Processing of Semiconducting Materials
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Lecture - 26
Characterization – 1

Till now we have concentrated our discussion on the fabrication of the materials and different kinds of structures.

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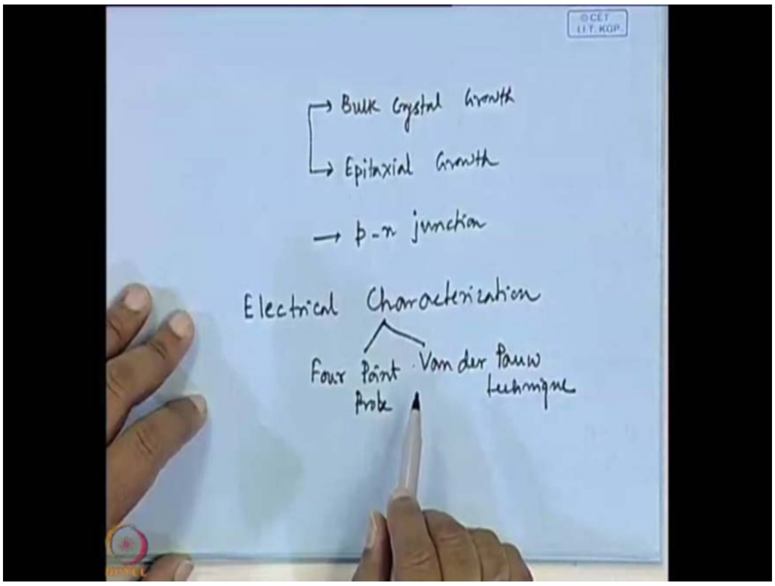

Say if you recollect, we can say that first we have started with bulk crystal growth, then we have concentrated our discussion on epitaxial growth of different materials. So mostly we have concentrated on these two aspects; one is bulk, another is the epitaxial crystal growth. Now after the growth is over or say in some cases, we have even grown the p-n junction as a test case.

So in all such cases, we need to characterise our sample, because how do you know? The properties of the grown epitaxial layers or the bulk crystal, unless we characterise it. Since this is an electronic material plus so we should concentrate our discussion on the electrical characterisations of material, because these all materials are used for electronic applications. So that is the reason, no mechanical testing or thermal testing is required for our material, because these are not the material to be used for any mechanical purpose, unlike in ceramics or polymers.

Therefore we shall concentrate our discussion on the electrical characterisation of materials. Now, so far as the electrical characterisation of materials is concerned, there are two ways using which we can characterise it; one is by the method of 4 point probe, another by van der pauw technique, van der pauw technique. Now using any of the techniques, basically we can characterise the resistivity of the material, right. That we have performed in your last class also, the resistivity of the materials. Now, once you know the resistivity of the materials, then the other properties of the material namely the carrier concentration or the mobility of the material can be calculated.

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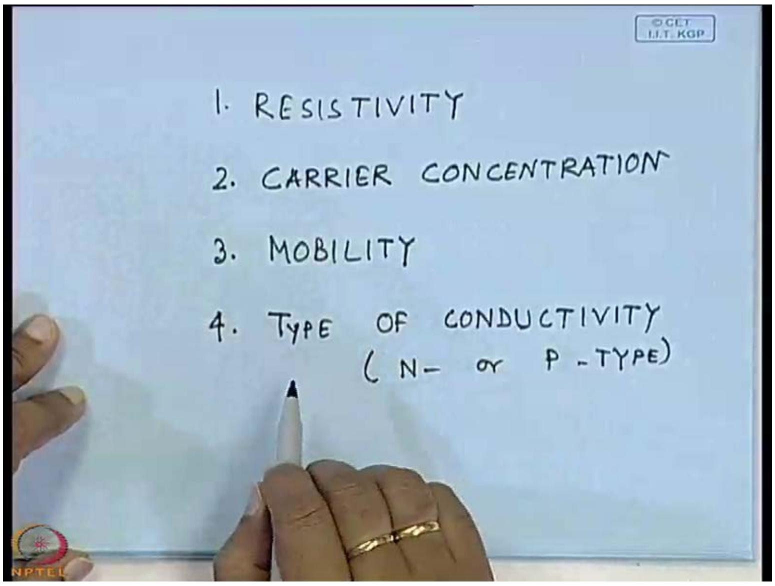

So, what are the aspects that we would like to characterise? One is the resistivity; number 2 is the carrier concentration; number 3 is the mobility; number 4 is the type of conductivity; type of conductivity means, whether it is N type or P type. So, these are the four basic characterisations that we follow after making a material or once the material is grown. Then these are the properties that we would like to study of a particular material; resistivity, can you know that? Where resistivity and the conductivity is the same thing only that, one by resistivity is the conductivity.

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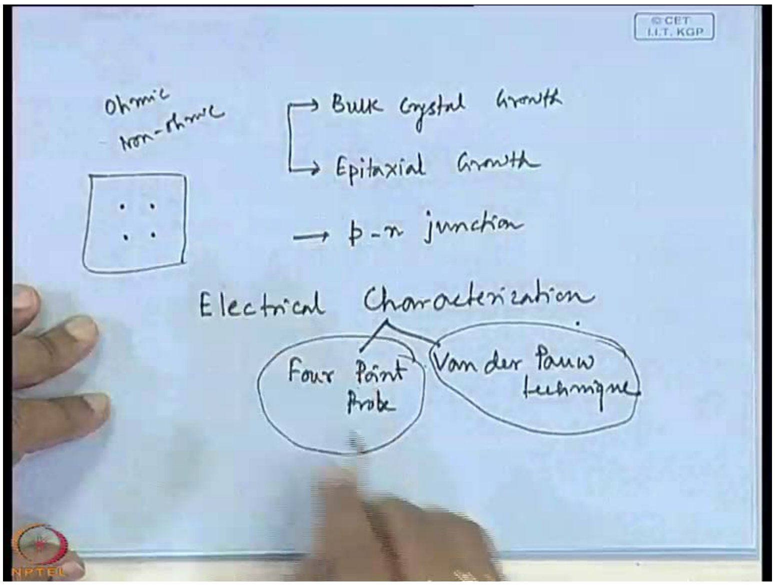

So as discussed earlier, that this electrical for electrical characterisation, either we follow the 4 point probe or we follow the van der pauw technique. Now, what is the difference between these two techniques? What is the difference between those, these two techniques? Is there any difference? When we shall use 4 point? When we shall use the van der pauw technique? The main difference between these two techniques is the contact in 4 point probe, we need not to make any metal contact on the sample. It is basically contact by pressing; it is basically contact by pressing as the name implies 4 point, that means there are 4 platinum or gold needle like contact, which is pressed on the surface of the sample, right.

