Processing of Semiconducting Materials

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Lecture - 1
Introduction to Electronics Materials

Good morning. Let us start our discussion on our course on electronic materials processing and device application. So, this is the course which will enable you to learn about the electronic materials and device. We all of know about different kinds of materials. Say the cement, concrete, bricks; those are also materials - those are used for building construction, but those are not electronic materials wood, steel. So, there are several materials which have their own applications, but you cannot use them for electronic device fabrication.

So, electronic materials are those materials which have some electrical property, and the main application of electronic materials is in the electronic device. So, if I am if I ask you to name some of the electronic device probably you will tell me that sir diode, transistor, fet, mosfet, light emitting diode, laser, solar cell all those are basically electronic device and the fabrication of those device is due to the electronic materials. So, before we begin we have let us have some idea about how the data is read or the data can be stored in an optical storage device. You all of have seen that optical storage device there is a CD or VCD or DVD, etcetera.

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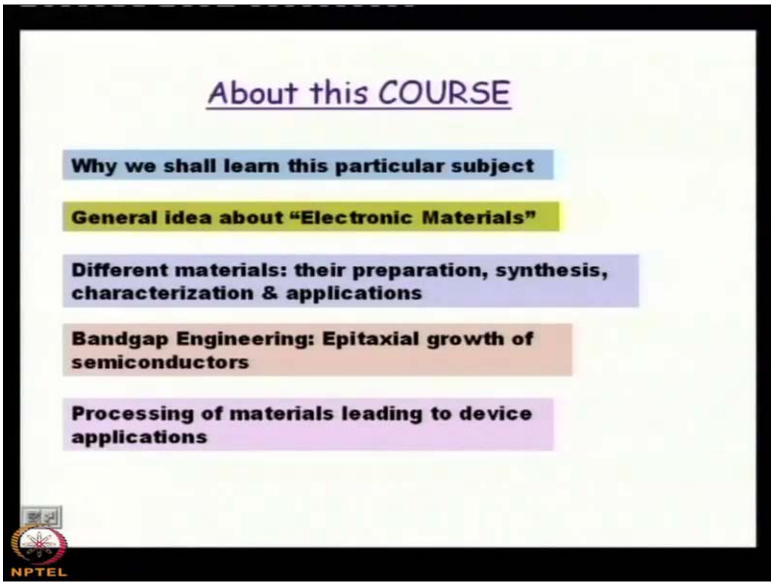

However, about this course I have some information for you why we shall learn this particular subject? Why electronic materials we shall learn? Then I shall give you some general idea about electronic materials, different materials their preparations synthesis characterisation and applications, band gap engineering epitaxial growth of semiconductors, processing of materials leading to device applications.

But remember that when I talk about that band gap engineering when I talk about band gap engineering, I shall introduce the nano structure devices, and nano materials, because you know that nano structure materials or the nano devices are very important devices in these days, so far us the research and application is concerned. So, obviously I should touch about that nano as well in this course.

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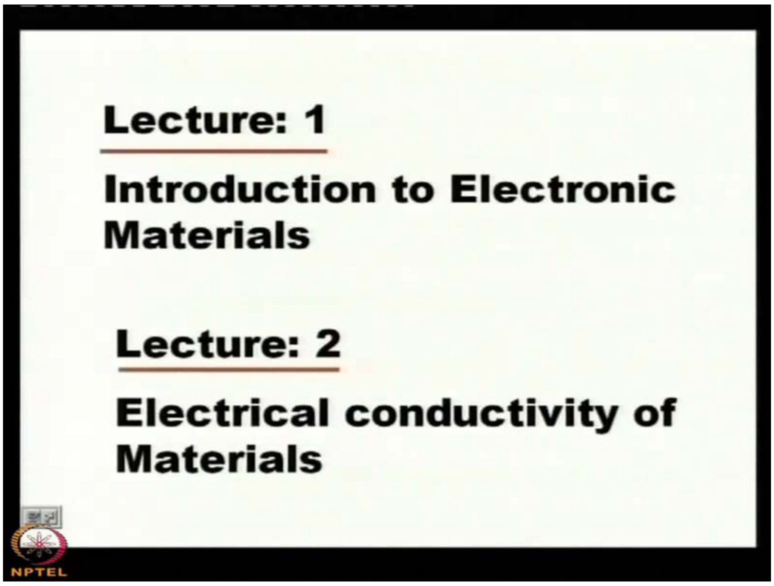

So, in my first lecture I shall introduce you about the electronic introduce about the electronic materials, and in my second lecture I shall give you the idea about the electrical conductivity of materials. So, as I am told as I have told you that let u start from the optical storage device, I shall give you 3 examples; one is optical storage device, second number is fiber optic communication, and third one is solar cell. Because these 3 electronic device or application is connected to the human civilization, and in present day communication system you know that the fiber optic communication has proved havoc.

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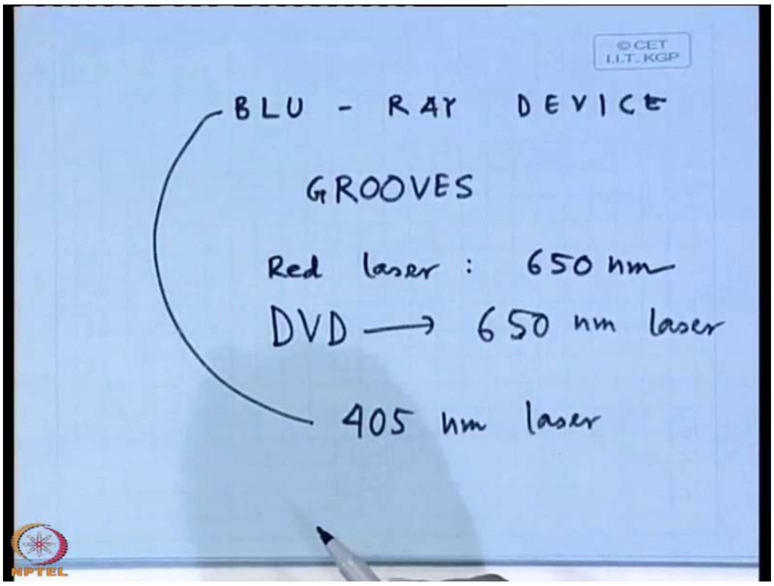

So, let us start from the optical storage device, you know that a optical storage device is nothing but a CD or DVD, another optical storage device which has been in the market is known as Blu-Ray device, Blu-Ray device, this is Blu-Ray device. So, I shall introduce this Blu-Ray device first. So, that you will be able to know why the electronic materials is very much important for human civilization, how a data is stored in a CD, can you tell me, how a data is stored in a CD or say in DVD. What is the mechanism?

