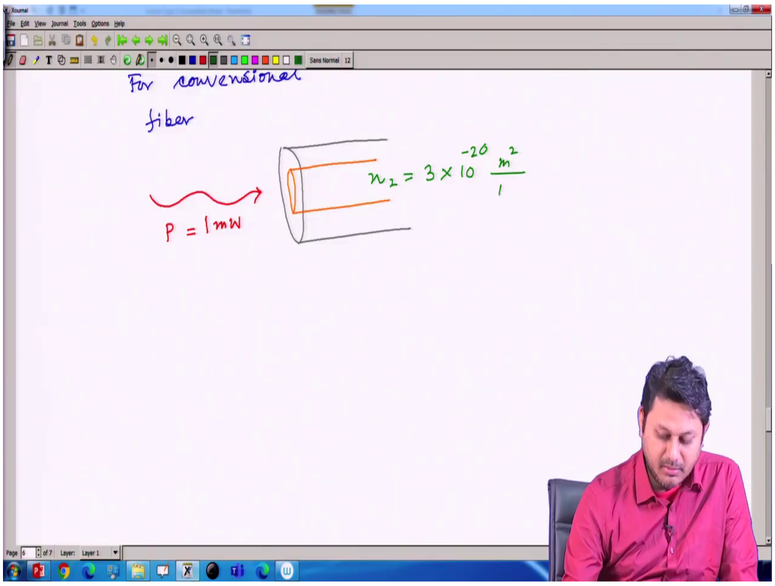

So, let us consider for conventional for conventional fiber; for conventional fiber. So, this is the fiber structure we have and we have a co-region here, and what happened that I launch an electric field with certain power. Let us take this power as normally, it is of the order of milli Watt normally, this is the this is the power we work with and then, the value of n 2 we know is 3 into 10 to the power of say, minus of 20 meter square divided by Watt.

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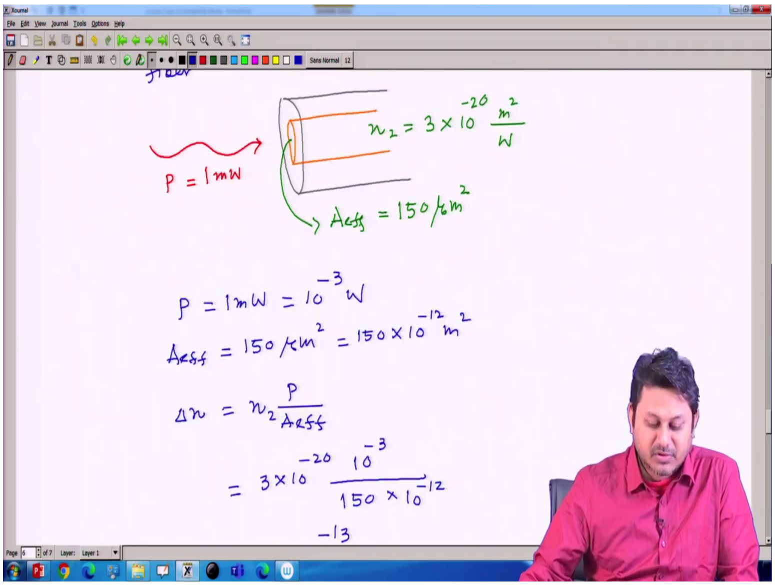

And one parameter is required that is A-effective. So, A-effective is of the order of say, 150 micrometer square. This is roughly the value for a fiber standard fiber. So, now, let us calculate, because all the values are there.

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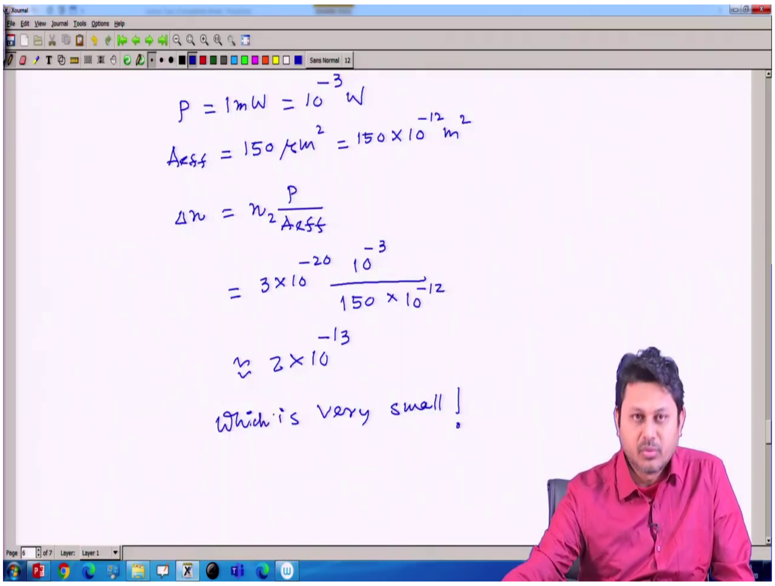

So, P is equal to 1 milli Watt given. So, this value is nothing, but 10 to the power of minus 3 of Watt. And then, A-effective is say, 150 micrometer square so, I can write it as 150 into 10 to the power of minus 12 meter square roughly. And then, delta n should be equal to n 2 then, P divided by A-effective this is the value of n 2 that is the change of refractive index due to the non-linearity. So, now, I will going to put this value whatever the value I have.

So, it should be 3 into 10 to the power of minus 20 and then, the power minus 3, because it is 1 milli Watt in terms of Watt, it should be 10 to the power minus 3 and then, 150 into 10 to the power of minus 12. So, if I calculate this value, it should be of the order of 2 into 10 to the power of minus 13, which is very very small; which is very small. So, delta n which is the change of refractive index due to non-linearity in general, very very small.

If I take the realistic value that normally, people use for the communication purpose in optical fibers. So; that means, normally we never find never we should never find any kind of non-linear effect, in terms of the change of refractive index inside the system in this kind of system. However, one can increase this value and one of the major way to increase this value to reduce the A-effective and increase the power.

So, in the next day we will try to put some values for certain waveguides, which is having a very very less; very very small amount of A-effective; these waveguides are called photonic crystal fiber. One can make this kind of fiber where they reduce the core area very very few few micron-square. So, then we can increase the value of delta n and if I increase that value of delta n, what kind of phenomena one can expect. So, with that note, I like to conclude today's class. So, see you in the next class and.

Thank you for your attentions.