So it is basically a press contract and I shall show you the attachments, using which you can contact by means of pressure; just a small pressure because, it is connected with some spring attachment. So it can adjust itself, but for van der pauw technique; you must have ohmic contact on your samples and when we talk about the ohmic contact. It means, first you take the sample, you clean it, then you make 4 metal contacts on it; 4 metal dots.

Suppose if this is your sample, you make 4 metal dots of say one millimetre diameter and these metal dots are thermally evaporated, on the surface of the material to be characterised. So if you want to characterise say this material, say this is one material. It want to characterise it, first make some 4 gold dots like this; then you connect copper wire etcetera and use the formula for the measurements of the resistivity, using van der pauw technique so ohmic contact is required.

So when we talk about ohmic contact, there must be some other contact then; otherwise, why we are telling that is ohmic contact. That means there may be non-ohmic contact as well there is no guarantee, that a metal and a semiconductor will provide you all the time ohmic contact, not necessary. The contact can be ohmic, it can be non-ohmic in nature; also depending on the work function of the metal and the semiconductor, that we shall discuss in a separate lecture. Whether is very important thing, when the contact will be ohmic; when the contact will be non-ohmic. Generally by non-ohmic contact, we understand it is a schottky contact, it is a schottky contact.

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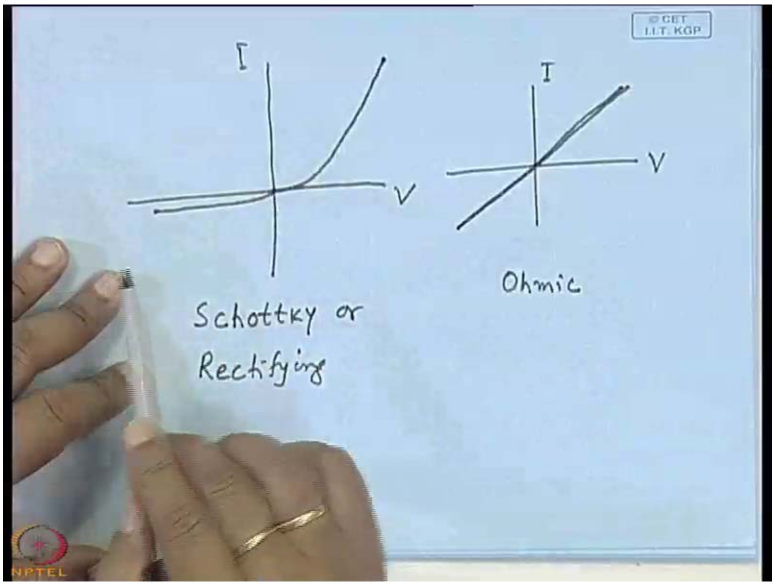

So that means for ohmic contact, the current voltage characteristics we will follow this kind of a variation. That means, it is perfectly linear on both sides of the origin. When the positive voltage is applied, positive current will be available; when negative voltage will be applied, negative current will be available with the same amount, same amount of current; same proportion, same amount of current we shall get on both the directions. So then we can say that it is a ohmic contact.

So this is the characteristic of ohmic contact and if it is not a ohmic contact, then the characteristics will follow such kind of a curve, which is known as the schottky contact or the contact or the rectifying contact; this is I V characteristics and in the reverse bias, small amount of reverse current will be made available. So this is these are the 2 contracts, which is ohmic contact, this is non-ohmic contact it is known as basically schottky or rectifying contacts. Why it is known as rectifying contact? Because you see that, this I V characteristics of a metal semiconductor assumes the form of a rectifier diode; because, that is the characteristics of a rectifier P N junction diode; in forward bias, it will allow current to flow, but in the reverse bias; it will not allow the current to flow.

So the current will be uni direction, current will be available in uni direction, directional, direction only. That means in the forward bias only the current will be available. That is the rectification property, this phenomena is known as the rectification. Using this property a c is converted to d c. So this van der pauw technique, for this van der pauw technique you need ohmic contact; for 4 point probe, you need not to make any ohmic contact. So that is very important thing, another important aspect of these 2 contact is that, as we shall discuss; you will find for 4 point probe, your sample is regular in nature, the shape must be regular in nature.

That means better if you can use a very thin slice of large diameter material. Why? That we shall discuss in detail, but in van der pauw technique, such kind of specific shape of the material is not required. So these are the main 2 differences between the 4 point probe and van der pauw technique. Remember that, using your 4 point probe or van der pauw technique, only we shall be able to measure the resistivity of the material, not any other thing.

The rest of the properties or the parameters can be evaluated by Hall Effect measurements, not by van der pauw or by 4 point probe, but for Hall Effect measurements you need the van der pauw configuration. That means if you want to make some measurements using Hall Effect, then you have to take the sample; you have to make ohmic contact in it, what you have done in case of van der pauw technique and then you have to measure. So that is why we say that for Hall Effect measurements, we always follow the van der pauw configuration; not the 4 point probe configuration. So these are the differences... Now for 4 point probe you see that, this is the sample of diameter d and the thickness is w (( )).