Student: Sir, in the form of dot.

But how the dot is…

Student: Dot represents like a 0 1.

Yeah, but how that dot is encrypted in the CD.

Student: With the help of laser beam.

Yes, exactly I was very much keen to know that term laser. So, CD or DVD or that type of a optical storage device, you need one laser for writing or reading the data stored in it or to store in it. Say this is an optical storage device, this is a CD could you see, this is a CD and you see that in this CD there are many grooves; there are many grooves there are many grooves which were encrypted as the pits in the CD. So, many concentric circles you can find in a CD right if you see a CD, if you go inside it you will find that there are many concentric circles in it.

So, the circles are basically encrypted inside the CD. So, the main portion is the land on the land there are grooves which are basically constructed by pits which you have told that the pits are the main building block. Now, a laser is used to fabricate one pit inside to each one pit inside which can store either 0 or 1. So, these laser basically is a red laser these days, this is basically a red laser these days and whose wavelength is 650 nanometer whose wavelength is 650, because you know that when you talk about a laser it has a particular wavelength right for reading or writing in a DVD, you need 650 nanometer laser.

But so far as this Blu-Ray device is concerned, we can use 405 nanometer laser. What is the colour of this laser? 405, can you tell?

Student: (( ))

405 nanometer laser, what is the colour?

Student: Violet one.

Yes, it is blue violet type of thing right, and what is the advantage of using a blue laser instead of red laser.

Student: More data data can be (( )).

Yes, because you know that the wavelength is very much important, and when we talk about 650 nanometer, basically the wavelength is larger than the blue violet type of laser which is 405 nanometer. So, if the wavelength is larger what is the limit? Limit is the diffraction, so the so the pits will be of low dimension if you can use very low wavelength laser.

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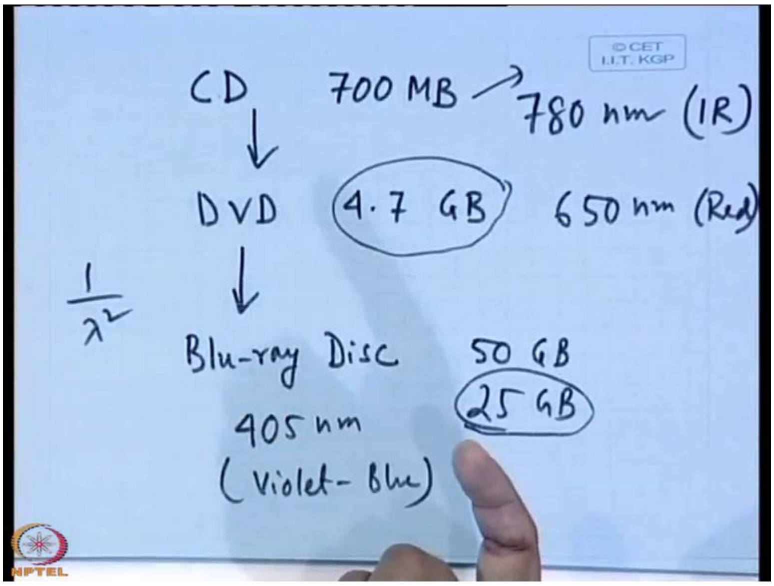

So, now I can give you the genesis of, I can give you the genesis of this storage device; first generation was CD right, what was the storage capacity?

Student: 700.

How much?

Student: 700 MB.

700 MB, 650 MB, 700 MB. So, let us take that it is 700 MB right, then DVD what is the storage capacity?

Student: 4.7 GB.

Right 4.7 GB for a single layer, if we use double layer it will be just double 8.5 GB, then the present generation storage disc is the Blu-Ray device, Blu-Ray disc; the capacity is 50 GB. Obviously for a double layer or 25 GB for a single layer right. Now, this 25 GB for single layer and 4 point say 7 GB for a DVD. So, it is almost 5 to 6 times higher in capacity. How it was possible the possible it was possible, because the electronic materials have travelled a long way, and now we are able to fabricate blue violet laser that was not earlier.

Earlier blue violet laser was not in the market people could not fabricate, because of some technological problem which we shall discuss in this course right. So, from CD to

Blu-Ray disc you find that enormous increase in capacity could be possible. Why it was possible, because as I told earlier thus because of the availability of the blue violet laser. Now, for 700 MB what people used for writing, what was the wavelength of laser do you know earlier what was the wavelength of laser which was used for the storing of 700 MB in CD.

Student: 6 (( )).

It is basically 780 nanometer 780 nanometer, and what is the wavelength colour of this wavelength, what is the colour of this 780 nanometer?

Student: Red (( )).

No, it is infrared, it is not red.

Student: Infrared.

Above 700, it is infrared, you cannot see through your bare eye unless we have some photo detector type of thing. So, this is basically infrared device, infrared laser infrared LED, then for DVD, I informed you it is 650 nanometer which is red, for Blu-Ray disc it is 405 nanometer which is violet or blu blu violet type of thing not a single colour. One thumb rule for the storage is that it is the storage capacity is almost inverse relation inversely proportional to the square of the wavelength inversely proportional to the square of the wavelength 1 by lambda square almost.

