Processing of Semiconducting Materials
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Lecture - 28
Optical Characterization

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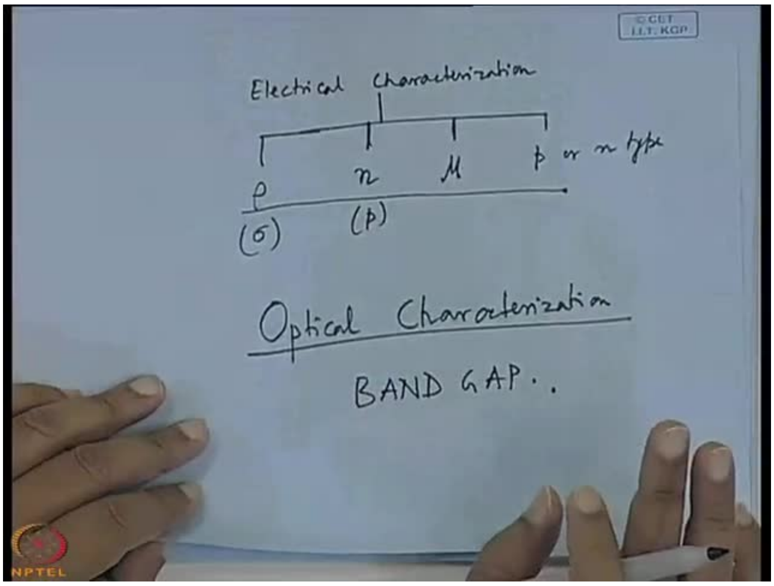

In our last lecture, we have discussed about the electrical characterization of the materials; electrical characterization of materials. In that characterization, we have seen that the major important parameters that we can characterize using the electrical methods are the resistivity or the conductivity. Then career concentration, it can be n type, it can be p type, then the mobility, basically this is the hall mobility, and another is the no there is the conductivity type of semiconductor. That means, it can be p type, it can be n type whether it is p or n type of conductivity.

So, these are the four parameters that we can measure using some electrical characterization techniques. And, mostly we have devoted our time on the four- probe method, Vander pauw technique and hall measurements. And we know that in hall measurements, we have generally use we generally use the Vander pauw configuration in presence of magnet field.

Today, we shall concentrate our attention on the optical characterization of materials.

Now, in this characterization technique as the name implies you can understand that we shall use some optical source; we shall use some optical source instead of electrical. In electrical characterization we have used the electrical source. It can be a current source; it can be a voltage source etcetera. In optical source, we do not use any current or voltage, only we use the optical source. And, one major advantage of this optical characterization is that you did not to make any contact. In electrical characterization we have seen that for your Vander pauw configuration, you have to make ohmic contact on the material. And, if you make an ohmic contact in a material that material cannot be used for subsequent processing that means it is in a sense destructive technique of characterization.

Because with that piece of semiconductor which you have on which you have made some ohmic contact that is basically contaminated. For this measurement, it is ok but for subsequent device processing you cannot use that piece. In optical characterization you need not to make any contact. So, that is very advantageous for optical, but from optical characterization only 1 important thing you can characterize.

It is the band gap of the material. So, from optical characterization you can measure the band gap of the material. And, you know that it is very important parameter for semiconducting materials or electronic materials. Particularly if you would like to use that material for optical application say for optoelectronic application you want to make a laser you want to make a light emitting diode or photo detector then you are you must characterize its band gap. Otherwise, how do you know? Whether it is direct or indirect and what is its value? Those things it is very important particularly for the new materials. So, as soon as you grow a material by any technique it can be say by bridge man technique. It can be say by czochralski technique or some epitaxial growth technique you take the sample you characterize a sample first by electrical and then by optical or the vice versa. First you use the optical characterization technique measure the band gap of the material and then you see the electrical characterization parameters. In that sense that if you resort to that sample for both electrical and optical characterization your characterization will be completed primary a characterizations will be completed.

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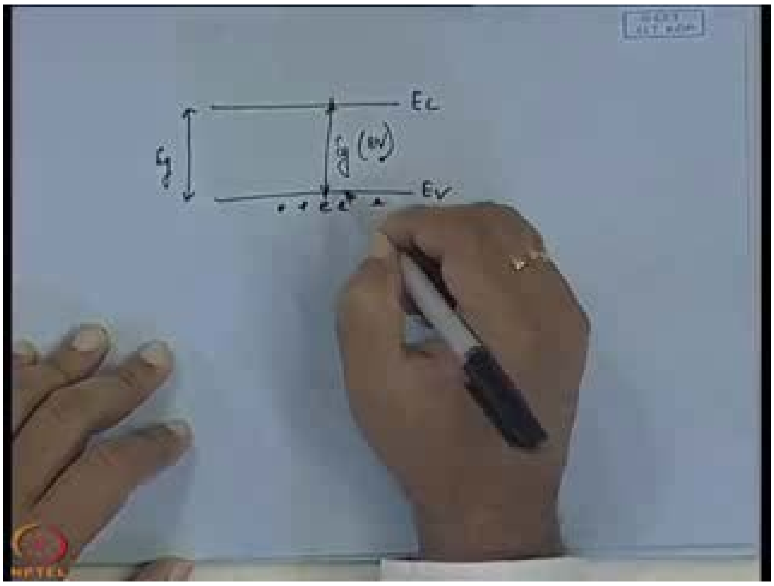

Now, to measure the band gap you know that band gap is a function of the wave length of light. You know that if I consider that this is the bottom of the conduction band end this is the top of the valence band, then 1 electron can be excited to the conduction band by application of some energy. If you excite that electron by some energy and that energy is basically the band gap energy. Then, only the electrons can be excited to the upper most level or the conduction band. Now, if you excite that electron to the conduction band that means minimum E g energy E g electron volt of energy is required for its excitation. That means, if you want to measure the band gap of the material you have to measure the energy of this energy. That means, the energy required to excite 1 electron from the valence band to the conduction band.