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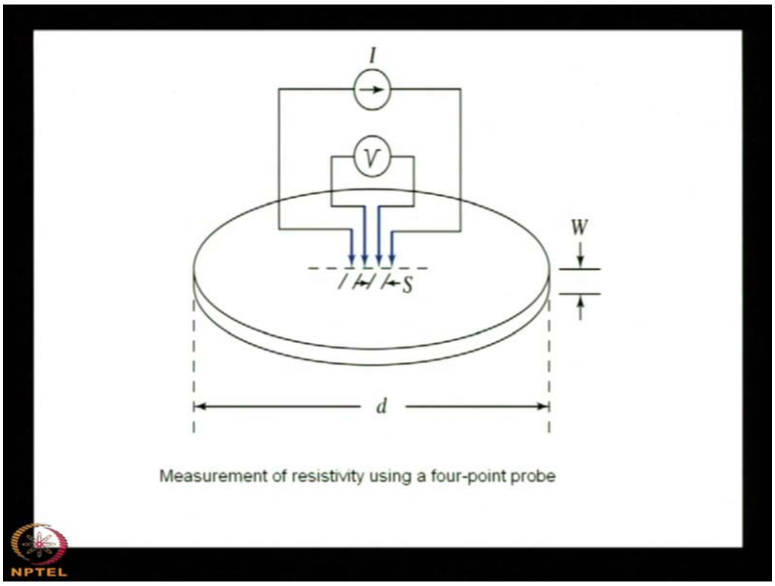

Then you see that 4 probes are there, this is a needle like probes; 1 2 3 and 4. Here I have shown like an arrow, so this is basically a needle type of material, made of either platinum or gold and it is placed on the surface of the material. You see that, between the 2 outermost probes, this is one outermost probe; this is another outermost probe, between these 2 outermost probe, a current is applied from the constant current source and the corresponding voltage is measured between the 2 inner probes.

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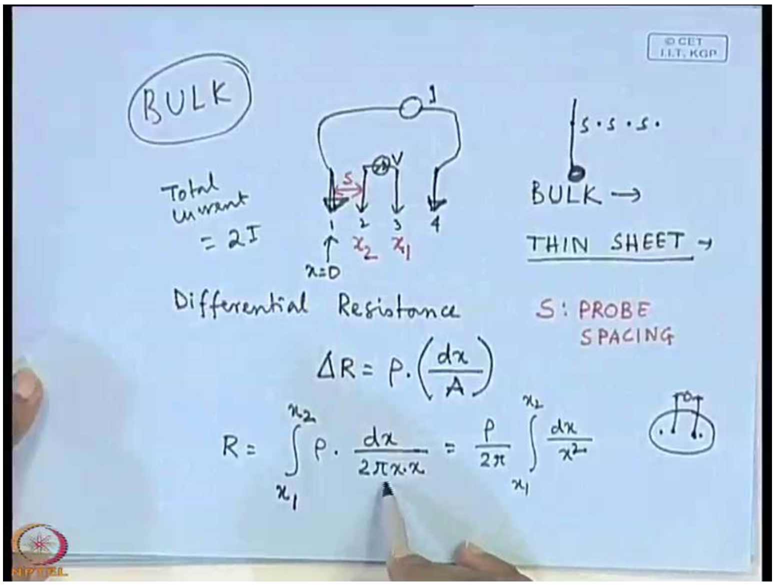

The potential differences between the 2 inner probes were measured using a voltmeter and the current is supplied between say 1 and 4. If I consider it as like this, say this is 1; this is 2; this is 3 and this is 4, these are the 4 probes. So current is between this 1 and 4 and voltage is between this 1 and 2; this is the configuration for the measurement of the 4 point probe. Under such a situation, what will happen that we can calculate. There may be 2 cases, one may be the bulk case; another is the epitaxial layers because, in semiconducting or electronic materials these 2 cases are possible; one is the bulk, another is the very thin grown layer which is known as the epitaxial layer. In that case we can consider that, it is a sheet of material because, very small thickness of the epitaxial layer we consider.

So we can consider that is a sheet; so one is the bulk, another is the thin film or the sheet or the epitaxial, whatever be the case that is known as the thin sheet say. So these are the 2 cases, which we can measure. Now if the bulk is considered, let us first take the case of the bulk; then the differential resistance, it is given by delta R rho into d x by A. What is this? This is R, R equal to rho into l by a. Since I am measuring the differential resistance that means, this l the length which we are considering is basically x plus delta x, between x and x plus d x. So very small region we are considering because, that is your differential resistance; that is why I am, I have put delta R also.

So if you take this kind of a configuration and you if you say that, this is say x 2; this is x 2, this is x 1 and the probe spacing is S, the probe spacing is S. S is probe spacing and x 1 and x 2 are the distances of the inner 2 probes from a particular coordinate axis. Now under this situation, I can make R equals to integration of rho into d x by what is the area? Here you see that, for a bulk material we are considering the bulk material, for a bulk material the current that means in 1 and 4; we can consider that, the current is we will assume a spherical shape because, from the you if you, if you consider a point inside the bulk material and if you think that from that point towards the surface, what should be the path of the current? It will assume a spherical type of path, as if the current is emanating; it is pushing through from the inner to the outer surface.

So under circumstance, the area will be twice pi a x into x; that means twice pi x square. Why? Because, you can consider that, what is 2 pi x; 2 pi x is the perimeter, 2 pi x is the

Perimeter.

Perimeter and if this x is very small, then we can consider that, that perimeter is the length and that is the breadth. So the area is 2 pi x multiplied by x for this case and what should be the limit? The limit is say from x 1 to x 2, that we have assumed. So you can write that this is equal to rho by twice pi x 1 x 2 d x by x square.