So, that means, if lambda is less storage will be...

Student: High.

High and also there is a square.

Student: More and more.

More and more high. How it was possible? It was possible, because of the availability of the material for the fabrication of blue and violet laser; that is the domain of electronic materials that we would like to such more and more materials for very fundamental type of applications right. That was possible, because of the advancement of electronic materials, because of various processing of electronic materials we are now in a position to fabricate blue violet laser, and the direct consequence of that discovery is that we can increase the storage capacity in a optical storage disc right.

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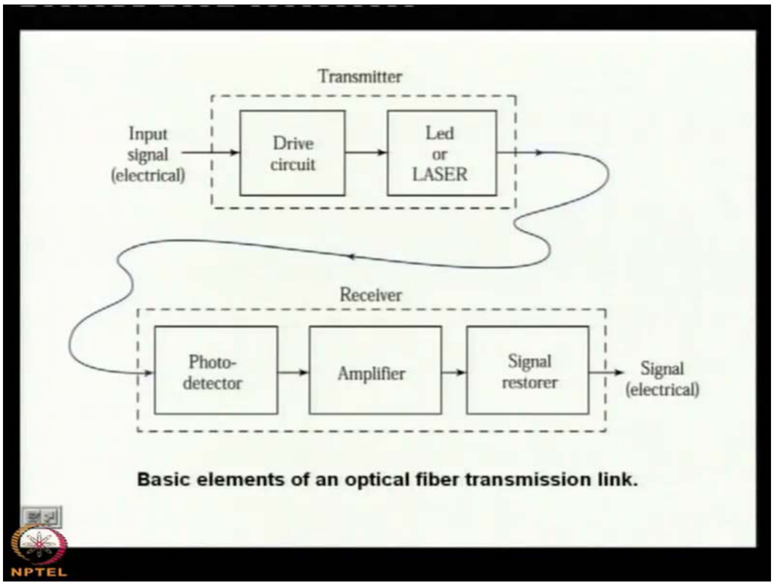

Now, let us take another example; that is related to the fiber optic communication that is related to fiber optic communication. You see that in fiber optic communication generally there are two generally there are two important device; one is the transmitter, another is the receiver; one is the transmitter, another is the receiver. I do not know one is the transmitter another is the receiver. So, in the transmitter you see that there is two main circuit; one is the drive circuit another is the LED or laser circuit. One is the drive circuit, another is the LED or laser circuit, what happens in fiber optics communication?

Suppose you would like to talk to your friends in Delhi or in US. So, what is the mechanism? The mechanism is that you are telling something that audio signal is first converted into electrical signal by means of a transducer.

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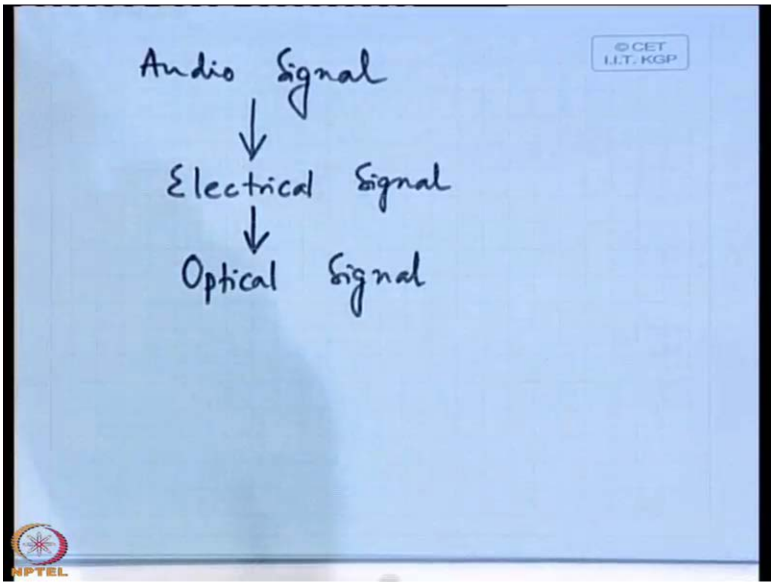

So, you have a audio signal, that is converted to electrical signal by means of a transducer, can you name which transducer is used in this case.

Student: Microphone.

Microphone. So, microphone is a transducer which is used to convert the audio signal into electrical signal. So, first the audio signal is converted into electrical signal. Then that electrical signal is converted into optical signal, this electrical signal is converted into optical signal, this optical signal travels through fiber optic or optical fiber. So, there is a fiber optic channel lying down the earth right, and through that fiber optic cable; these optical signal, these optical signal passes through that optical channel to the destination right.

So, this conversion of audio signal into optical signal up to that part, up to that part it is the job of the transmitter. So, when we say that a transmitter transmits a signal basically first your audio signal or say you have a video signal, it is converted finally into optical signal. Because fiber optic only supports travelling of optical signal light, and you know that it is the total internal.

Student: Reflection.

Yes. So, by the method of total internal reflection light travels from one place to another by means of fiber optic cable.

