Processing of Semiconducting Materials
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Lecture - 27
Characterization – II

Let us define the following parameters for the van der pauw resistivity measurement**.**

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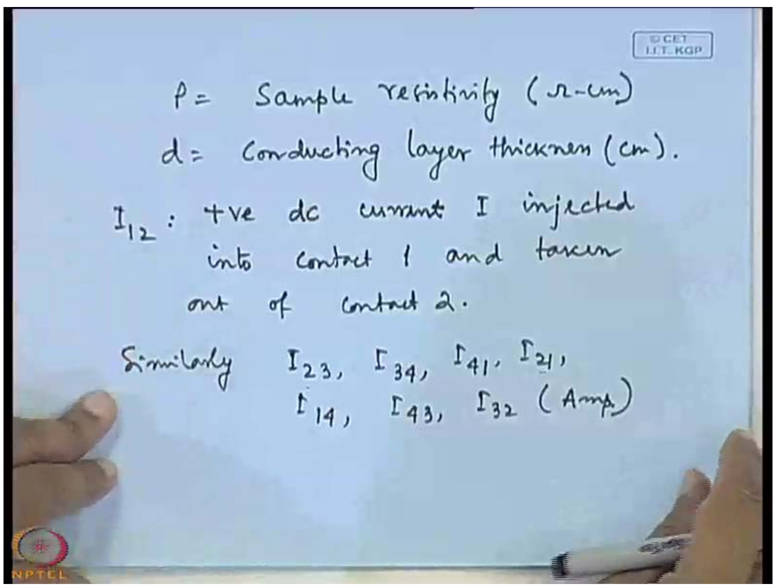

Say rho is the sample density, sample resistivity, it is in ohm centimetre; then d is the conducting layer thickness, conducting layer thickness. Since we are considering the epitaxial layer only, very thin film layer, so that is why the conducting layer thickness means; the thickness of the epitaxial layer in this case you can consider. The conducting layer thickness and this is in centimetre I 1 2 is positive d c current I injected into contact 1 and taken out of contact 2. That means it is the direction when we talk about that a positive d c current I injected into contact 1 and taken out of contact 2 that means it is the polarity of the current. So that means if you reverse the polarity, that means in that case the current will be I 2 1 instead of I 1 2. Instead of I 1 2 it will be I 2 1 and that means; the current will be injected at terminal 2 and will be taken out at terminal, so that means it is the reverse polarity of the current.

So I 2 is the positive d c current similarly, I 2 3, I 3 4, I 4 1, I 2 1, I 1 4, I 4 3 and I 3 2 all in ampere that means how much current do you have? 8 how much current do you have? You find how how many? 8 I 1 2, I 2 3, I 3 4, I 4 1, I 2 1, I 1 4, I 4 3 and I 3 2; so 8 currents we have to measure. 1 2 if 1 2 is the positive then 2 1 is the negative. Then if I say 2 3 is the positive then 3 2 is the negative, if 3 4 is the positive then 4 3 is the negative, if I 1 4 is the positive 4 1 is the negative or the vice versa. So that means finally you have to measure 4 current, but if you use a constant current source then you apply current from a constant current source. That means; these values are your predetermined values you will send the current one micro amp 1 mili amp or 1 nano amp whatever be the case, it depends from the resistivity. So 8 currents we have to consider. Similarly, the voltages actually we have to measure the voltage, you are giving the current and the corresponding voltage you are recording.

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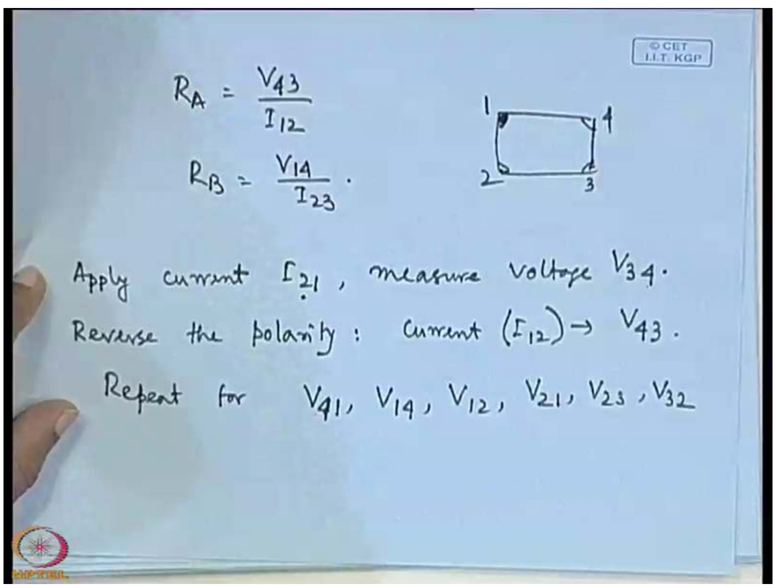

So for voltage measurements this thing we can consider that, apply current I 2 measure voltage V 3 4 under this configuration; reverse the polarity current will be I 2 and the voltage will be V 4 3. Repeat for V 4 1, V 1 4, V 1 2, V 2 1, V 2 3, V 3 2, here also you find that 1, 2, 3, 4, 5, 6, 7 and 8 8 voltages are there because for 8 current you will get 8 voltage right? So you send current you record the voltage straight away. There is no ambiguity in it and the configuration is in the counter clockwise direction. If you take this one as the 1 then it is 2 3 and 4 these are the small OME contacts, small means the diameter is of the order of 1 millimeter.