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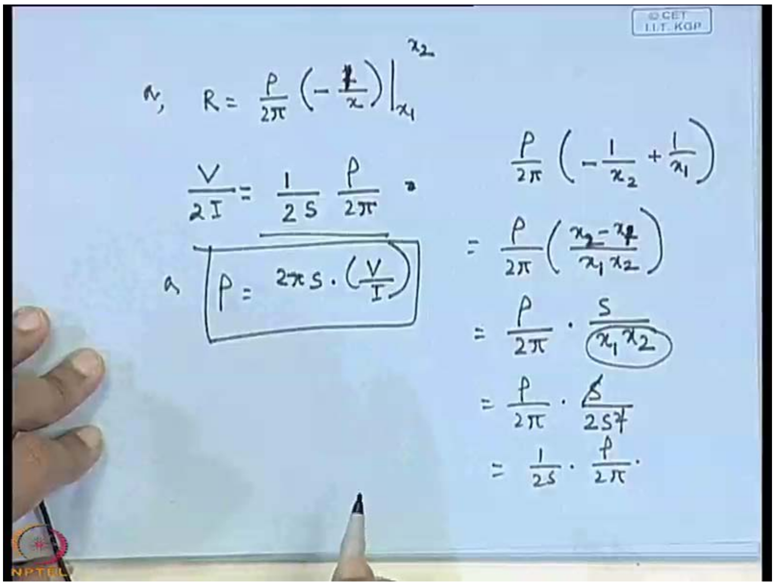

Then if you work out this integration, what you will get? or R will be equals to rho by twice pi minus 2 by x x 1 x 2, this is equals to how much?

Student: 2 by is the (( )).

No, no not 2 by x, this is 1 by x.

Student: 1 by x 1 minus 1 by x .

1 by x, so under the circumstance it is if you put the value, you will find that it is one by...

Student: (( ))

Yes that means this x 2 minus x 1 is basically the probe spacing, what is x 2 minus x 1? It is the probe spacing between the 2 probes; the space between the 2 probes and we have assumed it as S. We have assumed it as S, that means we have consider that it is a uniform probe spacing. There are 4 probes; 1 2 3 and 4 and each having distance S, the spacing.

So this is equals to 1 by 2 x into rho by twice pi. Now what is R?

y 2 times 2 y (( )) simply rho upon 2 pi s (( )) how do you (( )) because 1 by x 1 minus 1 by x 2. So the (( )) is x 2 minus x 1 that is s, but divided by x 1 into x 2.

Divided by...

Student: x 1 into x 2.

That would be equals to...

1 by...

rho by twice pi.

One by x 1.

Minus.

(( )) x 2 1by x 1.

Minus.

x 2 1 by x 2.

Yes.

plus 1by x 1.

Yes.

Then x 2 then rho upon 2 it comes up to a s upon x minus x 2 x 1 minus x 2.

Divided by x 1 into x 2 x 2 minus x 1 (( )) minus...

This thing.

Yes.

Student: x 2 minus rho one by x 1 x 2 that is numerator is x 2 minus x 1 by x 1 x 2 that is equals to rho rho by 2 pi.

Twice pi.

Student: x 1 into x 2 s by x 1 into x 2.

x 1 into .

Student: x 2.

x 2. Then what is the value of x 1 into x 2?

Student: (( ))

What is the value of x 1 into x 2?

Student: (( ))

What is the value of x 1 into x 2? What is x here?

x.

Yes.

Student: (( )) .

Suppose, suppose this is your 0, suppose this is your coordinate axis 0.

Student: Its x square x (( )).

Yes then it is s square. Suppose I consider this as the x equals to 0.

Student: (( )).

Then.

Student: It will come x two, S 2 S then, a square a by a square 2 S square.

That is equals to rho by twice pi s by...

Student: 2 S square.

2 S square. So that means equals to 1by twice S into rho by twice pi. Some approximation is there obviously right?

Student: So could you just explain once again (( )).

Which one?

Student: Area.

Yes area is basically here you see that we are considering the bulk. So when you consider a bulk material, you can assume that the current is coming out from the inner to the outer side. Why? Because, basically the current flows the contact is on the surface; it is a bulk material, the contact is on the surface. So when current is coming out from this point to that point it is coming out through the bulk. So that means, as if the current is thrusting or pushing outward; that is a projection from the surface. So it will like a surface a sphere.

So now in that sphere, the if you take the area; so what is the area? Because, we are considering the area A.

Student: (( )) in.

The area is basically, the circumference is twice pi R right and if the this R is very small, if this R is very, very small then you can consider that, the 2 pi R is the circumference; which will act like a rectangle with 2 pi R as a length and R is the breadth. So it is 2 pi R into R; that is, that is possible if you consider, if you take the projection of that thing for a very small area current follows the (( )) if we are no.

Here we can, we are considering see, see we are considering the resistance is uniform.

Student: (( ))

We are considering it is a uniform here, there is no variation of resistance is possible because, the grown material is a uniform material. You are not measure using this technique, you cannot measure the resistivity of wood or, or bricks. It is for the well synthesized semiconducting material. Now you can think that area in other way also here some suggestion, what is your suggestion?

Student: (( )) how much the area 2 pi h

Yes. That is given.

We can discuss in later also. So now this is the resistance R and this R equals to how much? V by... I. Why I? It is I or anything.

Yes. No I is there, but whether it is I or 2 I or three I or 0 I.

Student: 2 I (( )) 4 I is a (( ))

No it is 2 I because, it is basically the superposition of current. It is basically the superposition of current because...

Student: (( )) surface we are applying current here that may measure the voltage that was here (( )) no.

No, no it is because you see that, between these 2 probes when we measure the current, the current is total current we are measuring, it is equals to 2 I. It is not only I because, 2 probes are there, if it was a total 2 probes material characterisation; you are measuring, you are sending the current between 2 and measuring the voltage, then it is V by I; since we are introducing 4 probes.

So basically that is a superposition of current between the outer probes and it is 2 I. So this r equals to V by twice I or rho equals to you see, what is the value? rho equals to twice pi by twice pi into S into V by I. That is the solution for this 4 point probe bulk material, not the thin film or thin sheet material; it is rho into twice pi S V by I, where S is the uniform spacing between the any 2 between any 2 probes.