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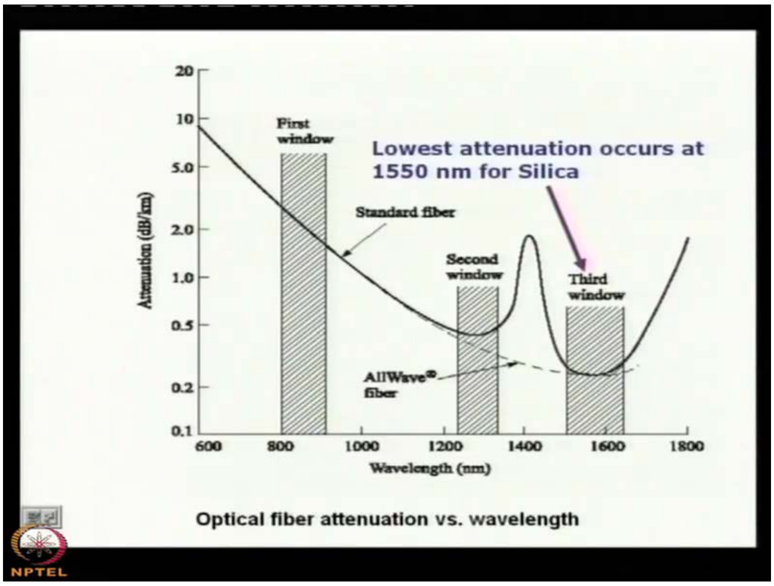

Now, if I see you if I show you this graph. What is there? You see that it is in the y axis I have plotted the attenuation in decibel per kilometre and in the x axis I have plotted the wavelength in nanometer. So, it is a attenuation versus wavelength curve, it is a attenuation versus wavelength curve.

Now, what is attenuation?

Student: Loss.

Loss attenuation is exactly opposite to the amplification right, what we mean by amplification, it is a gain in attenuation it is opposite to the amplification it is basically loss, so loss of signal. So, when the signal travels from one place to another by fiber optic cable; obviously, there will be loss of the signal. Now, if I look into this curve you see that if I look into this curve, you you see that there are 3 windows; one is first window it is around 800 nanometer, you see in the x axis what is there for the first window 850 nanometer around. I am not I have not shown one particular value right, second window it is basically within 1200 to 1400 and the exact value is 1300, it is 1300 or 1.3 micron.

And third window is around 1600 the exact value is 1550 micron nanometer, sorry. So, this is first window you see that in the first window it is around 850 nanometer, then there is a second window it is 1330 nanometer basically 1300 nanometer and it is 1550 nanometer the third window.

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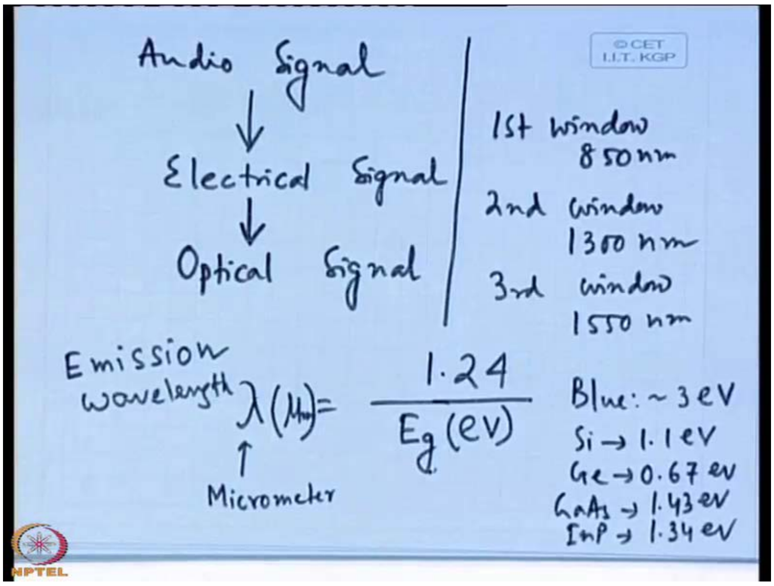

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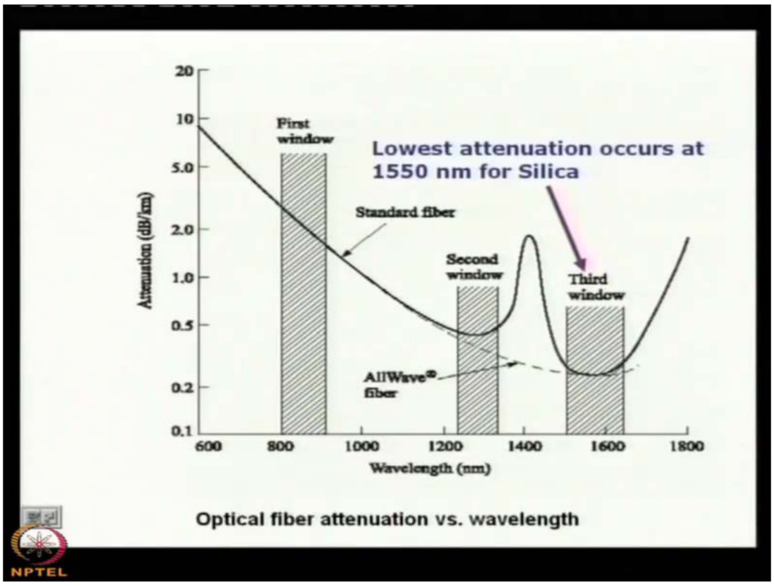

So, let me write down the windows. First window, second window, and third window; for first window it is around 800 nanometer, say it is 850 nanometer. And in micron what is the value 0.85 micron 850 nanometer means 0.85micron; that means, 8500 angstrom. Second window it is 1300 nanometer and the third window is 1550 nanometer right.

So, we have 3 window, and these 3 window you see that why those are known as window, because the attenuation is minimum on those 3 wavelength. The attenuation is minimum. What was the lowest attenuation? It is in the third window you see it is in the third window, and the maximum loss was in the first window if you compare the 3 windows; if you compare the 3 windows the lowest loss is in the third window.

You see that the lowest loss is third window, it is almost 0.3 decibel per kilometre have you seen it is or almost 0.3 decibel per kilometre. And the value in the second window it is almost 0.5 decibel per kilometre, and here it is almost two decibel per kilometre right. So, there are 3 windows; first generation fiber optic communication used the first window, what is this window? Where the loss is minimum, whose loss it is? The loss is of the signal when it travels through a silica fiber.