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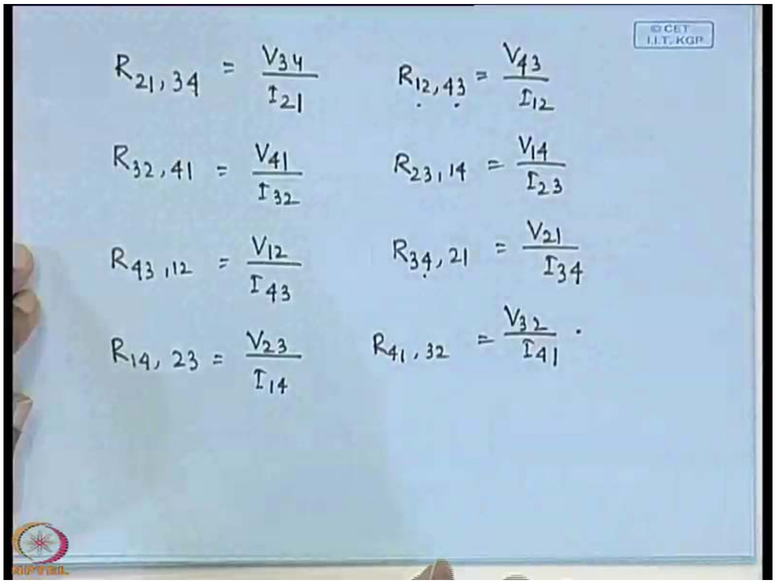

Then the next thing is that, there will be 8 resistance because 8 voltage and 8 current we got. So when you divide that voltage with current, you will get the resistance; so you will get 8 resistances. Let us see a R 2 1, 3 4 that is resistance it is V 3 4 by I 2 1. Similarly, I 1 2, 4 3 that is equals to V 4 3 by I 1 2; R 3 2, 4 1 that means V 4 1 by I 3 2; R 2 3 1 4 that means V 1 4 by I 2 3. Similarly, R 4 3, 1 2 that is equals to V 1 2 by I 4 3; R 3 4, 2 1 that means V 2 1 by I 3 4; R 1 4, 2 3 that is equals to V 2 3 by I 1 4; R 4 1, 3 2 that is equals to V 3 2 by I 4 1.

So these are the resistances you get from the measurement of 8 current and voltage clear up to that point it is clear? Just simple we have taken the ratio and you see that R 2 1 means we have marked the resistance, we have denoted the resistance by two numbers 2 1 comma 3 4 2 1 is the current, 3 4 is the voltage. Here you see that R 3 4, 3 4 is the current, 2 1 is the voltage. First we have use the current then, the next number is the voltage. You can determine by R 1, R 2, R 3,R 4 that is also possible, not necessary that we have to marked in this manner.

Now you get 8 resistances 8 resistances then you have to check for the consistency of the measurements that is very important because you cannot take any value for the resistance How to check the consistency that is that is the most important part of this measurement otherwise there is nothing in this kind of measurement only the consistency part.

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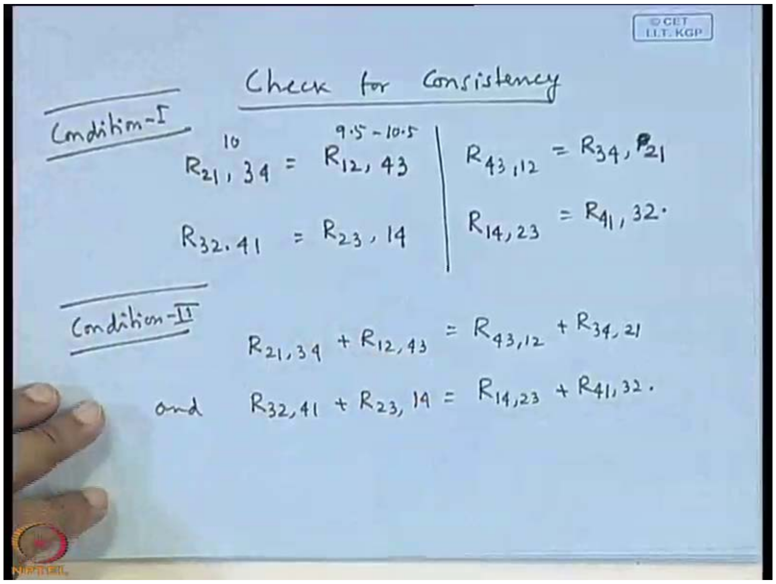