Now if we consider the thin sheet, for thin sheet we can start from these equation, for thin sheet we can start from these equation only difference is that, here the current will be the circular ring type of thing because, it is a thin sheet; it is not coming from inside the bulk. So that means here, it will be twice pi x into t if t is the thickness of the material.

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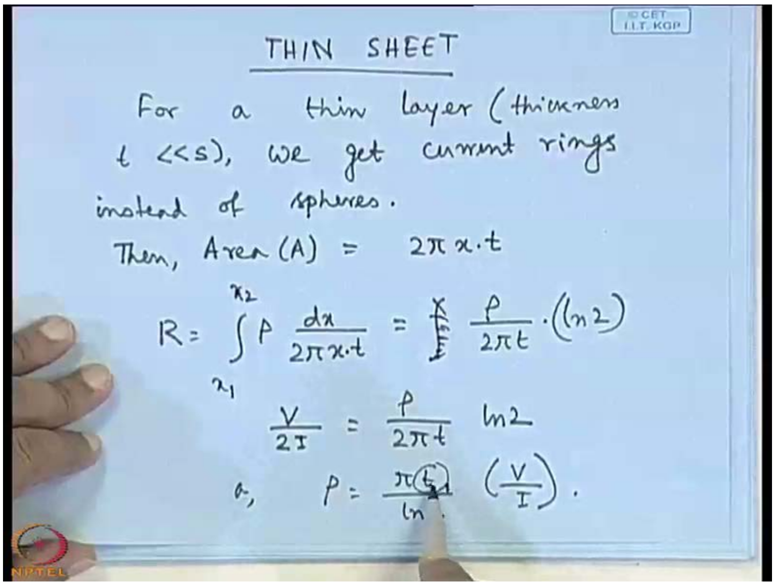

If t is the thickness, let me write down for thin sheet. For a thin layer thickness t very, very less than S; we get current rings instead of sphere. Area equals to, then area equals to twice pi x into t, t is the thickness of the thin layer and the derivation will be R equals to x 1 to x 2 rho d x twice pi x into t. That is equals to if you consider this thing you find that, you will find that it is equals to rho by twice pi t into l n 2 equals to l n 2 because, 1 by x is...

Student: (( ))

l n and it is l n by 2. So again here you see that, r equals to V by twice I as usual this is equals to rho into twice pi t into l n 2 or rho equals to pi t by l n 2 V by I and in this relation, the important aspect is that it is independent of the probe dam spacing. Earlier it was functions of S, earlier we have seen that rho was twice pi S V by I. Here you see that, there is no S or the probe spacing; only the thickness t is important here in this case and this is equals to pi l n 2 t V by I.

Student: Thickness is independent of x

Which thickness?

Student: T

t is the material property, t is the material property which you are going to characterise.

Student: (( ))

Suppose, yes t is the thickness of the...

Student: (( ))

Yes if it is a epitaxial layer then, t is the thickness of the epitaxial layer. Suppose you have grown Silicon epitaxial layer on Silicon substrate, your silicon substrate is say 400 Micron.

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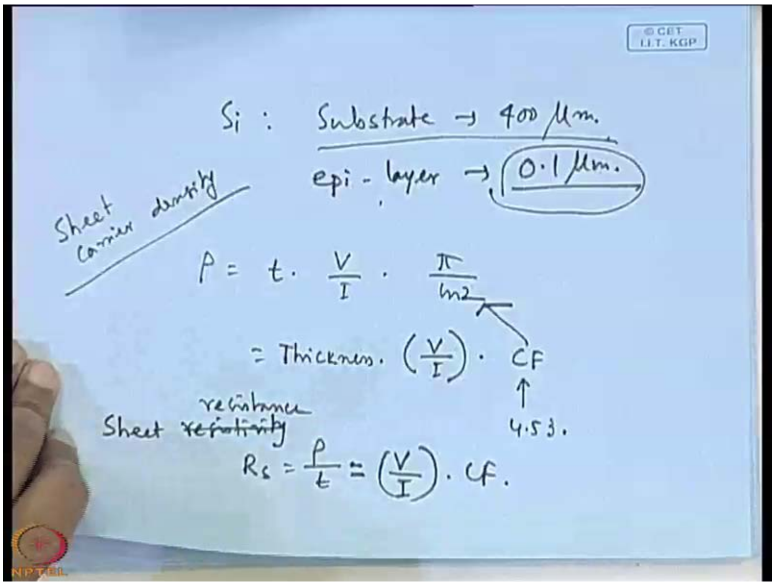

Your silicon substrate is say 400 Micron, is 400 Micron and epitaxial layer on it is say 0.1 Micron, then t is 0.1 micron. Remember that in such case, the substrate used is taken as very high resistive; otherwise the contribution of the substrate will be there in your measurement for 3 5 semiconductors, generally we grow the epitaxial layer on semi insulating surface there is available. For semi insulating means, you are growing that 0.1 micron layer on an insulating sub base.

So that means the contribution of the substrate is not there in the epitaxial layer, electrical resistivity; right. Suppose this is your substrate, this substrate is 400 Micron and this is your layer of 0.1 Micron or 1 Micron. So that means you have grown this layer on this substrate, then using a 4 point probe; you are measuring the characteristics of this layer only, not this layer.

So now how you will decouple it? Decouple you can make in such a way, that you can grow this layer on a very high resistive substrate. So that, what you are telling? That the current will follow the least resistance path and it will not take the bulk. Only the surface property will be available; otherwise, you can use a semi insulating substrate on which, you can grow the epitaxial layer. In that case there is no scope of the current to flow through the substrate because, you have been using the semi insulating.

So all the current will be pass through that epitaxial layer; otherwise, you can use sapphire substrate. You know sapphire is a non-conducting substrate A l 2 O 3, so you can take a sapphire substrate a glass substrate, glass is also non-conducting in nature. So you can and use those substrate for the growth of the epitaxial layer, for electrical characterisation; otherwise, how you will calculate the mobility or the carrier concentration. How will you ensure that the carrier concentration or mobility is not coming from the substrate? So, what is semi insulating?