So, that is the loss of a silicon fiber when a signal travels through it, and it is a very much function of the wavelength. So, colour of the light is very important which colour of light is travelling through the fiber optic channel. For first window it is two decibel per kilometre, for first window it is two decibel per kilometre. Why we have agreed to that because we do not have any other material using which we can fabricate a laser which will give you the emission of 1300 nanometer or 1550 nanometer.

Let me explain let me simplify this thing, I have talked about the optical signal. Now, this optical signal is coming out from where it is coming out from the light emitting diode or the laser. Do you know the full form of laser? It is light amplification by stimulated emission and radiation right. So, this optical signal is coming from the light emitting diode or LE or laser, it has a characteristics wavelength a laser or a light emitting diode cannot emit any colour of light can it, it cannot emit any colour of light because of the material constant, because of the material constant.

Now, what is the material constant? The material constant is its band gap, the material constant is its band gap. In the next class I shall show you how the light emits from a semiconductor, because almost all light emitting diode or laser or that type of device is made from semiconductor, and these days polymer and ceramics is also used, but the major share is the semiconductor. Electronic device means it is made of semiconductor. Why the polymer or the ceramics are not used that I shall also discuss in later events.

Now, the light with which is coming from a material say if it is band gap is E g. What is the unit of band gap electron volt, it is very small. So, joule or other type of energy unit is not used only the electron volt is used. So, if the band gap is in electron volt and the wavelength of emission is in micron, this is mu m micrometer, this is lambda - lambda is in micrometer m i c r o m e t e r, which is denoted by mu m. It is the emission wavelength, it is emission wavelength. And this emission wavelength is related to the band gap of the material by this expression lambda equals to 1.24 by E g, if you take E g in electron volt and lambda in micron.

So, if you know the band gap of a material you can calculate the emission wavelength from it right, what is the band gap of silicon?

Student: 11 1.1 (( )).

Yes, the band gap of silicon is 1.1 electron volt, so if you put 1.1 electron volt here. So, what is the emission from silicon? Lambda is equals to 1.24 by 1.1; that means, 1.1 micron almost; that means, 1.1 micron. Though silicon is not used for fiber optic communication or any other kind of LED or laser fabrication that is a different story I shall tell you also, silicon is not used for any light emitting device silicon is not used.

Silicon is a very good material for electronic device particularly for IC technology, the whole chip fabrication is based on silicon, the whole chip fabrication is based on silicon, because of the advancement in the processing technology of silicon. And it is very inexpensive also, that is why the computer is very cheap these days, it is because of the silicon and the processing technology of silicon. Silicon is a electronic material remember, whole computer industry is either some plastics are there, like your cabinet etcetera or the chips are there which are all made of silicon that is also electronic material.

So, if you know the band gap of a material, you can tell us about the wavelength emitting from it. So, can any method any material be used for any kind of emission, is it possible? Is it not possible. Suppose you need one material which will give you blue emission. So, what should be the band gap of the material, can you calculate? What should be the band gap of the material if you want blue emission from it.

Student: 1.24 by lambda.

What is the value?

Student: One.

E g will be 1.24 by lambda, and what is the value of lambda for blue?

Student: (( )).

Say it is 450, let us take one value it is 450 nanometer. So, in micron it will be 0.45 micron. So, 1.24 by point…

Student: 4 5.

4 5, then what will be its value? It is around 2.89 say around 3 around 3. So, if yes; obviously, all in electronbild in our discussion in electronic material class, the band gap will be always in electron volt we do not use any other unit, because that no possible. So, for blue we find that its around 3 electron volt right, what is the emission of silicon? It is what is the band gap of silicon?

Student: 1.1.

1.1 electron volt. What is the band gap of germanium? 0.67 electron volt, band gap is very precious, its value is very precision, you have must have you must know about these that you cannot tell that the band gap of silicon is 1.2. Though 1.1 and 1.2 is almost equal even then it is it must be precisely reported 1.1 electron volt, the band gap of germanium is 0.67 electron volt not 0.7 electron volt; 0.67 and 0.7 is almost same, but even then in semiconductor these can cause havoc these difference.

So, germanium is 0.67 electron volt, another material is gallium arsenide, it is what is the band gap of gallium arsenide?

Student: 1.4.

One point.

Student: 4 3.

Very good, indium phosphide indium phosphide, what is the band gap of indium phosphide? 1.34 electron volt. So, what we see from this table, we see from this table that silicon germanium gallium arsenide or indium phosphide, they cannot be used for blue emission, why? The blue emission is 3 electron volt, and the band gap of these those materials is well below 3 electron volt; well below 3 electron volt right. So, for blue type of emission you need any material having band gap around 3 electron volt; those materials are known as wide band gap material, those materials are known as wide band gap material.

So, now when we tell about that the first window is 850 nanometer, what is the band gap corresponding band gap of 850 nanometer, it is 1.24 by 0.85 and what is it value?

Student: Around one 1.5.

Around.

Student: 1.5.

What is the value?

Student: 1.5.

No, it is less than1.5.

One (( )) two.

Say around 1.4, 1.3, 1.5. So, you see that it is nearer to gallium arsenide, you see that it is nearer to gallium arsenide 1.34 3 electron volt. So, the first generation - fiber optic communication using the first window of 800 to 850 nanometer the material used was gallium arsenide or aluminium gallium arsenide for fabrication of light emitting diode which is known as the fiber optic source.