The consistency part is that check consistency check for consistency R 2 1, 3 4 must be equals to R 1 2, 4 3 R 4 3, 1 2 must be equals to R 3 4 R 3 4, 2 1. Similarly, R 3 2, 4 1 must be equals to R 2 3, 1 4 and R 1 4, 2 3 that is equals to R 4 1, 3 2 this is condition one and condition 2; R 2 1, 3 4 plus R 1 2, 4 3 must be equals to R 4 3, 1 2 plus R 3 4, 2 1 and R 3 2, 4 1 plus R 2 3, 1 4 must be equals to R 14 23 plus R 4 1, 3 2. These two conditions must be satisfied, so if you want to check the consistency you check in this manner. You have 8 resistances, you see whether these resistances equal to that resistance or whether this resistance is equal to that resistance or if you add these two resistances whether there total value is equals to the sum of the two resistances R 4 3, 12 and R 3 4, 2 1. So these are the consistency checking.

Now what is the tolerance limit? What is the tolerance limit? Within 5 percent this must be equal within 5 percent better for very good result, if you one precision then within 3 percent this must be true. So that means; if the variation is more than 5 percent, you must be sure that there must be some error in the measurement. There must be error in the measurement, if this is more than 5 percent. what is more than 5 percent? Suppose this is 10 what should be the value of R 1 2, 4 3.

Student: (( ))

9.5 to (( ))

At the most if you want precision 9.7 to 10.3; so if it is ten its value must be within 9.5 to 10.5, so such kind of precision is required and we can allow tolerance up to the limit. If you find that it is 10 and it is 17 or if it is 15 and it is 12, then you see that what actually happens in your measurement; I understand then be sure that there have some error in it and so the final result will not be very encouraging.

Now that this is our, you see that this is our expression, we are very close to solve this expression because, that is the van der pauw equation. We want to determine the R s provided we know R A and R B to determine R A and R B, we have calculated 8 resistances and we have checked that consistency as well.

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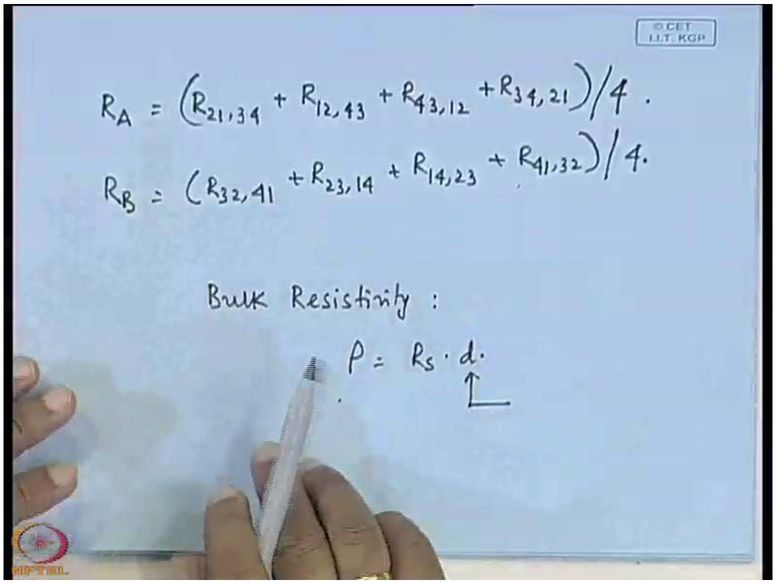

Now R A and R B, R A equals to R 2 1, 3 4 plus R 1 2, 4 3 plus R 4 3, 1 2 plus R 3 4, 2 1 by 4 and R B equals to R 3 2, 4 1 plus R 2 3, 1 4 plus R 1 4, 2 3 plus R 4 1, 3 2 by 4. So if you know R A and R B from this equation, you can use these expression to calculate the sheet resistance using van der pauw equation that means; we have to solve it numerically, numerical solution otherwise how you will solve it that means you have to make a very small computer program and you have to take the advantage of the iteration because you see that this plus this will be 1 so every time you have to calculate this thing with that thing and you have to take the difference and whether that is very close to one right?

So likewise, using a very small computer program which is known as the numerical solution because, analytical you cannot solve this result analytical; it is not possible to solve this equation. So normally you have to use a numerical solution right? If you can you can, everything is there with (( )). So you can take the data, so numerically you can solve this equation to achieve at R s. Once you know the R is the sheet resistance, this sheet resistance you know; then resistivity bulk resistivity rho equals to R s into d s is the thickness of the layer, d is the layer thickness you see that d is the conducting layer thickness.