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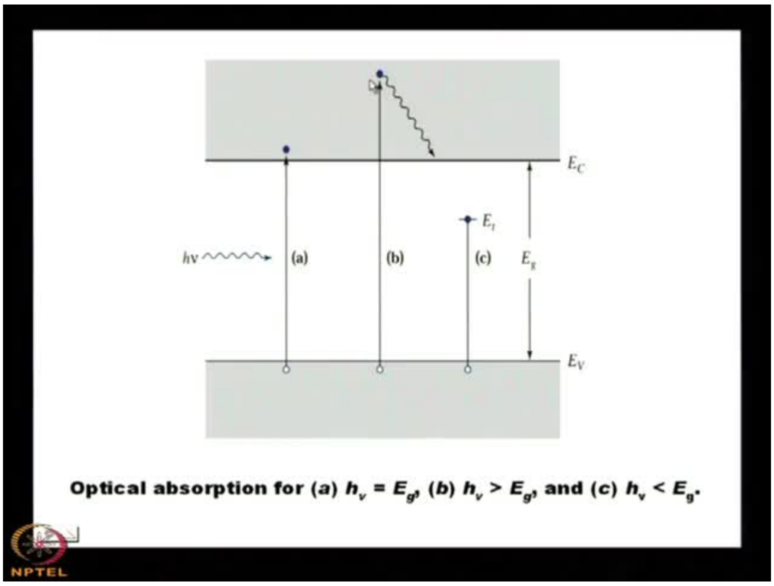

Optical absorption for (*a*) $h_v = E_g$, (*b*) $h_v > E_g$, and (*c*) $h_v < E_g$.

Now, if we see this view graph, you see in this view graph the as soon as you excite the electrons with some energy there may be different situations. Here, I have seen you the three situations. In situation a it is band to band transition that means the energy is basically equal to band gap energy.

You see that h nu equals to E g. It is h nu not h suffix nu it is h nu equals to E g. In case a it is h nu equals to E g; then, what is the situation in b? What is the situation in b? That it is more than the band gap energy that you have supplied energy, which is more than the band gap energy. So, what happen? The electrons move from the valence band to the deep inside the conduction band. But what is the average thermal energy in the conduction band? Do you know? What is the average thermal energy in the conduction band? It is 3 by 2 k t, it is generally 3 by 2 k t. So, if it is 3 by 2 k t and what is 3 by 2 k t? That means 3 by 2 k t is very near to the conduction band. What is k t? At normal room temperature it is 26 3 by 2 k t means 39 almost 38, 39 mille electron volt. So, that means it is very near to the conduction band edge.

So, that means when you supply more energy h nu very, very greater than E g. So, electrons moved from the valence band deep inside the conduction band but its energy is this 3 by 2 k t. So, what will happen? It will release its energy? And will come near the conduction band edge that a phenomenon is known as stabilization or thermalization. It is basically the thermalization you have to thermalize the conduction band electrons which are in a excited state that is thermalization. That is thermalization thermalization that is thermalization. And, this thermalization will provide the electrons to come to the conduction band edge by dissipating the extra energy. And, that energy will be dissipated in the crystal lattice as heat the extra energy will be dissipated as heat. That means the excited electrons will scatter in the crystal lattice. So, there will be scattering and during scattering it will lose its energy and that energy will be dissipated as heat.

So, finally it will come to the conduction band edge. So, there can be two situations. One is that if the energy is nearly equal to by the band gap there will be the transition from band to band or intervene transition. And, here you see that here the energy of excitation is more than the band gap. So, it will go deep inside the conduction band and then it will thermalize. And, there can be another situation c that when the energy is less than E g. When the energy is less than the band gap energy then what will happen? The electrons will be excited provided there is any trap state or defect level inside the band gap provided.

If there is no defect level then it will not be excited. If there is defect level then only it will reach there here you see that there is a defect level E t. So, it will reach to Et but suppose you have excited the electron in the valence band with an energy less than Et then it will not be excited to E t here there is a electronic state here. So, it can be excited to that level provided there is a level and the energy is equal to that trap level or defect level. Then you can expect that the valence electrons will move to that level. Otherwise there is no chance of excitation of the electrons from the valence band. So, there can be 3 situations depending on the nature of the energy of excitation.

Now, what will happen if you excite suppose there is no in state inside the band gap, there is no state, there in no Et or Ed type of state. There is no trap level; there is no defect level inside the band gap. And, you are you have supplied energy less than Eg then what will happen? No excitation takes place that means for that wave length to the electron it is transparent it is transparent. If you think in terms of the wave length that means light, color then it is basically transparent.

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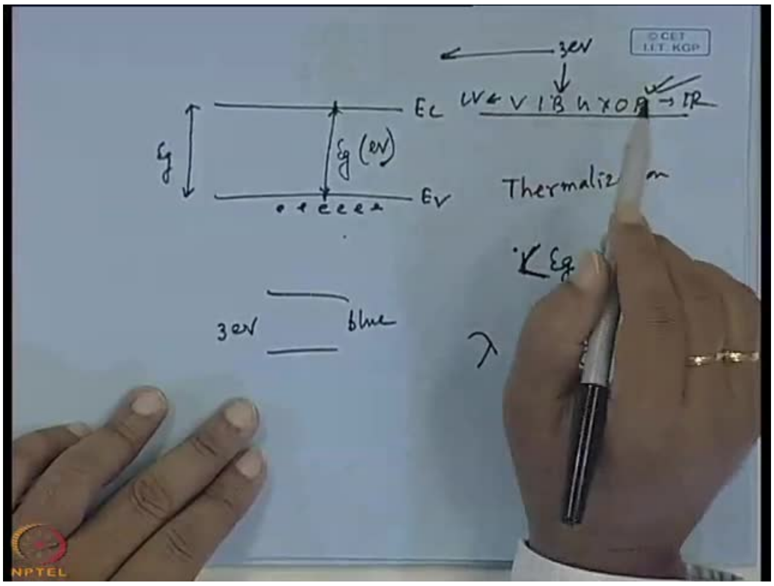

That means less than E g that means greater than h nu by E g lambda. If the energy is less than E g what is the meaning? Wave length is greater, because when the energy is less, wave length is greater. So, that means suppose the band gap is blue. Let us take an example the band gap is blue that means say it is. So, if you see the electromagnetic spectrum so V I B G Y O R this is infrared this is ultraviolet. So, that means it will if it is say 3 electron volt let us take an example. It is say 3 electron volt the band gap. So, that means blue is 3 electron volt that means it will be excited using energy 3 electron volt or more more means in the left side.

