Photonic Integrated Circuit
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Lecture No. 40
Absorption and gain in semiconductors

Hello, everyone. So, now let us look at how we could create photons that could help us in amplification. So, that is the whole purpose of us starting this whole discussion of trying to understand this different transition rates and so on. So, the purpose here is to create photons, but not just creating photons, for sake of it, but we want to create these photons in order to either amplify or to create oscillations that should result in lasing.

So, let us look at this whole process of absorption and amplification. So basically, absorption is a lossy mechanism, that means you are going to lose a photon, but then the amplification is the gain mechanism where you are going to generate more number of photons. So, let us see how we are going to get this absorption result in amplification.

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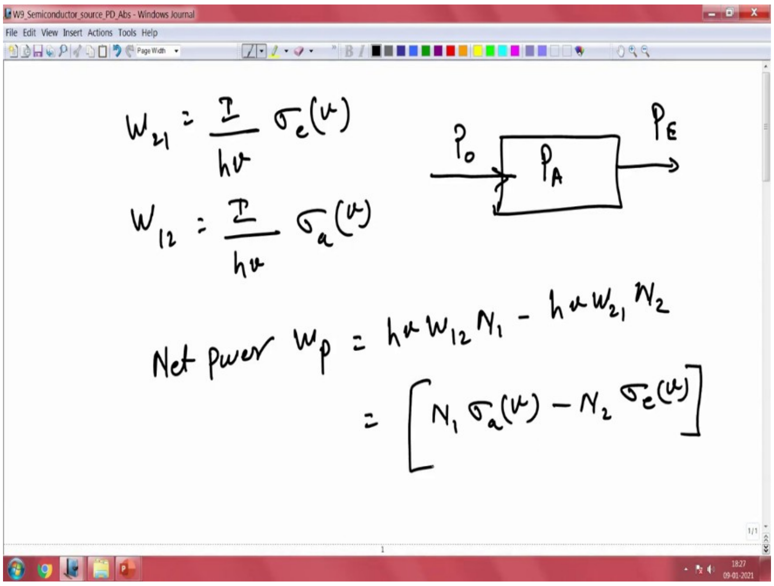

So, let us pick up from where we left in the last class. So, we had mentioned that we could write the absorption, let us say, the rates as a function of photon flux that we have for both emission and also absorption here. So, what the average power, so the average power that you have inside is nothing but the difference between the absorption in the material and the emission.

So, when you take a material here, so I am putting a certain input power inside, that is P_0, let us say and then there is some power emitted and then in the material, there is some power that is absorbed. So, what is the final average or the net power, it is nothing but the difference between the emitted and the input power that is what is absorbed here. So, let us look at the difference between the absorbed power and the emitted power. So, that is your net power.

So, net power that we have that is w_p is nothing but $h\nu w_{12} N_1 - h\nu w_{21} N_2$. So, here we can cross out terms and that basically $N_1 \sigma_a(\nu)$, so that is your absorption, $N_2 \sigma_e(\nu)$. So, this is our net power. So, between absorption and emission, what is the difference?

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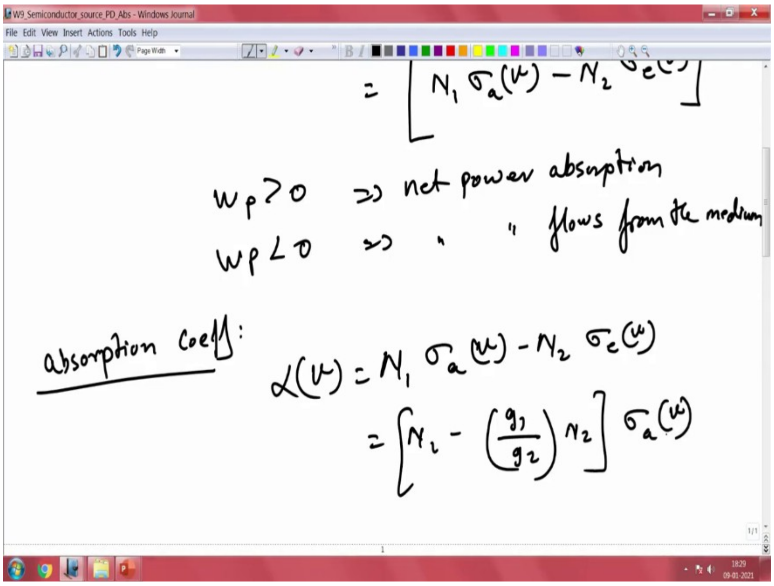

So, when w_p is greater than 0, that means you have net power absorption, net power, that means all the power is getting absorbed and if w_p is less than 0, then you have power, net power is, flows through the, flows from the medium. That means there is generation here. So, let us look at the absorption and generation coefficient. The absorption coefficient, what is absorption coefficient?