So if you know d you can measure the bulk resistivity, so you have two option; one is first you consider a very thin sheet of material at the top consider, then measure the sheet resistance using van der pauw equation and then multiply that sheet resistance will the thickness of the material to get the bulk resistivity of the material. So that is in an nutshell the calculation of the resistivity by van der pauw method. It is not straight forward the 4 point probe is straight forward.

So so when only the precision result is required when your sample needs to be characterized very precisely, then you adopt van der pauw technique otherwise you can go for the 4 probe method, but if your sample is very high resisted then 4 point probe method will not give you any result or so; then we have to measure using a van der pauw configuration. So this are the two techniques using which we have measured the resistivity, you see that we have started our discussion with the measurement of resistivity, this is the resistivity. Now, so far as the carrier concentration mobility and type of conductivity is concerned, you have to use the Hall Effect measurements, Hall Effect measurements and Hall Effect measurements, you know that you have to make a make use of a magnetic field.

Student: Sir.

Yes.

Student: If we have a contact layer of Aluminum and Silicon.

You have a contact between Aluminum and Silicon, yes.

Student: Under what condition it is a (( )).

No, no that we shall discuss, it depends on the work function of the metal and the semiconductor, it depends on the work function of the metal and semiconductor. If if you join suppose let me just explain in this way.

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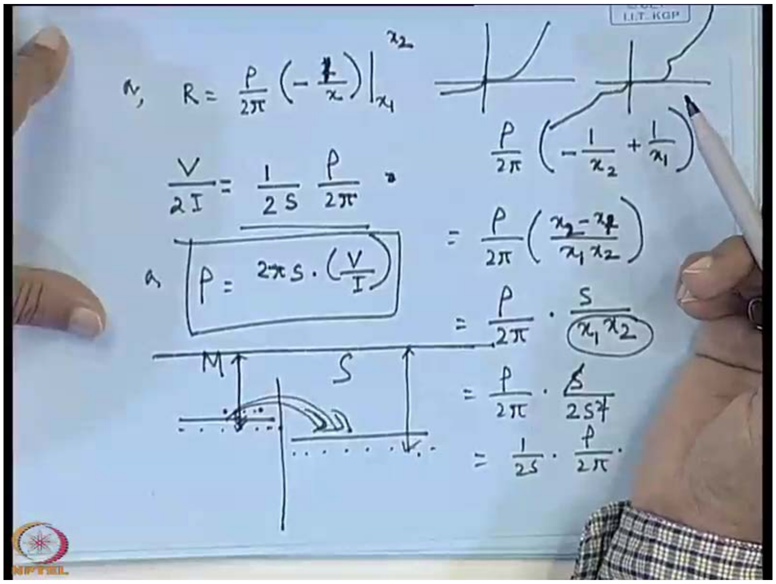

Suppose this is your metal left side is metal and this is semiconductor this is Fermi level for metal, this is Fermi level for say n type semiconductor. Here you see that with respect to some vacuum level, this is small compared to semiconductor, that work function is small in case under this situation. So the metal electrons yes will be able to go for this side ok? Now the question is that; under such a circumstance when there will be equilibrium then there will be a barrier how long they will go?

Student: Unless they are equal…

Yes unless they are equal, then the Fermi level will align and then there will be a potential barrier as usual, so then it will not move to that side. So the free movement of the electrons are not possible under such configuration.

Student: (( ))

Yes, it may be schottky, it may not be schottky but it is non ohmic in nature. Sometimes you will find that the actual schottky curve is like this, but in some cases you will find that it is like this or it is like this. This is not a perfect schottky, this is not a perfect schottky, this is non ohmic in nature. Then we have to start the what type of the whether it is due to thermionic emission or generation recombination or the some hetero structure type of conduction. There are many conduction in semiconductor; one is ohmic another is schottky, but apart from that you can consider different kinds of mechanism also or a mixed mode conduction mechanism, in some cases hopping conduction takes place. So there are many various transport mechanism in semiconductor, but that would be non ohmic in nature.

Now in Hall Effect generally we put a magnetic field and a current is passed through the material and the magnetic field is perpendicular to the direction of current. Then a Hall Field is generated that field is mutually perpendicular to both the magnetic field and the (( )) electric field and that field is known as the Hall Field which is generated; it comes from the Lorentz force, current and magnetic field is there. So it will be q into v cross B.