Because it is you see that energy is increasing in that manner. So, that means wave length is decreasing that means if you use any radiation higher then blue radiation in terms of wave length. That means if you use red or infrared or orange or yellow is it possible to excite the electrons from the valence band to the conduction band. No, that means higher wave length will be transparent for that material. Since, lambda is 1 by Eg proportional to 1 by Eg. So, that do not confuse with the energy and the wave length more energy required means.

Student: (( )).

That means higher wave length will not be used in that case for the excitation. Suppose if you consider red. Then what you can expect? Only infrared will not be used. You cannot use infrared but any wave length which is less than the red. In terms of wave length not in terms of energy. You can use blue, you can use green, you can use yellow, and you can use ultraviolet, any kind of radiation you can use. What will happen when energy lies between E t and E c?

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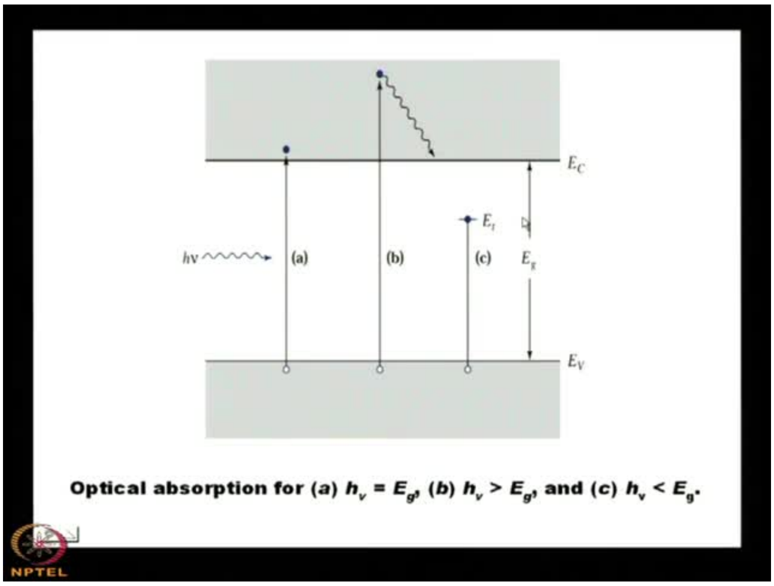

Optical absorption for (a) $h_\nu = E_g$, (b) $h_\nu > E_g$, and (c) $h_\nu < E_g$.

E C nothing will happen some of the electrons will move to Et that is all because here there is no states. So, electrons will not be there. If sufficient energy is there then electrons can reach to E C. Yes, obviously and another important factor you see that here it also it also depends on the density of states in that level. Not only that, the level is sufficient at the same time there must be density of states in that level.

That means sufficient empty spaces for electrons in that level then only the electrons will reach there. Now, you have had a you have made a question that if the energy lies between E t and E C then since there is a level at Et. So, it will be populated; some part of the energy will be used. Because E t minus E C in that sense that means you have given you have excited the electrons with sufficient Et energy at least Et energy we have supplied. So, some of the electrons will move from the valence band to the Et level that is all and the rest of the energy will not be used; unless it is equals to EC then some of the electrons will move to Ec. So, that means if you suppose this is the situation that there is a defect level in between the band gap. And, you supply energy which is equal to the band gap that means there is a chance that Et level will also be populated there is a chance that Et level will also be populated. So, that is the reason that sometimes we perform these experiments in 0k, 10k, 12k or 4.2k that means in the helium temperature liquid helium temperature 4.2 k or 77k which is the liquid nitrogen temperature.

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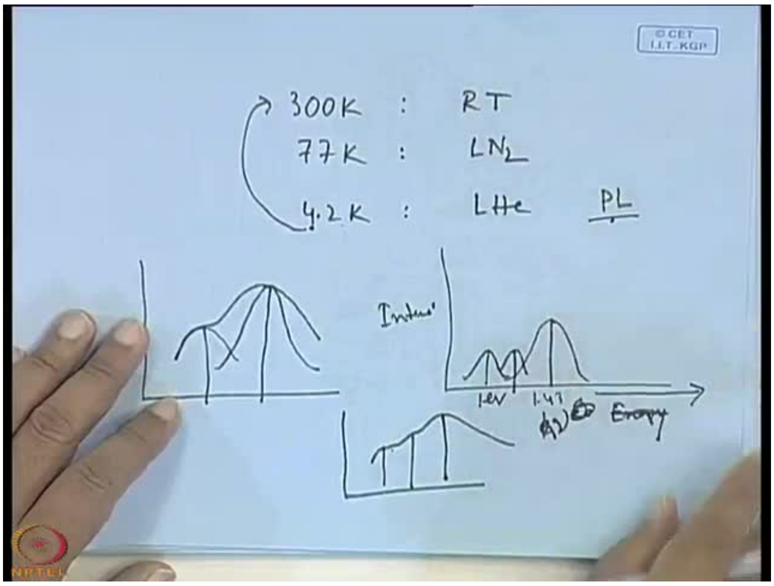

I hope that you know that so far as the temperature is concerned 300k corresponds to room temperature. Then 77k it is corresponds to liquid nitrogen temperature and then 4.2k it is liquid helium temperature. So, generally in our experiments we use these 3 kinds of temperature because these are available. Liquid nitrogen is available, liquid helium is available, liquid carbon dioxide is not available. So, we cannot use that temperature but you can vary the temperature say from 4.2 to 300k. You can continuously vary if you have a close cycle cryostat that is the instrument is known as the close cycle cryostat then you can vary the temperature from 4.2k to 300k. Every 10k or every 20k you can take the reading.