We have seen this absorption coefficient in a different avatar earlier on when we discussed about the material dispersion, here this is coming from the two-level system. So, when you have a two-level system, what is that absorption is going to be so, it is nothing but $N_1\sigma_a(v) - N_2\sigma_e(v)$. In other words, $[N¿¿1 - \left(\frac{g_1}{g_2}\right)N_2]\sigma_e(v)¿$. So, this is our absorption coefficient.

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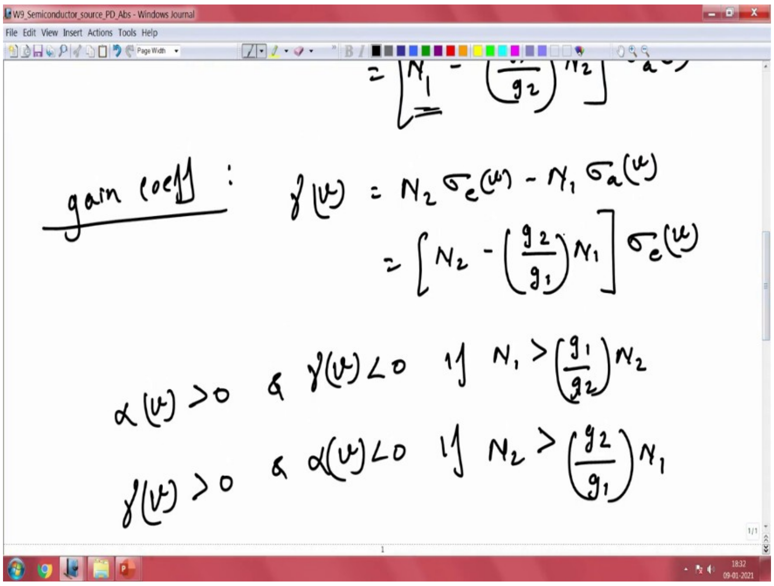

And then we have the emission or the gain. So, the gain coefficient here is γ(ν), which is $N_2\sigma_e(v) - N_1\sigma_a(v)$. So, it is the inverse of what we have here. So, that would result in N_2

minus, so this is N_1, $[N¿¿2-\left(\frac{g_2}{g_1}\right)N_1]\sigma_e(v)¿$. So, this is our gain coefficient. So, now the emission and gain coefficients are clear coming from our cross section, the emission and absorption cross section that we saw earlier. So, now, let us look at, you know, the scenarios where, what happens if α and γ are positive or negative.

So, $\alpha(v)>0$ and $\gamma(v)<0$, if $N_1>\left(\frac{g_1}{g_2}\right)N_2$. So, let us look at this. So, your α is going to be positive, when the $N_1>\left(\frac{g_1}{g_2}\right)N_2$. So, the N_1 has to be higher, in that case your γ or your gain coefficient will be negative, so that is natural. So, you if N_2 is much larger then you are going to have a negative term here. So, it is going to be negative, the gain is going to be negative and your α, absorption is positive. So, this, this is one scenario.

And the next scenario is $\gamma(v)>0$ and $\alpha(v)<0$. So, this happens if $N_2>\left(\frac{g_2}{g_1}\right)N_1$. So, this is the next scenario where you have greater N_2 compare N_1. So, in this case gain is going to be positive while your loss is going to be negative. So, these are all the two states, that we define as absorption and gain. So, now we can even simplify this by considering this absorption and emission cross sections are now very different.

So, we have two different factors, what if we say the emission and the absorption cross sections are identical, that means g_1 and g_2 are also equal. So, let us say we assume that the degeneracy is also equal.