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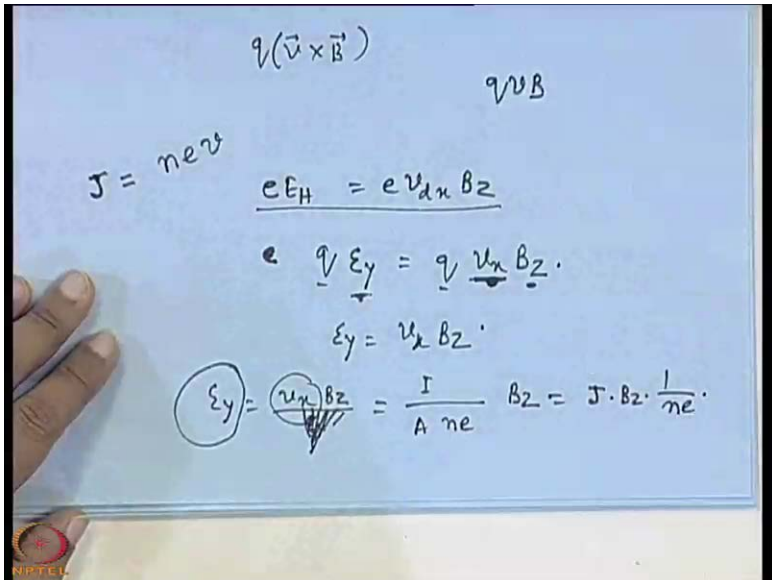

So it will be q into V cross B, q into V cross B and obviously these are the vectors in one dimension. We can consider that it is V into B in one dimension to particular for a particular one dimensional case; this can be replaced by the dot product, not the cross product.

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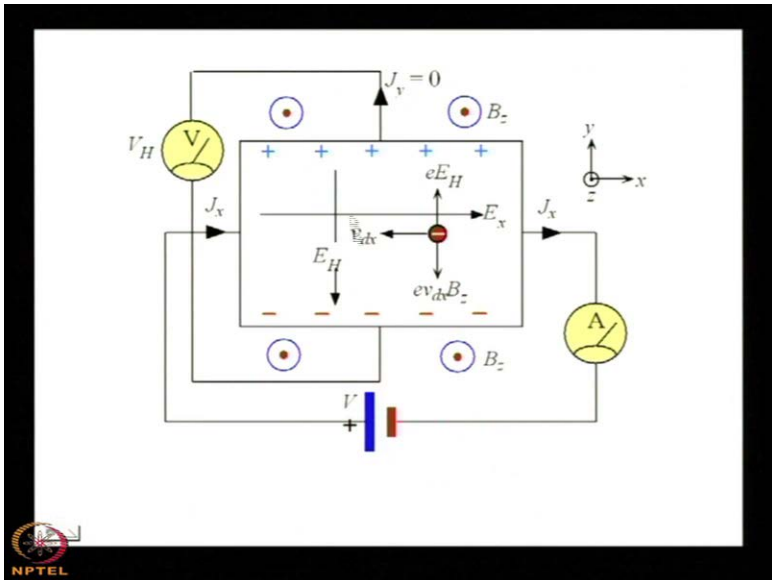

Now you see that suppose you have this type of a semiconducting bar or let us consider that this is the metal bar. Let us consider that this is a metal bar; forget about semiconductor in the first case. The current passes through this x direction, positive x direction it is say; it is the positive x direction and the magnetic field is in the which direction? z direction.

So, the hall field will be developed in the y direction. So first what will happen? When the current will pass through the semiconducting material, the electrons will move towards the bottom and the holes or the positively charged ion, say in case of metals there is no holes. So only the say if it is a copper, so there will be c u 2 plus copper ions. So, those are the uncompensated ion, which will be on the upper side; it is because of the magnetic field, that the force due to the magnetic field Lorentz forces, they will push the positive particles upward and the negative particle downward.

So there will be a you can consider that there will be a dipole type of array situation or arrangement; under such a circumstance an electric filed will be generated, and that is why this E H will be generated which is the hall field, it is because of the Lorentz force. And you see that how long this positive and negative polarization will be there; how long?

Student: When this electric field equal to magnetic field…

Yes when the electric field equals to the force due to the magnetic field. So that means, when in this case, in, in this case you see; that e E H equals to e V d x B z in this case. In this particular case, you see that e E H that means it is the force E H is the field, when the field id multiplied by the charge it becomes force and here also this B z is the magnetic field and Lorentz force is e V B z. So under such a circumstance, when they will be equal; such kind of polarization will be stopped. So polarization will be available till this field is not perfectly balanced, when it is not balanced.

Student: Sir current is flowing from left to right.

Yes.

So electrons are flowing; current is flowing, yes so the electrons are flowing and the negative x direction.

Student: (( ))

The electrons are flowing in the…

Student: Negative x direction.

Negative x direction.

Student: So the force Lorentz force on the electrons will be downward in the (( ))…

Yes.

Student: And holes are flowing in the positive x direction.

Yes.

Student: (( ))

It is metal, it is metal not it is semiconductor because, the discussion is very becomes convincing if you use a metal; because, first the Hall Effect was discovered in probably 1800 29 or such in a metal only, not in a semiconductor. Then we have use the theory of Hall Effect in semiconductor also, so this type of a situation will be there; when e E H equals to e v d x into B z or if you use standard phenomena. We can write down that e or say it is q E y is equals to q V x into B z, you see that V x is the drift velocity; it is in the positive x direction because, the electric filed was in the positive x direction and q is the charge E y is the hall field generated in the...