Now, why I am invoking the concept of temperature here it is because when there is a defect level. The defect level is active only at room temperature or temperature which is near to the thermal energy at that temperature at 77k or 4.2k. This level will not be there. Why? Because there will be no ionization at that temperature. Unless that level is ionized then the level will be inactive, only when there will be ionization it will be active. And, for ionization you have to supply minimum energy which is not possible at 4.2k or 77k. So, that is the reason if you perform this experiment at room temperature may be you can get a broad peak or a number of peaks corresponds to each of the transitions. Each transitions will give you a peak but at low temperature the defect states are inactive. So, they will not give you the peak.

So, that means optical characterization particularly the photo luminescence experiment at low temperature is very much use full to characterize the defects in a semiconductor. Let me explain that thing also suppose you have a material this kind of material. And, how many peaks you can expect? There will be 2 peaks; why, because this electron will come down to the valence band. So, you will get one energy say that energy if you plot against Eg or say with energy this is say intensity and it is energy h nu h nu energy. So, first thing you see that there is a band to band transition and say its value is say it is gallium arsenide. Let us take an example. So, what is the value of this band gap? 1.43. So, that means 1.24 by 1.43.

What is the value? 1.43 Basically if you if you take the energy because i have plotted in the y x axis the energy. So, it is 1.43. So, let us say that this 1.43. So, you will get a peak at 1.43 this is photo luminescence experiment PL experiment photo luminescence. That means you are exciting the sample with some optical source due to that excitation the electrons move from the valence band to the conduction band. And, when they are de-excited to the lower level then they emit light and you are collecting that light and you are plotting as a function of intensity. Then you will get 1.43 electron volt peak due to this transition.

Student: (( ))

No, that is not possible for light emitting diode or from this sample. That is possible if you use a particular type of sample say, which is used for the laser emission then that is possible. And, also if you can take the spectrum at very low temperature but there will be thermal broadening means the because of the temperature difference that peak will broadened thermal broadening will be there. So, you cannot expect a peak like the delta function at normal room temperature.

Student: (( )).

Normally, one electron absorbs one photon normally or in the other sense one electron hole pair will give rise to one photon. But in some cases not in this semiconductors there is a term which is known as multi excited generation MEG. And, a large number of research was being done throughout the globe on this multi excited generation. That means 1 electron hole pair will give you more than 1 photon. That is possible in some structures in some Nano materials particularly zinc selenide, zinc sulphide, lead telluride type of material. And, what is the advantage? The advantage is that in photovoltaic application like in solar cell.

What we do? Generally 1 photon give rise to 1 electron hole pair but if 1 photon give rise to many electron hole pair multi exciton generation is their then the efficiency will be very high. Even if it absorbs very small energy because of the multiplication of the exciton the efficiency will be very high. So, people have been trying particularly if you search the sites of national renewable energy limited NREL which is in Colorado USA. You will find that they have been trying for a long time of developing materials have been multi capable of giving multi exciton generation MEG but that is not possible in normal semiconductors.

So, one peak will get from this transition. Then, what will be there? There will be another peak for this transition. What is the energy? Energy is less than 1.43 electron volt you see energy is less than 1.43. So, if energy axis is this that means it is increasing from in the positive x direction. So, that means there is a chance that at one say it is 1 electron volt there is another peak there is another peak. This peak is due to the defect level and that peak is due to the band to band transition, but I have drawn very sharp peaks. In practice such sharp peaks are not available say that type of a thing you will you will get overlapping of the peaks.

Then you have to deco volute these peaks by mathematical techniques. And, you can fit that peak into 2 peaks namely this thing and that thing fittings and you will get 2 values of the energy. Their by you can characterize the defects in a material. If there are more number of defects says one defect is at 1.2 electron volt say. So, you will get another peak at 1.2 electron volt here which is 1.2 electron volt then your then your compounded peak will be like this type of a thing. This is for 1, this is 1.2, it is 1.43 that means you have to decouple the peak by some mathematical fittings. You have to reserve to some programming then you fit the peak and you can extract the corresponding energy and intensity of the peak.

So, that means characterization is not very simple thing. You will get a broad peak say and you are telling that is a gallium arsenide you have given me but you see it is the I find a very large and broad peak. It will be there because it is full of defects then you should expect that you will get broad peak. Unless you decouple all the peaks by suitable computer feed mathematical program then only you can say that this is these are there and that is very interesting also. In photo luminescence what actually is done? The sample is excited by means of a optical source.

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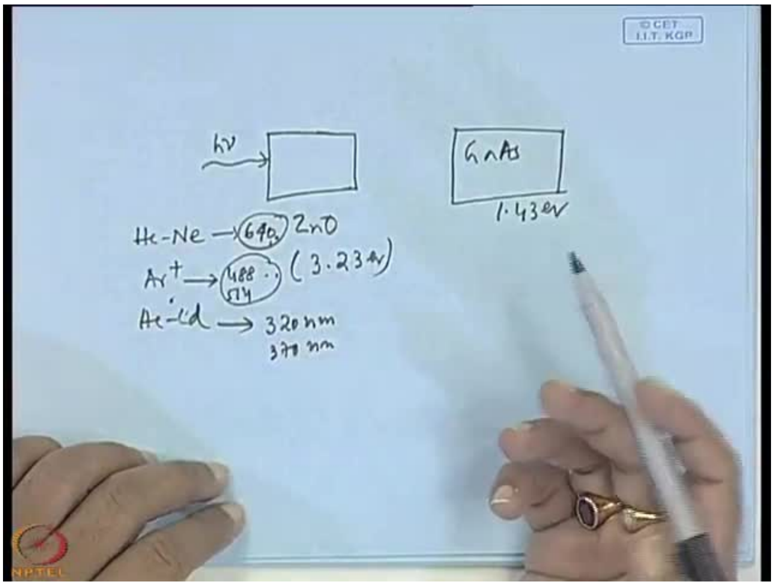

In photo luminescence what actually is done? The sample is excited by means of a optical source. Generally, the optical source is a laser source generally. So, that means what kind of laser you can expect? It must be greater than the band gap energy of the material otherwise the laser will not be able to excite. So, chose that laser in that manner. Suppose your material is zinc oxide. What is its band gap what is the band gap of zinc oxide?