Semi insulating means, it is very high resistive say the resistivity is 10 to the power 7 10 to the power 6 home centimetre, very high; not a characteristics of the semiconductor. In semiconductor what is the resistivity?

Student: (( ))

0.00 to 1or up to say 10 home centimetre. Here it is 10 to the power 6 10 to the power 7 home centimetre, that means the resistivity is very high. So you cannot consider it as a normal semiconductor that is why it is known as a semi insulating substrate. So in this case you see that, for the thin sheet there it is independent of the probe spacing S and only it depends on the thickness of the material. Now this thickness of the material in some books or in our lab we have mentioned that, there must be a correction factor; probably you can remember that thing. Here you see that, this expression, this expression rho equals to t into V by I into pi by l n 2; that is equal to the thickness multiplied by the ratio of voltage to current multiplied by the correction factors C F.

This is the correction factor pi by l n 2 and it can be different also for different material, remember that in this particular case. We have considered that the current rings will be there, current rings will be there or the it is an uniform thickness, but in actual practice there may be some difference with the ideal sample situation. The sample may be rectangular in nature, may be circular may not be circular in nature. The thickness may be different, that means from plus x to minus x direction there may be some variation of the thickness that is possible.

So under such a circumstance you have to use the correction factor. Generally in this in such a case, the correction factor is taken as 4.53, why? It is the value of pi by l n 2. It is the value of pi by l n 2, pi by l n 2 is 4.53. Right now, another important thing is that, since we are considering a thin sheet or an epitaxial layer; so what is the sheet resistivity? Sheet resistivity R s is equals to rho by t, sheet resistivity R s is equals to rho by t or this is equals to V by I into correction factor C F. Then we should write it is sheet resistance not resistivity why? Because, rho is the resistivity and we are dividing the resistivity with thickness. So that means, it becomes resistance ohm centimetre by centimetre; so it becomes ohm.

So it is sheet resistance; now why the sheet resistance we have calculated? Because, it is a thin sheet, so we can characterise that thin sheet with thin sheet resistance or the sheet carrier density. In later stage we shall find that, we have measured the thin for thin sheet; we have measured the sheet carrier density, sheet carrier density; that means the density of carriers in that particular sheet of material or in that thin film of material.

So this is the 4 probe method; now if we consider the another point I I should mention that, here you see that the correction factor is pi by l n 2 and we have consider that it is a, it is a uniform circular material or the sample having thickness t, but if it is other type of sample of say irregular shape. It can be rectangle, it can be triangular shape; any kind of shape is possible, then this correction factor will be different and this correction factor is available you can write down the site from where you can take the correction factor.

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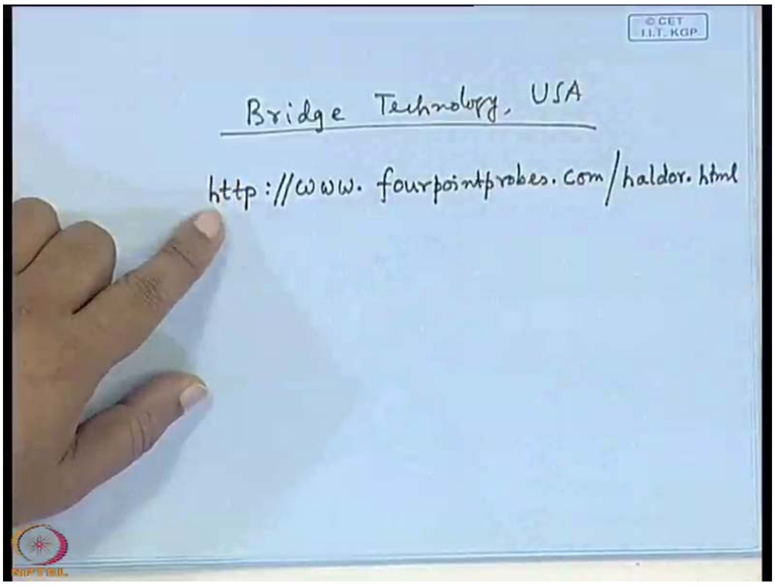

It is provided by bridge technology, 'B R I D G E' bridge technology USA; through http: //www.fourpointprobes.com / haldor, haldor.html. If you visit this site you will find that, the they have listed the correction factors for all types of samples. They have listed the correction factors for all types of samples; they are provided the graphs for different kinds of samples.

So depending on your actual sample shape and geometry, you can choose the proper correction factor because, correction factor is very important. In most of the cases you will find that, our sample is not uniform; then this theoretical correction factor which we have used pi by l n 2 is not valid. Then you can visit this site, you can check what is, what should be the correction factor for your case and you can put the proper correction factor; instead of 4.53, right. So this is all about the 4 point probe.

So in a nutshell 4 point probe you do not need any metallic contact or ohmic contact, only you have to measure the current between 2 numbers only. You have to pass some current between 2 outermost probes and we have to record the voltage between the 2 innermost probes and you must know the thickness of the samples that is all and if it is uniform in nature, that means if your diameter of the sample is very very greater than the probe spacing. If your diameter of the sample is very very greater than the probe spacing, then you can consider that, the correction factor as 4.53. It is valid generally for d greater than S d greater than S diameter greater than the probe spacing, then you can consider that it is 4.53.

But the diameter is basically the characteristics of a circular sample or a sample having circular shape because, all all the wafers are available in circular form; that is why we are discussing as a circular shape sample, but in your laboratory. When you grow a sample it can be rectangle, it can be any, any, anything. So depending on that, we have to change the correction factor which is available from this site.