Student: Y

y direction and B z is the magnetic field or E I equals to V x into B z. Now you see that, this is equals to E y equals to V x B z by E y; what is V x? And what is E y?

Student: Sir u I equals to (( )) by u I

u I equals to E z by E y (( )) b x equals to

Student: (( ))

u I what is E y?

Student: (( )) in left side c y (( )) v z by E y

Then what is V x? Now I have to calculate the V x to determine E y, so E y equals to V x into B z and V x equals to you know that…

Student: (( ))

J equals to…

Student: n u.

n e v right. So you can replace this v x by J by n e or if you use the current, then I by…

Student: (( ))

I by A n e into B z…

Student: Sir n E is (( )).

No, no it is ok? It is correct. That means J into B z into 1 by n e.

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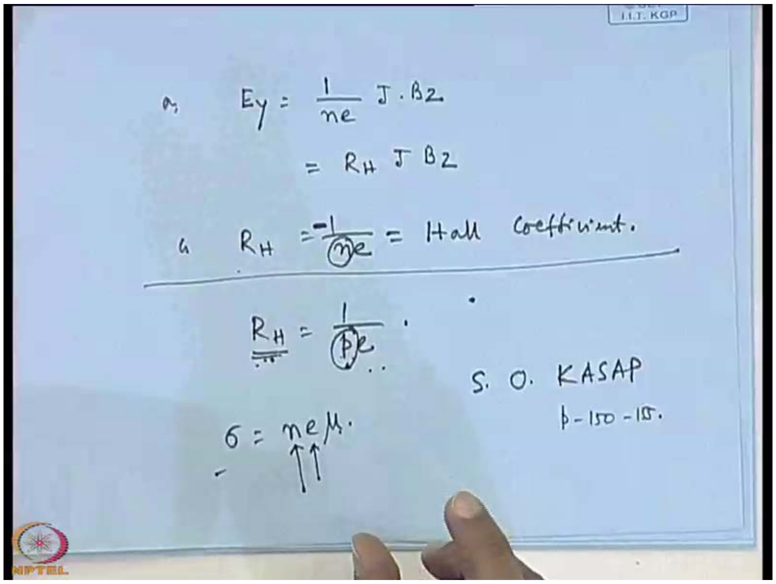

E y equals to this or we can write E y equals to 1 by n e J into B z, that means is equals to R H J into B z or R H is equals to 1 by n e. R H equals to 1 by n e, this is known as the Hall Coefficient; obviously, if this is an n type semiconductor this will be negative because, the charge is negative. If you take a p type material, then it becomes positive; that means R H equals to 1 by p into e, R H is equals to 1 by p into e.

Student: (( )) metal then how n type of …

It is only electrons are there, only electrons are there; so it is ok up to this point it is over, but if you take a p type semiconducting bar or an n type semiconducting bar, then that only difference will be that, the Hall Coefficient will be positive for p type semiconductor and it will be negative for n type semiconductor; because of the charge consideration. For metal it is always negative, but there is one difference in beryllium it is positive.

Student: Beryllium.

For metal because of its band theory, it comes from its band theory. You can explain that nature of that curve, nature of that Hall Coefficient from the band theory, it is I can give you the value; let me give you the value B beryllium, its value is plus 3.4; R H is plus 3.4. It is due to band theory of solid, we are not going to consider.

So under this circumstance, you can calculate the Hall mobility; you see that once you know the Hall Coefficient R H, you can calculate the carrier concentration either it is p or n. Carrier concentration why? If you can measure R H, that is equals to 1 by p into e; e is the electric charge which is known, so once you know the Hall Coefficient you can measure the…

Student: Carrier concentration.

Carrier concentration and also the polarity that means the conductivity type, if the Hall Coefficient is positive, then the conductivity type is n type is governed by the electrons. If it is positive, if the Hall Coefficient is positive, then the material is p type that means it is governed by the conduction of holes. So depending on the polarity of the Hall Coefficient you can consider, whether it is positive p type or n negative n type. So the type and the conductivity that means, n or p as well as the carrier concentration can be calculated from the Hall Effect.

Now how you can calculate the mobility?

Student: Sir my question was for semiconductor.

Yes.

Student: In semiconductors the hole and electrons both are depositing on the bottom.

Both the will be top side also why? Because there will be uncompensated charges as value, when in a semiconductor there are four types of situation; one is electron another is hole third one is the uncompensated positive charge and fourth one is uncompensated negative charge, that means the ions. So four types of consideration is there and I can give you the reference you write down, so that you can go through it. You write down, it is the book of S O Kasap and the page number is it will be say 150 or such page 150 to 155 you find, how in a semiconductor the Hall Effect is explained. That is given and in terms of p and n it is given that is a long calculation and we are not going into those details thing because, that is not required also and if both the carriers are there. In a semiconductor you know that, though the majority carriers are n there are some minority carriers of p or the vice versa.

Student: So in metals the voltage generated due to the (( )) charged on the…

Yes.