Student: (( )).

No. it is 3.23 or 2 7 2 8 electron volt let us take it is 3.23 electron volt. So, that means what kind of excitation source you can expect? Say it can be helium- neon laser, it can be argon ion laser, it can be helium- cadmium laser these lasers are available in the market. These are all semiconductor laser with very compact very intense source and very easy to handle. So, you must know what is the emission from these lasers? Argon ion laser there are 2 lines the available in argon ion lasers. One is 488 another is 514 nanometer. 488 mean it is blue 514 means it is green. Helium- neon it is.

Student: 626328.

Yes. 6 2 6 3 2 8 that means say 640 nanometer or 67680 nanometer that means it is red rightly said. It is red. So, can these lasers be used to excite the electrons from the valence band of zinc oxide to the conduction band? You tell whether these lasers can be used to excite the electrons of zinc oxide from the valence band to the conduction band. What is your suggestion? Why you are using the calculator? It is very simple 3.23 means

Student: (( )).

It is almost ultraviolet it is almost ultraviolet. Then, red transparent, green transparent, blue transparent. So, only helium-cadmium laser having say 320 nanometer type of wave length or 370 type of nanometer wave length can be used for the zinc oxide emission. So, care must be taken. If you design an experiment do not try to use helium- neon or argon ion laser for the photo luminescence of zinc oxide do not try because you will get nothing because no electrons will be excited. So, that is very important consideration for designing experiment you must know. If you do not know the band gap you cannot excite that thing. Suppose, you want to use gallium arsenide sample. This is say gallium arsenide sample its band gap is 1.43 electron volt. What you expect? What kind of source out of these 3 is used? Why?

Student: (( )).

Yes, Tell.

Student: (( )).

Yes. All the sources can be used because it is infrared, 1.43 is infrared. So, below infrared any source you can use blue, you can use green, you can use red, you can use ultraviolet, you can use you can use any source. So, that is the constant depending on the band gap of the material. Now, let us sees that how the band gap is determined from the optical absorption spectroscopy? The band gap of material is measured using optical absorption.

This is a material when light falls on it, it will absorb energy which is equals to Eg and other energy will be transmitted. If you have a detector here and if you have a source here; then the detector will detect that light which is coming out from the material after transmission. Which is absorbed cannot be detected by the light by the detector because it has been absorbed. So, suppose you first excite the material with a light source having all kinds of wave length; that is available by using a white light source because a white light source contain all kinds of wave length.

That means, to specify one particular wave length you have to use a monochromator because monochromator job is to measure the wave length of light. Suppose it is white light it is coming out from this source say it is a sodium vapor lamp or mercury vapor lamp or any white light source. So, light is coming out. So, if you fit a monochromator here, that monochromator will give you the intensity verses wave length of this light. So, monochromator can separate different wave lengths and this corresponding intensity from a white light source. So, you give you place a monochromator. So, that you can estimate what is the light that is going inside the material? And, in the output you need also another monochromator because there also you need to know what the lights which are coming out.

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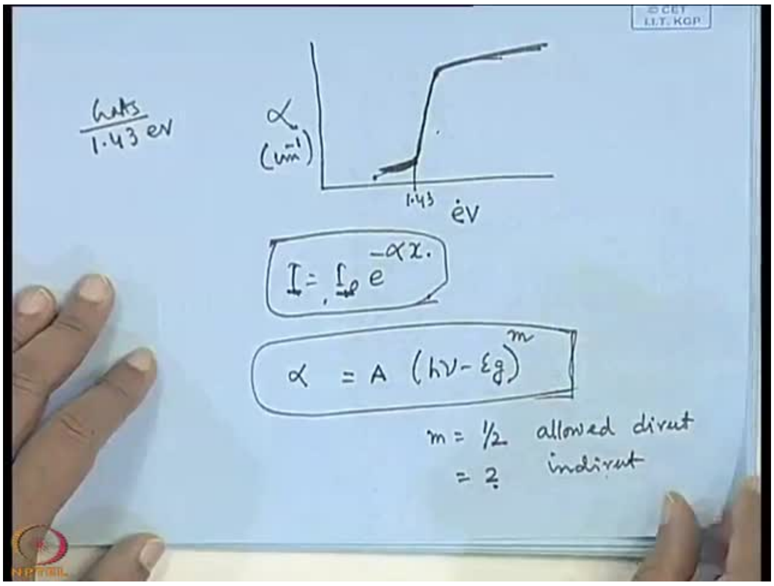

$I = I_0 e^{-\alpha x}$.

$\alpha = A(h\nu - E_g)^m$

$m = 1/2$ allowed direct

$= 2$ indirect

Then, the absorption curve will be like this. This is the absorption curve which say band gap, which say energy e v. This is the absorption. What is the meaning of the absorption? Suppose it is 1.43 electron volt gallium arsenide. At 1.43 it will absorb the absorption will be highest at this wave length then there will be saturation then there will be saturation. And, below 1.43 there will be very less absorption or there will be almost no absorption in a perfectly material there will be no absorption. So, this is the absorption curve it is known as the absorption coefficient verse centimeter and it is the energy. So, this type of a curve you will get that means it will absorb the light very near to its band gap. Below that band gap so far as the energy is concerned it will not absorb above the band gap it will absorb. And finally finally it will be thermalization in fact.