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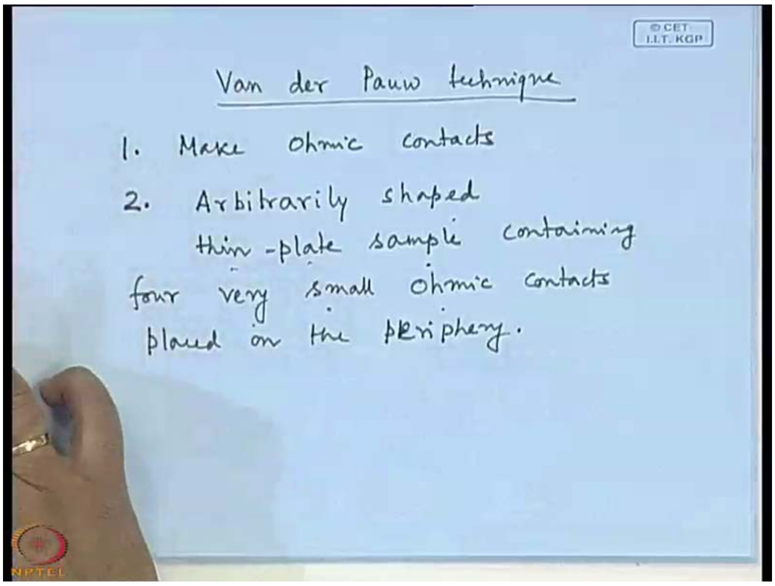

Now the next part of our discussion is the van der pauw technique, first thing is that make ohmic contacts, which was not required for your probe make ohmic contacts. Number 2 is that, you can use arbitrary shape; thin plate sample containing 4 very small ohmic contacts placed on the periphery, preferably in the corners.

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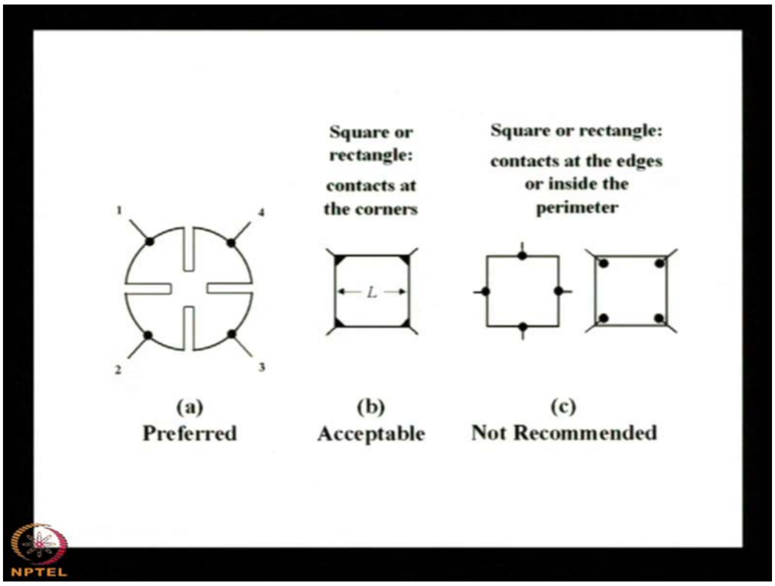

I can show you the configuration, yes this is the configuration of the ohmic contact for van der pauw configuration. See this is if this is a circular sample these are the contacts so that is preferred. In the corner it is acceptable for square or rectangle, but for square or rectangle contacts at the edges or inside the perimeter because, it is inside the perimeter or it is at the edges it is not recommended. It is to minimise the current path and to minimise the current resistance that, this kind of circular shaped or this kind of square or rectangle shaped sample is acceptable. These are the dots are the ohmic contact, through which the current or voltage will be measured. You see that, this is 1 this is 2 this is 3 and this is 4; that is in the counter clockwise or anticlockwise direction we have put the numbers 1 2 3 and 4. That means, it can be arbitrarily shaped, thin plate sample; thin plate means thin samples, epitaxial samples.

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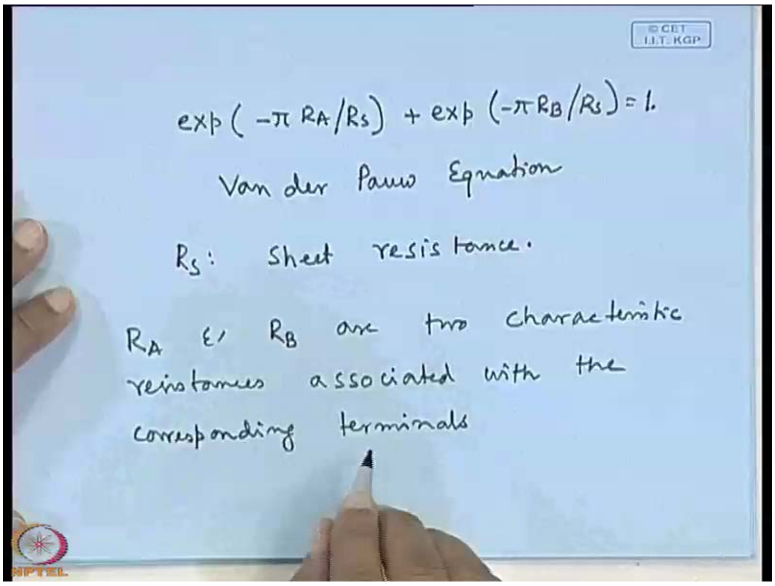

Containing 4 very small ohmic contacts placed on the periphery or in the corner, preferably on the corner and if this is the situation, if this is the situation; then van der pauw configuration, you can measure the resistivity by using the van der pauw equation it is known as exponential minus pi R A by R S plus exponential minus pi R B pi R S equals to 1.

So this is the van der pauw equation, this is van der pauw equation. So originally the van der pauw propose such equation to measure the resistivity of a sample using that kind of a configuration. Now you see that, R S is the sheet resistance, R S is the sheet resistance which we would like to measure and R A and R B are the two characteristics resistance, which we would like from the we would like to measure using our van der pauw configuration. R S is the sheet resistance and R A R B are the 2 characteristics resistance. R A and R B you can write down R A and R B are 2 characteristics resistances associated with the corresponding terminals.