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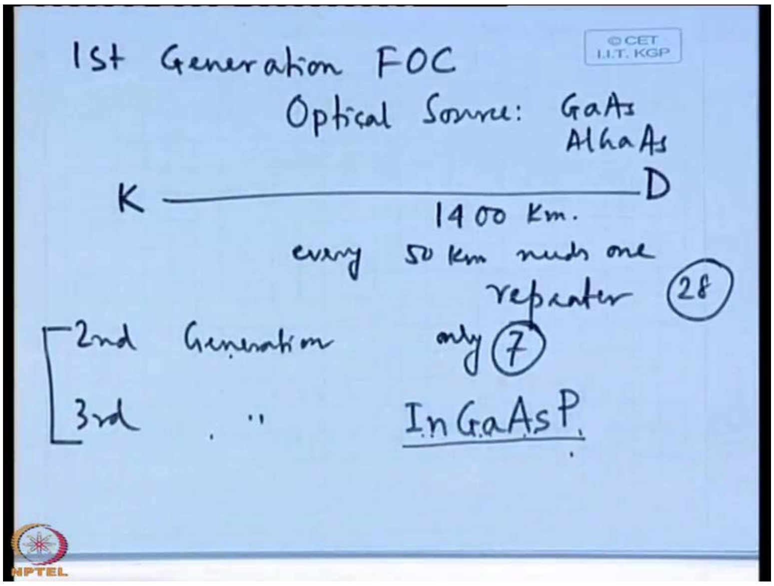

So, first generation fiber optic source; first generation fiber optic communication optical source using gallium arsenide, aluminium gallium arsenide; gallium arsenide and aluminium gallium arsenide is widely used for the fabrication of optical source. This optical source is basically light emitting diode on laser right, then the loss is very high you see that the loss is very high. Here you would see the loss is almost two decibel per kilometre, then people searched for searched for another material which will give you the emission around 1300, because in 1300 the attenuation is lower than two, it is almost 0.5. That means, one fourth type, one fourth time of the original value of the first window.

The attenuation is one fourth of the first window attenuation. So, what is the implication of this one fourth, why not tell that it is one fourth. So, what is the implication of one fourth? Implication of one fourth is that the signal will be will attenuate, the signal will be attenuated. And if it attenuates at say after ten kilometre for first window, for second window it will be how much? 40 kilometre its almost four times larger right, I repeat that for first generation fiber optic communication people used gallium arsenide aluminium gallium arsenide related fiber optic source, and the attenuation is attenuation is two decibel per kilometre.

Now, if we can reduce the attenuation. So, we have to use the second window or the third window; for second window the value is point 5 decibel per kilometre, it is 0.5 decibel per kilometre its almost one fourth of the first value first window. So, now, say this is Khargpur and this is Delhi, what is the distance 1400 or 1500, 1400 say kilometre; for first generation fiber optic cable because of the signal attenuation, you have to use repeater station at certain intervals, why the repeater is required?

Student: (( )) maintain the loss.

Yes to compensate the loss of the signal. So, that it can reach to its destination, suppose earlier every 50 kilometre needs one repeater, every 50 kilometre. So, how many repeaters was required?

Student: 28.

20.

Student: 8.

8, almost now for second generation it is 4 times. So, every 200 kilometre needs one repeater, how many repeaters were required?

Student: 7.

7. So, drastically improvement of the signal right, so only seven repeaters are required. So, if you can reduce the number of repeaters then what is the gain? Gain is....

Student: (( )) cost.

Cost; obviously, the gain is cost, you can reduce the cost exponentially. And remember that, because of those factors fiber optic communication is very cheap these days, even we can talk to a friend in Delhi 60 paisa per minute. That was possible, because of this revolution remember. Second generation only 7 here 28 repeaters were required, that is an example. Now, if you can use the third window, for third window what was the value? It is 0.3. So, even less. So, instead of 7 repeater, now you need 4 to 5 repeaters right. So, that is the advantage of using the third window or second window; the second window I show you that for second window the value was 1300 nanometer and for third window it was 1550 nanometer.

So, what is the material can gallium arsenide or aluminium gallium arsenide be used for the fabrication of fiber optic source, which can operate in 1300 or 1550 nanometer, no;

why? Because of the limitation of their band gap, because of the limitation of their band gap. Now, you just calculate what should be the band gap of the material, if I seek an emission 1550 nanometer; that means 1.55 micron. So, you just calculate 1.24 by 1.55.

So, what should be the value?

Student: Around 0.7.

Yes, around 0.7 electron volt, and what is the material which has this kind of band gap?

Student: Germanium, Germanium.

But that is another problem Germanium is an indirect band gap semiconductor, and indirect band gap semiconductor cannot be used for making optical sources. So, you cannot use germanium; another problem is that the precise value of germanium is point 6 seven electron volt, but here you will find that it is 0.78 electron volt. So, 0.78 and point 6 seven is not similar in semiconductor industry, then you can use.

Student: Silicon.

How silicon it is 1.1 electron volt, 0.78 electron volt is the precise value for 1550 nanometer, no such material is available in nature. Naturally no material is available which will have 0.78 electron volt or 0.75 electron volt band gap right. So, you have to go for what?

Student: Search of material.

Yes, search of materials and people have searched, they came out with one very important material which is not a elemental semiconductor, it is a compound semiconductor of 3 5 nature; 3 5 means the elements of those materials belong to group 3 and group 5 of the periodic table when I talk about 2 6, 3 5; that means, it is related to your periodic table groove right.

So, for this 1550 nanometer for second generation and third generation, for second generation and third generation – indium, gallium, arsenide, phosphide; indium, gallium, arsenide, phosphide. So, this is a compound semiconductor belongs to group 3 5, why? Because you know that indium and gallium belongs to group 3 of the periodic table, and arsenic and phosphorous belongs to group 5 of the periodic table. So, basically this is a 3

5 semiconductor, and this 3 5 semiconductor is used for second generation and third generation why? Because the band gap can be tuned to 0.75 or 0.78 or 0.8 electron volt which is required for 1300 or 1550 nanometer fiber optic sources.

So, this is another material which is very useful and the evaluation of materials came in this manner when some requirement was there people searched, and they came out with the solution; and the solution for this fiber optic communication is indium gallium arsenide phosphide. Now, it is very mature technology and the loss is also very less you see, the loss is also very less and since it is a very mature technology and loss is also very less. So, people has been using indium gallium arsenide phosphide for the fiber optic sources, and that is why the fiber optic communication is now inexpensive, because of the sources in fiber optic communication which is required in the transmitter side.