So, this type of a curve you will get. And, I equals to I0 e to the power minus alpha into x is the intensity of light which will be transmitted. I is the intensity of light which will be transmitted if you excite the material with I0; I0 is the initial photon flask. And, e to the power minus alpha x alpha is the absorption coefficient and x is the thickness thickness. So, this equation will give you the absorption or the transmission. If this is transmission then absorption will be 1 minus I; because I plus t equals to1.

So, you can set your experiment in the absorption mode in the transmission mode, in the reflection mode because they can be internally converted to each other. But the principle is that it will absorb light and you fit a detector on the other end. So, that the detector will detect that light which will be transmitted and thereby you can plot a curve. It can be transmitted transmission verses wave length or energy or the absorption verses wave length or energy that you can calculate using suitable relations.

And, you know that the band gap can be direct or indirect. Here alpha equals to some constant A h nu minus eg to the power m. This is the equation using which the absorption can be calculated. A is a constant A is a constant, eg is the band gap, alpha is the absorption coefficient. What is m? m equals to half for allowed direct transition or it is equals to 2 for indirect transition because generally the transitions can be either direct or indirect. So, m can be either 2 for indirect or half for direct.

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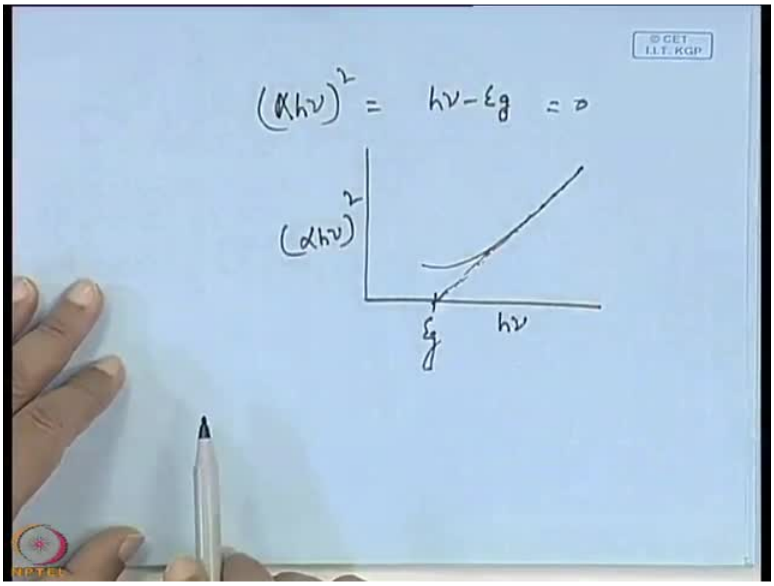

Then, the plot of alpha h nu square equals to h nu minus eg; from the plot of alpha h nu square verses h nu. You will get a curve like this. If you plot alpha h nu square verses h nu you will get a plot like this, and if you take the extrapolation of the straight portion in the energy axis that will give you the band gap. Because when alpha h nu square equals to 0 or eg equals to h nu this comes from this equation.

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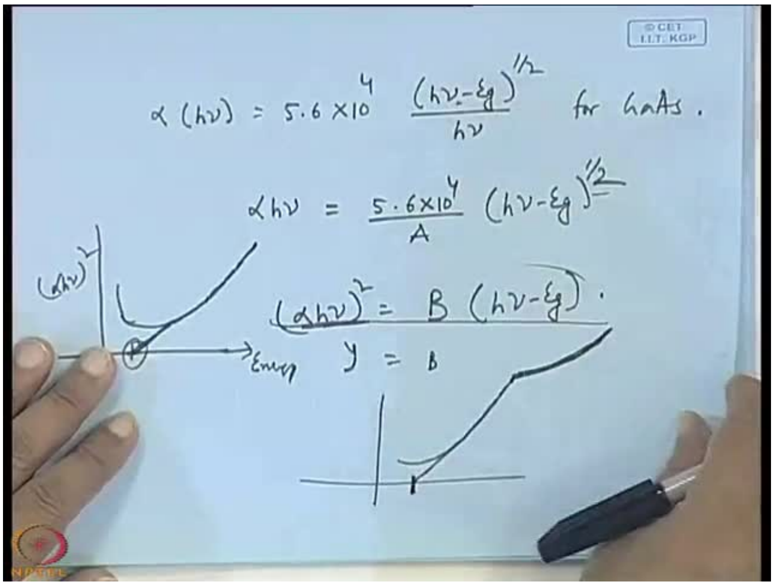

$\alpha(h\nu) = 5.6\times10^{4}\,\frac{(h\nu - E_g)^{1/2}}{h\nu}$ for GaAs.

$\alpha h\nu = \underset{A}{\underline{5.6\times10^{4}}}\,(h\nu - E_g)^{1/2}$

$(\alpha h\nu)^2 = B\,(h\nu - E_g)$.

$y = B$

We are not going to deduce the equation but if you want to see more about it actual expression is alpha into alpha is a function of h nu it is equals to 5.6 into 10 to the power 4 into h nu minus eg to the power half by h nu this is for gallium arsenide. The exact function expression for gallium arsenide is this alpha equals to 5.6 into 10 to the power 4 h nu minus eg to the power half by h nu.

So, if you multiply then alpha h nu equals to 5.6 into 10 to the power 4 let us say at A. It is h nu minus eg to the power half. If you make the square; alpha h nu square equals to say some constant b into h nu minus eg. So, it is y square equals to something it is basically a parabolic type of curve will be there. What should be the nature of the curve here? It is parabolic in nature. So, your curve will be like this or say that type of thing but the straight portion if extrapolated in the energy axis. This is the energy axis, this is alpha h nu square then that will give you your band gap. So, band gap very easily we calculated using this type of plot.

Student: (( )).

Alpha h nu verses h nu.

Student: (( )).

Why?