And positive ion or some so electric field is generated and semiconductors go through charges and (( )). No in, in semiconductor if it is an n type semiconductor, you can consider it is like a metal. If it is an n type semiconductor then for all practical purpose, you can consider the theory of the metal to be applicable in case of n type semiconductor; only the uncompensated charge charges will be on the surfaces, in metal also you find that if you take a copper sample, the electrons will be deposited on the bottom and what will be there in the top? It is the uncompensated or the positive ions, copper positive ions. That will be there; when electrons will leave that means, positive ions will be generated.

So one electron in the bottom means, one ion positive ion in the top so there by the field will be generated in n type also; n type also the electron comes from the ionization of the donor in purity. The same thing will happen.

Student: Sir.

And if you need more discussion you consider S O Kasap page 150 to 155. Now let us discuss about the mobility, you know that sigma equals to n e mu; n you can calculate from the Hall Effect, e is the electronic charge and what is sigma? Sigma is the conductivity it is inverse of Resistivity.

Student: Resistivity and resistivity is measured from the…Van der pauw.

Van der pauw or the four probe method. So if you use a van der pauw configuration to measure the Hall Effect, then it is better to use the van der pauw configuration because, for hall effect you need to…

Student: (( ))

Use the van der pauw configuration. So there by you use a van der pauw configuration, you measure the…

Student: (( ))

Yes and then calculate the mobility, that mobility is known as the Hall Mobility; obviously, it is from the Hall Effect; it is the Hall Mobility. So that means from a semiconductor piece, you can determine all the parameters; the resistivity, carrier concentration, mobility and type of conductivity; those four things are the basic characteristics of a electronic material. Not do not do not mix up with other materials, which is say structural or organic or polymeric not that; here the concept is the electrons because it is we are instructed about its application in the electronic field, in electronic applications.

So these four very basic characteristics are can be recovered from the electrical characterization, if you have van der pauw and hall's setup and very simple also…

Student: Sir, any difference between Hall Mobility and general

Student: Drift mobility.

Drift mobility.

Yes there is difference, but drift mobility you cannot determine directly. Mobility can be because, when we measure the mobility it is basically the Hall Mobility; say if you say that the mobility of electrons in Silicon is 1300 centimeter square per hole second, that means it is the Hall Mobility because, directly the mobility can be determine from the Hall only. Whether it is mentioned or not that is the different story, but it is basically the Hall Mobility; from the drift of the electrons there is a drift of mobility also the concept is there, but you cannot measured that thing directly..

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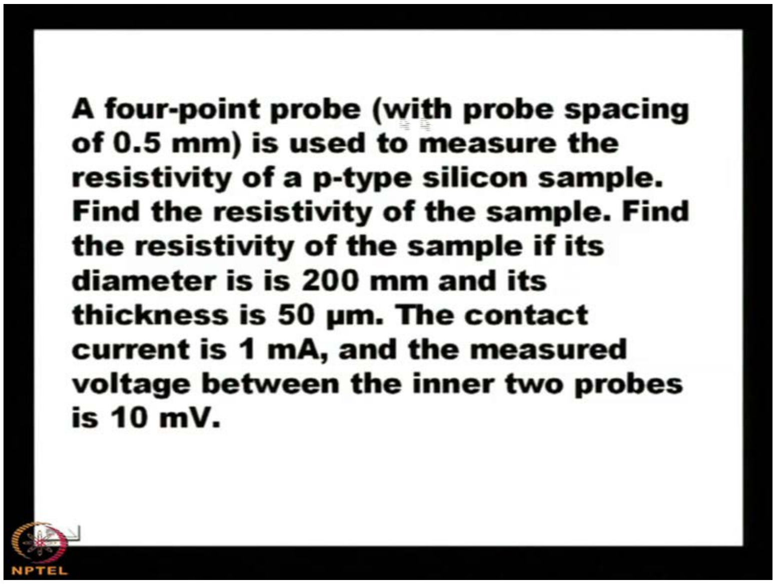

Now if you go for this numerical problem, then you can clear some of the concepts; a four-point probe with probe spacing of 0.5 millimeter is used to measure the resistivity of a p-type silicon, find the…

Student: Sir sir how do you (( ))

If four point probe with probe spacing of 0.5 millimeter is used to measure the resistivity of a p type silicon sample. Find the resistivity of the sample, find the resistivity of the sample if it is diameter is 200 millimeter and its thickness is 50 micron. There are two same it is repeated, find the resistivity of the sample, find the resistivity of the sample if it is diameter is 200 millimeter and its thickness is 50 micron.

The contact current is 1 milli milliampere given and the measured voltage between the inner two probes is ten millivolt it is also given. That, that means current is given; voltage is given; thickness is given; diameter is given and probe spacing is given. So using four point probe method you have to measure the resistivity of the p type silicon sample. So that is all, you write down in short because, this slide you will get, you can copied from the computers. So absolutely do not waste your time in writing, only in short hand just current is there, voltage is there, thickness is there, diameter is this; probe spacing is this. What is the rho? You have to calculate rho only, you calculate the rho. So the measured 20 m m is it is circular. Obviously the diameter means, that it is circular in nature. I hope so…

Student: (( )) have to make it own centimeter (( )).