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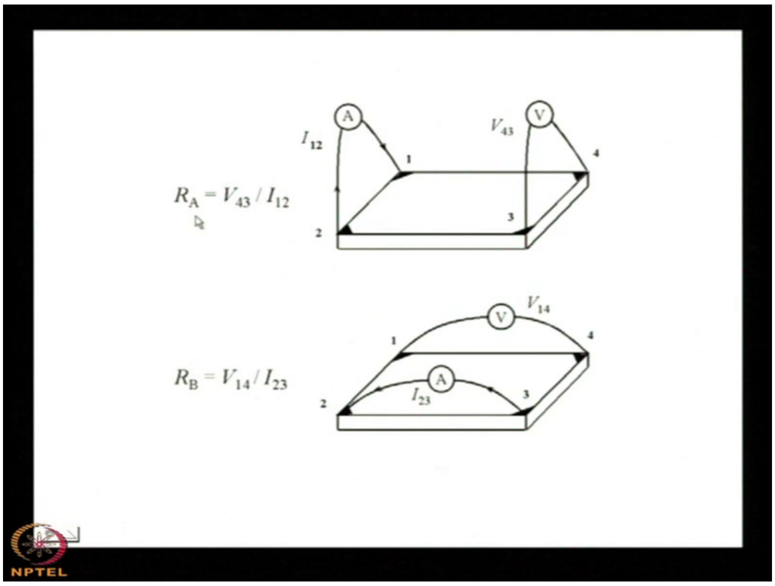

You see that, this is the R A and R B; R A means what is R A? R A means you see that, you see 1 2 3 4 are the metallic ohmic contacts 1 2 3 4. R A is voltage you have to measure between terminal 4 and 3.So you have connected the voltmeter between terminal 4 and 3 and you have to measure the current between terminal 1 and 2. That means you send current between terminal 1 and 2 and measure the voltage between terminal 3 and 4; then if you take the ratio of the voltage to current, you will get R A; the characteristics resistance between these 2 terminals.

Similarly for R B you see that, you send the current between terminal 1and between terminal 2 and 3, between terminal 2 and 3 and you measure the current between terminal 1 and 4. So that means there are 2 configurations; one is the adjacent configuration, you see that here 1 and 2 are the and here it is 1 and 4. The voltage is measured, earlier it was measured between 3 and 4.

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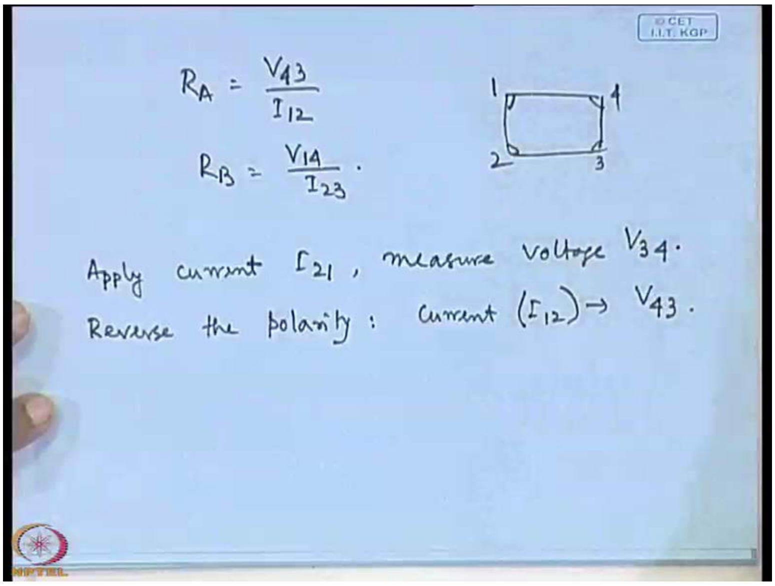

So R A and R B can be calculated using these two values, that means R A equals to V 4 3 by I 1 2 and R B equals to V 1 4 by I 2 3. If you consider that, this is 1; this is 2; this is 3 and this is 4. Then generally the situation is very simple, apply current I 2 1, measure voltage V 3 4, reverse the polarity.

Now current is I 1 2 and the corresponding voltage is V 4 3; what we have done? You see that, first apply current between 2 and 1; measure voltage between 3 and 4. Then you reverse the polarity of the current, so now the current will be between 1 and 2; earlier it was between 2 and 1. Now it will be between 1 and 2 and the voltage will be between 4 and 3. So all the time you have to take data for the forward as, as well as the reverse polarity; we should not use the forward because, configuration one and configuration two just change that direction of the current.

Why we want to change the direction of the current? It is very much important to minimise the error in the measurements and also the contact resistances the thermoelectric effect etcetera to minimise those effects. You can change the direction of the current to measure the current and voltage and in the next class I shall show you, how from this measurement of current and voltage lead to the determination of the electrical resistivity in case of a thin sheet of materials using van der pauw configuration.

So basically, you find that one hazard is there, that we have to make ohmic contact and ohmic contact is not very easy thing to make. First we have to choose the proper metal; suppose, Aluminium in Silicon is ohmic, but Aluminium in gallium arsenide is non-ohmic right. So very high purity material is required, otherwise there will be oxides; if there is an oxide in between your semiconductor and metal, then what will happen? Current will not pass the oxide is an insulator right.

So those things we have to take care and then you have to anneal it, anneal it means first you make the ohmic contact and put your sample in a furnace. In argon atmosphere or nitrogen atmosphere to anneal it, anneal it means to prevent further oxidation and also the adhesion between the semiconductor interface and the metal will be good; that means some metal will diffuse through the semiconductor to make it very good contact and, and very important consideration is that, if you want to make good contact; try to make the top level highly doped, that means you want to make a contact on silicon.

So you grow silicon then make a very thin layer of silicon having highly doped. Then you make the ohmic contact why? Because, the highly doped area is almost similar to the metal; so that means there will be a metal-metal type of interface. Instead of semi condor type of interface; so these are the tricks that one can play around for making the very good ohmic contact.

Thank you. Let us take a break and then we shall again start.