Student: (( )).

Y equal to 4 ax. Y square equal to 4 ax.

Student: (( )).

I am is not is y square verses this.

Student: (( )).

Which one.

Student: (( )).

Say this is ok. It is y equals to something.

Student: (( )).

No. If you want parabola, if you do not want parabola.

Student: (( )).

Not exactly straight line because we have seen in many cases it is not exactly straight line because of the complicated nature of the absorptions curve. That is because of the not the not because of this nature of this curve it is because of the data we get.

Student: (( )).

No. It is not a parabola it is like this it is like this. Then the straight portion when interpolated in the energy axis then it will give you the energy eg. This portion is straight line, but not the whole portion is straight line. In indirect band gap we have seen that this portion again increases or decreases type of thing like this that portion that is for indirect band gap. Because for indirect band gap it becomes square for indirect band gap this becomes square. Then you have to plot root over of alpha h nu as a function of h nu not alpha h nu square versus h nu remember that.

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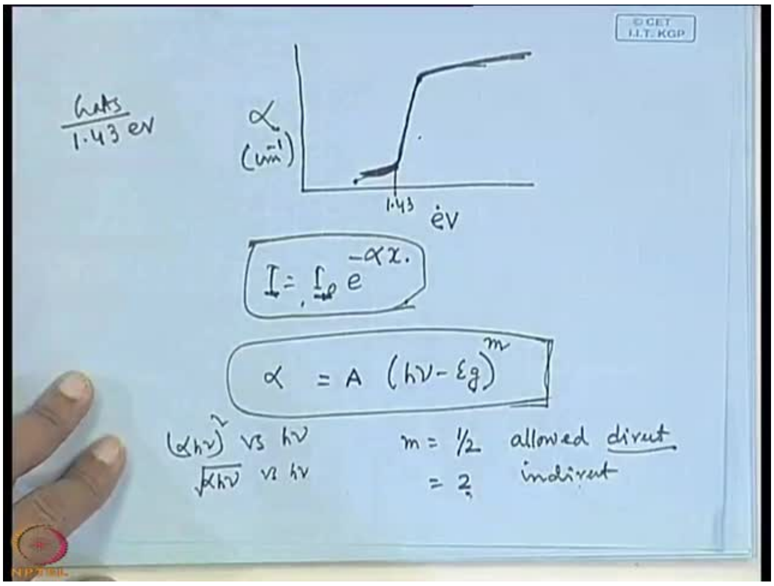

When aim is half then direct gap then alpha h nu square is plotted as a function of h nu. But when it is 2 for indirect band gap semiconductor then it is alpha h nu root over of versus h nu is plotted. And, the same technique is adopted that the linear portion when extrapolated in the energy axis will give you the band gap. So, that is very easily you can calculate the band gap of the semiconductor using absorption spectroscopy where it is not a destructive technique.

Student: (( )).

Maybe, it may be localize state it may be thermal broadening there may be different kinds of processes inside the semiconductors. And, there can be say variation of the energy also say it is h nu and h nu plus d h nu so many possibilities are there. Yes the measurement also there. So, there are many also there is a effect of detector on there because detector linearity is not ensured all that time because of the variation in temperature. So, many possibilities are there.

So, it is nutshells that you can use the optical absorption measurement for the determination of the optical band gap of the semiconductor remember that. The absorption process means? You are exciting the electrons in the valence band of the material to the conduction band and you are using a detector to measure the transmitted light. Because the absorbed light it has absorbed; only the transmitted light you can have. And, then you can plot basically it is the plot will be I by I0 which is known as the optical density I by I0. It is I by I0. Why? Because I by Io sorry I0 by I because you are giving I0; I0 is the initial photon flask and I is the transmitted light.

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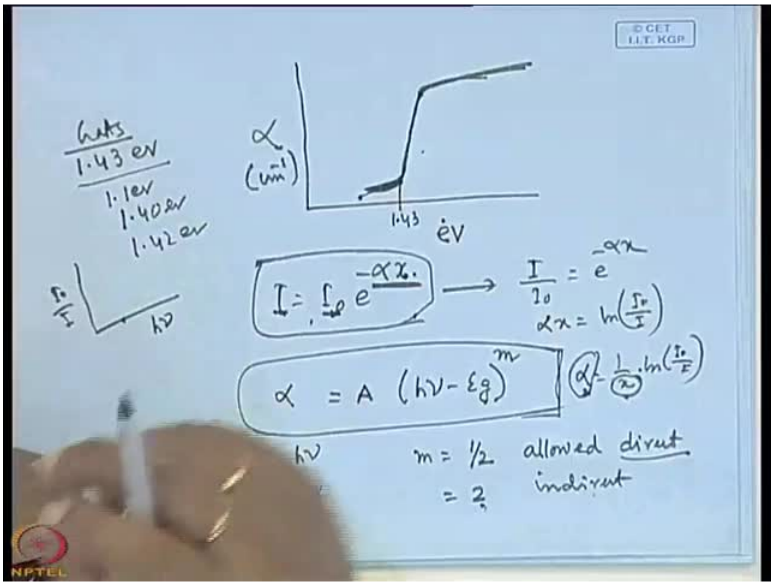

So, basically it is I0 by I which is basically plotted. And, from that plot you have to measure alpha h nu square versus h nu. That means you need the thickness because you need the thickness; x is the thickness. Unless you know the thickness you cannot measure alpha h nu square versus h nu. So, thickness is important. Then how you will determine alpha? From this equation how you determine the alpha?

Actually, see I by I0 equal to say e to the power minus alpha x or alpha x equals to ln I0 by I. Alpha x equals to ln I0 by I. So, alpha equals to 1 by x into ln I0 by I. I0 by I you can obtain from the absorptions spectroscopy; generally it is plotted I0 by I versus h nu. When you see when you talk about spectroscopy that means it must be against energy; in all spectroscopic technique it must be against energy. Spectroscopy is the findings against energy remember. Electrical characterizations are not spectroscopic technique because no energy is associated in electrical measurements.