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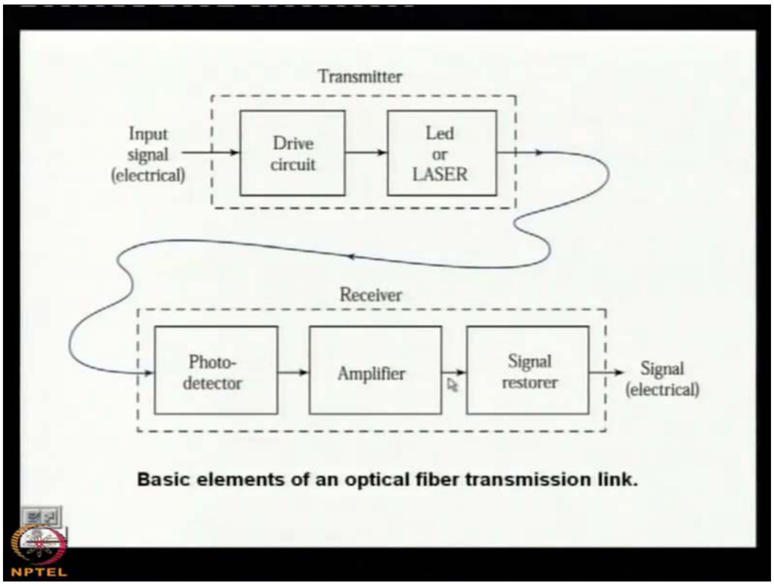

Another thing you know that the receiver portion, I was talking about the transmitter portion now this is the receiver portion. You receiver portion you see that the light comes by this fiber optics cable by the process of total internal reflection in the optical fiber. In the receiver station you see that there is a photo detector right. So, remember first we converted our audio signal into electrical signal and then to optical signal, now we shall do the reverse thing, because if some optics come in front of you can you say what is their inside the light? You cannot say we are not, so intelligent that just seeing the light we can say that my friend is calling, and he is asking about my health, can you see by that light? Not possible.

So, basically we have to convert that optical signal into audio signal. So, first that optical signal will be converted into electrical signal, which is done by this photo detector which is done by this photo detector. So, photo detector basically absorbs light it receives light and proportional electrical signal emits from it, and proportional electrical signal it converts optical signals into electrical proportional electrical signal for LED or laser it converts electrical signal into…

Student: (( )) optical signal.

Yes, optical signal, and the reverse happens in photo detector. So, for electronic material the photo detector is also very important device, this photo detector is nothing but an electronic device which can convert your optical signal into electrical signal right. So, two at least at least two or three device we are familiar with for from this discussion; one is LED - light emitting diode, another is laser, third one is photo detector.

So, in our electronic material class we shall discuss the details of the materials how those materials are processed, how the materials can be made it can be synthesized then the characterisation of the materials, how the materials are characterised? How do you know? That it is indium gallium arsenide phosphide, how do you know? That it is silicon. Who will tell you? What are the characteristics characterisation tools using which you can tell that sir this is this material. And using the those materials we shall go up to the point of device fabrication. How we have complete device say light emitting diode or a solar cell can be fabricated that can be done in this class.

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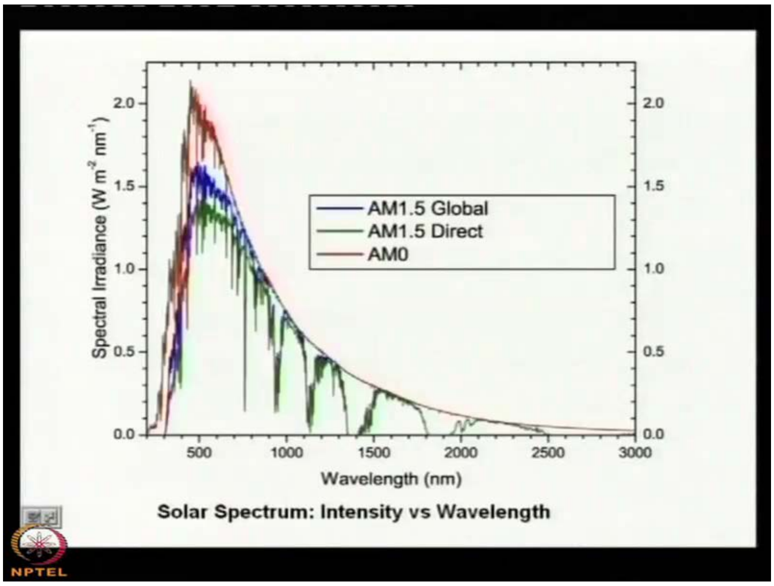

Next example is the solar cell; 3 examples I am giving; one was related to your, what? Optical storage device where I have shown you that from infrared 780 nanometer to 650 DVD, 2405 Blu-Ray right capacity from 700.

Student: 700 MB to...

Yes from 700 MB to...

Student: 50 GB.

25 GB atleast.

Student: For single layer.

For single layer, yes that is also single layer 700 is also single layer, and 4.7 GB DVD is also for single layer that is not for double layer. So, if we compare the single layers then Blu-Ray is 25 GB that one example. Second example was fiber optic communication, the first generation people used gallium arsenide, indium gallium gallium arsenide aluminium gallium arsenide, it is because of the constant in wavelength which comes from the band gap.

So, band gap is the constant basically, you cannot change the band gap of the material you cannot, band gap is the intrinsic property of that material. So, if you would like to change the band gap then you will have to go for the band gap engineering; that is there in this course I shall show you how the band gap engineering can be done for materials? You can play with the materials, you can do many materials you can process many materials having band gap as per your choice; that is band gap engineering that have limitation also that we shall discuss.