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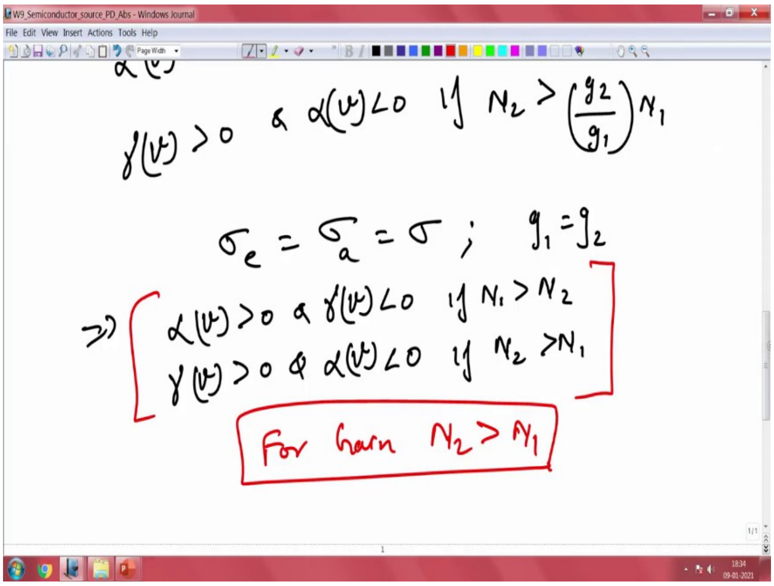

So, the idea here is, let us say $\sigma_e=\sigma_a$ which is equal to σ and $g_1=g_2$. So, in this case these terms will vanish, and this would imply $\alpha(v)>0$ and $\gamma(v)<0$ 0, if $N_1>N_2$ and $\gamma(v)>0$ and $\alpha(v)<0$, if $N_2>N_1$. Look at this scenario, this is a, this is a very familiar scenario, you must have studied in your basics of lasing and light emission, you should have higher population in the excited state in order to have gain.

So, for gain $N_2 > N_1$. So, for gain $N_2 > N_1$. So, this is the condition that we should all try to achieve in order to make sure that you have light emission from the system. Otherwise, your light will be just absorbed, and nothing would be emitted from the system. So, there is a slightly a different way of writing this as well, I will just mention it for completeness.

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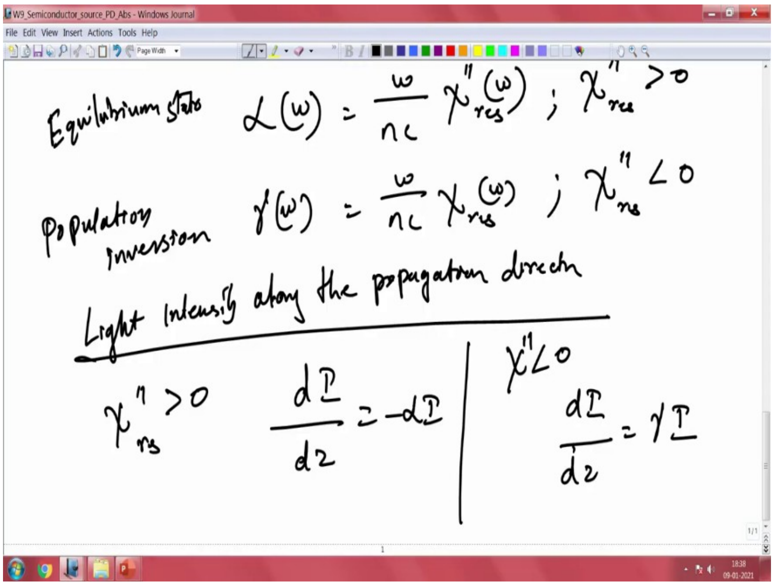

So, you could write the absorption coefficient as a function of susceptibility here. So, you could write this as the imaginary part of the susceptibility and the same thing is true, so, when your susceptibility is greater than 0 and you have $\frac{\omega}{nc}$, where your susceptibility is less than 0. So, here we have a steady state, and this is the population inversion, and this is equilibrium state.

So, this is, this is very vital to understand, when you will have emission. So, you cannot have emission when you are in equilibrium, there should be a non-equilibrium in order to generate photons. So, you have to drive the system to non-equilibrium in order to do that, but then when you are having loss or gain, how will the light intensity evolve. So, light intensity along the propagation. So, now we talked about absorption and emission, but now, when the photon is going through the system, where our optical wave is going through the system, what will be the effect of having loss and what is the effect of having gain in the system.

So, let us say we throw out the face information is not required, then your intensity, when you are, when your susceptibility is greater than 0, the imaginary part of the susceptibility is greater than 0, here we have loss. So, that means your dI/dz is nothing but -αI and when you have gain, where you are susceptibility is less than 0 your dI/dz will be γI. So, this is how your intensity is going to increase as you move along the direction of gain, while you will have, you know absorption as you move along...α times 'I'.

So, this is, this is how we understand this and now, we have a gain in the system. So, there is a propagating wave, and we have α and we have γ, the gain and loss parameters and now, we can apply this to our system. So, now we can use this gain and loss into our amplifying medium or lasing medium in order to build light emitters. So, let us look at that in the next lecture session. Thank you.