Only when energy is associated with any measurement that technique is known as spectroscopy. Now, here you see that you will get a curve of in the x axis it is h nu and in the y axis say I0 by I. So, that means first you have to calculate alpha. You calculate alpha you must know the thickness 1 by x is the thickness. So, you must know the thickness once you know the thickness you can calculate alpha for that corresponding h nu then you make a chart of h nu and alpha. At what h nu what is the value of alpha? Because the value of alpha is very h nu dependent then you alpha h nu square plots against h nu.

Student: (( )).

Material thickness material thickness.

Student: (( )).

No, no. it is the material thickness.

Student: (( )).

Yes. Basically suppose if this is your material then it is the thickness of this material because you see that unless light is transmitted the detector will not be able to detect. So, if the thickness is very high that no light is coming out then you cannot detect basically then you cannot measure the band gap of that material using absorption spectroscopy.

Student: (( )).

Yes. The thickness of the material is constant. X is the thickness of the material which is constant.

Student: (( )).

For that specimen.

Student: (( )).

It is obviously sample dependent.

Student: (( )).

No, some of the some of the light will be absorbed before x. Obviously it is always there it depend it is very, very sensitive to the wave length of light; absorption is very very sensitive to wave length of light. So, some of the photons will be absorbed in the surface some of the photons will be absorbed in within 10 percent of x. Some of the photon will be absorbed within 23 percent of x, some of the photon will be absorbed within 80 percent of x. That is why you are calculating. Your monochromator at the output basically calculates that thing. What is the intensity at what wave length?

Student: (( )).

Band gap. Signature of the band gap because when gallium arsenide is there the maximum wave length which it can absorb is 1.43 electron volt and above maximum. What about the band gap of say energy of say 1.1 electron volt or 1.40 electron volt or say 1.42 electron volt. It will not it will not absorb but, it will absorb if have if you have some defect states inside the material. So, there will be signature in a surface states there are therefore there are dangling bonds some light will be absorbed.

So, there will be some absorption from the say x surface to the bulk there will be say some 10 percent, 20 percent absorption will be there. And, the detector will detect that light only, unless there is absorption then it will be a flat response. It will be a flat response but we want that some absorption takes place that is because we want to know that thing from that information we will calculate the band gap of the material. Ok. Yes.

Student: (( )).

So, may be that will be there. It will be there that is why some broadening takes place in photo luminescence also. Why the, why the photo luminescence peak is like this?

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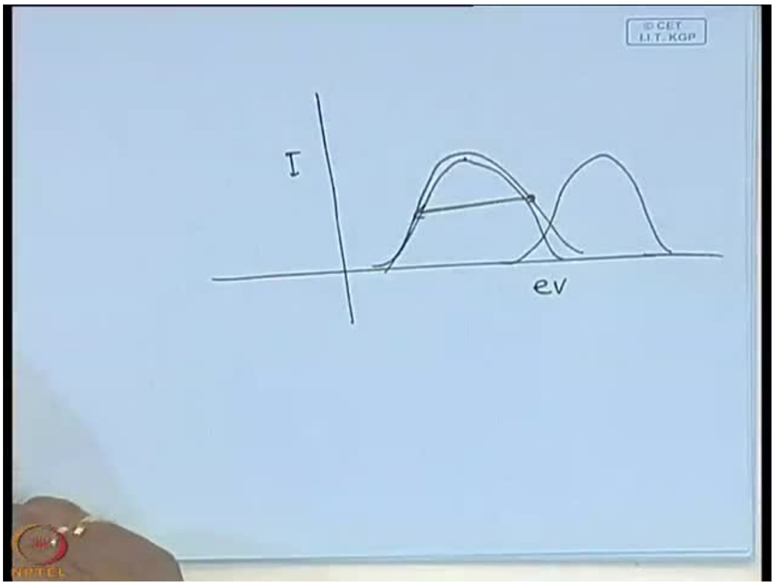

It is because of this broadening. Why the broadening is there? This because of various kinds of vibrations it is because of various kinds of vibrations and thermal phenomena that the broadening takes place. And, remember that the photoluminescence is exactly opposite to what we have learnt in the optical absorption. Absorption means light absorbs and the transmitted light is measured. In photo luminescence the emission of light from the material is detected using a detector.

Student: (( )).

No, there is not there is no appreciable time this is instantaneous almost. If there is a delay then that is not photo luminescence that is phosphorescence not photo luminescence, photo luminescence is instantaneous. You excite the material with photon source and immediately the excited electrons will jump to the valence band there by different kinds of emissions corresponding to band to band transition or band to donor transition or acceptor to band transition or defect to band transition. There may be different types of transitions the details of which we shall learn in our optoelectronic class in the next semester.

So, at that time, you will find that because of different kinds of transitions light will be emitted. And, that light is collected in a detector through a monochromator and we will get this type of a peak. So, in photo luminescence it is also it is intensity versus wave length or energy whatever be the case. And, the peak will be there that kind of peaks will there; that peak corresponds to the transition.

So, that is the difference between photoluminescence, and in photoluminescence also you can through a photoluminescence you can detect the band gap also, because band to band transition will give you the emission peak at the band gap, so that you can detect. Apart from the band to band transition, you can detect the defect levels, if you make it at low temperature. In low temperature, those defects will not be there, at room temperature those defects will be there.

So, by comparing the photo luminescence spectra at different temperature you can estimate the defect inside the material. Remember that there if there is no ionization there will be no defect inside the material. It is defect less unless it is ionized, when the electron and hole will be recombined at the defect level. If there is an electron or hole in the defect level, when there will be an electron and hole defect level if it is ionized only then. Otherwise there will be no electron and hole in the defect level and that ionization is not possible at low temperature. So, low temperature will get very sharp peak, free from any defect possibly. And, for a material it cannot be delta function for any structure it can be like laser or etcetera.

Thank you.