So, let us come to this point of solar cell, you know that what is solar cell; solar cell is basically.

Student: A electronic device.

An electronic device, which converts.

Student: (( )) light into (( )).

Solar radiation or light into…

Student: Electric potential.

Electric or basically current or voltage, final output is current or voltage. So, it converts light into electricity in broad sense it converts light into electricity, and you know that the solar cell is basically a pollution less device right, no input is required, because of the sun ray or the sunlight solar because of the solar radiation. You need not to give some energy in it all other device for getting energy say electricity, you have some input what kind of input? It can be turbine, it can be diesel using which you can get electricity right.

So, various thermal or hydroelectric power stations we have seen that a large amount of cost is involved, and also pollution is involved, but for solar cell you do not have any input energy, because of the sunlight it is there without any cost anything you can use it. Just put your solar cell on the roof top; it will absorb sun ray and it will convert solar radiation into electricity. And you use it absolutely there is no problem, but if you see from this diagram that the spectral irradiance versus wavelength curve, it is basically a spectral irradiance versus wavelength curve.

It is solar spectrum and you can find that you can find that these from 500 to say it is 500, 600, 700, 800, and here it is four 400, 300. So, basically from 300 to 800, the intensity is high from 300 to 800, the intensity is very high. What is AM1.5, AM0? It is air mass, we shall discuss these things when we shall go deep inside the solar cell theory, this is air mass for a particular direction of the sun.

So, this light we want to absorb, this light we want to absorb, but the absorption is also an intrinsic property of the material; absorption is also an intrinsic property of the material. It depends upon the band gap of the material, it depends on the band gap of the material, you cannot name one single material which can which can absorb this whole solar radiation; that is not possible from 300 nanometer to 800 nanometer it is not possible, why? Because of the band gap.

And in my next class I shall show you those things, how it actually happens, but let us assume that one single material cannot be able to absorb this whole radiation. So, various kinds of materials are required. So, for solar cell fabrication our basic aim is to absorb as much solar radiation as possible to absorb as much as much solar radiation as possible, we see the absorption of 300 to 800 basically. So, one single material is not possible.

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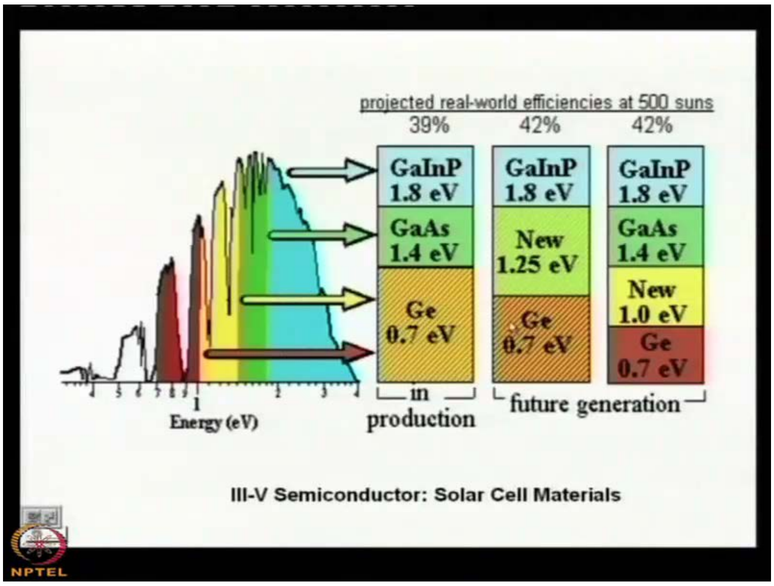

So, many materials are involved you see that in this view graph I have plotted the 3 5 semiconductor energy versus intensity, the left one - this one is basically the solar spectrum which I have shown in the previous view graph. And this is germanium, gallium arsenide indium gallium phosphide, you see that the band gaps are given here, it is 0.7 not exactly point (( )) 0.67 then gallium arsenide 1.43, then indium gallium phosphide is 1.78 electron volt.

So, that the efficiency becomes 39 percent is quite high, for silicon solar cell what is efficiency? The theoretical efficiency is 18 percent and in actual it is 11 percent for 3 5 semiconductor it is 39 percent or if you can use the new material etcetera which is proposing. You can even go to higher efficiency upto 42 percent. Where these solar cells are used? These are very costly, where it is used? It is used in satellite application; in satellite these solar cells are used, the whole satellite runs by solar cell. The main power source is the solar cell and there very high efficiency solar cell is required, that is why 39 percent, 42 percent we are talking about.

But you see that this fabrication is not very easy thing, here the fabrication is not very easy thing, see 4 3 materials are involved; one is germanium, another is gallium arsenide, third one is indium gallium phosphide; they have different band gap and so they have different lattice constant.

Student: (( ))

Yes, but fabrication of layer is not very easy task, because of the constant is lattice parameter that we shall discuss. So, for solar cell also you see that there is a scope for new you see that this is new 1.25, it is new one electron volt.

So, new materials are involved. So, there is immense scope for electronic materials even we can search for new and newer materials for some specific applications. So, that is why the implication of electronic material in our day today life is very much right, one thing you must remember that electronic materials are those materials which support the conduction of electrons in it, which supports the conduction of electron in it. That means, which can carry current, some electrical properties are there in the material and that is the main functionality of those materials in electronic materials.

So, let us conclude this class what we have learnt from this class? We have learnt from this class that there are scope for electronic materials, there are some newer materials we have discussed, and in human civilization many materials are involved; steel is also very important material, but that is not electronic material. Wood is also very, very important material, rubber is also very important material, plastic is one of very important material, concrete cement bricks are also important materials, but those are not electronic material; for specific electronic device application in our day today life we must have electronic materials and those are basically semiconductor in nature though polymer and ceramics are also used in some specific cases which we shall discuss in later stage.

Thank you.