That is your choice, either in ohm centimeter or in ohm meter; there are two possibilities.

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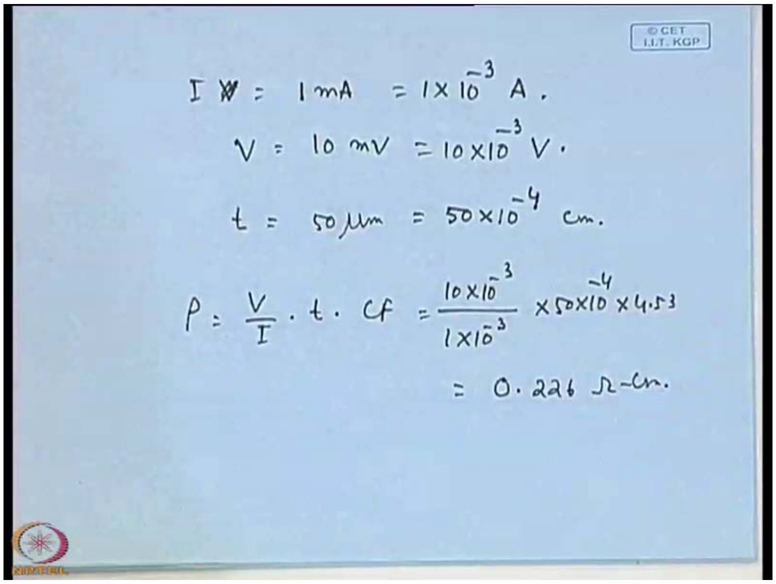

It is V is given ten one milliampere, it is one into 10 to the power minus 3 ampere. Then, sorry it is I. V is given V is how much 10 millivolt, that is 10 into 10 to the power minus 3 volt. Then what is the thickness? Thickness t is given, it is 50 micron; that means, how much?

Student: 10 into minus (( )).

50 into 10 to the power minus 4.

Student: Centimeter. Cm.

And one thing you need it is the correction factor. What is the correction factor?

Student: 4.5.

Yes, 4.53. Why it is 4.53?

Student: 50 (( )) 5 by 1818 d divided by (( )).

That is pi by pi by l n 2 is the circles for circular sample, but here why it is so?

Student: t divided by (( )).

Yes, basically here the diameter you see that, to solve this type of a problem diameter has no use in the equation. Is it there in equation? No. No. Then why it is given? It is given to ensure that the diameter is very very greater than the probe spacing; the probe spacing and also the thickness. Here, the probe spacing is 0.5 millimeter so 200 millimeter is very very greater than 0.5 millimeter. Even, suppose you are using a rectangular or square samples. If, you find that the thickness is very very greater than the probe spacing. Then you cannot use 4.53 as the correction factor. But if the thickness is less, compared to your probe spacing, the probe spacing is generally one millimeter; here it is given 0.5 millimeter, but generally it is it is 1 millimeter 1 millimeter; and what is the thickness? If you use a thin flame sample the thickness is 1 micron or even less than one micron.

So, 1 micron is less than probe spacing and then you can use 4.53 as the correction factor. But if the probe spacing is less compared to your thickness, then you cannot use; that means for bulk sample.

Student: (( )) then it is given it is given there in our condition?

It will be given probably or you have to justify why you are taking that value. In most of the cases you will find that you can use 4.53; most of the cases. Because, the probe spacing is large compared to the thickness. Then what is the value?

Student: 1.42 (( ))

1.42.

2.26 (( )).

Yes, so that means, rho equals to v by I, into t into correction factor, this is equal to 10 into 10 to the power minus 3, by I is to 1 into 10 to the power minus 3, into 50 into 10 to the power minus

4, multiplied by 4.3 or 0.5 and you will to find that it is 226 ohm centimeter 0.226 ohm centimeter.

Student: (( )) from the formula R (( )) by l.

What is the value?

Student: R into R equals (( ))

What is your rho value? Value of rho.

Student: Rho value is coming 2.5 into 10 to the power 4 meter

Then in ohm centimeter what is the value?

Student: Continuous 4.6 (( )) power 6

So that is wrong

Student: (( ))

Because you have to use the formula for the 4 probe not for the formula designed by yourself.

Student: That is (( ))

Then why you use the 4 probe or van der pauw?

Student: R double plus R equivalent to (( )) thickness.

That is for ohmic conduct. Cleverly we have used that value also, because rho into R into a by l. But generally that is valid for ohmic conduct. For ohmic conducts you need not to use any 4 probe or van der pauw configuration; it is very straight forward. Just by 2 probe; that means, you send voltage and get the current and you take the ratio you will get the resistance.

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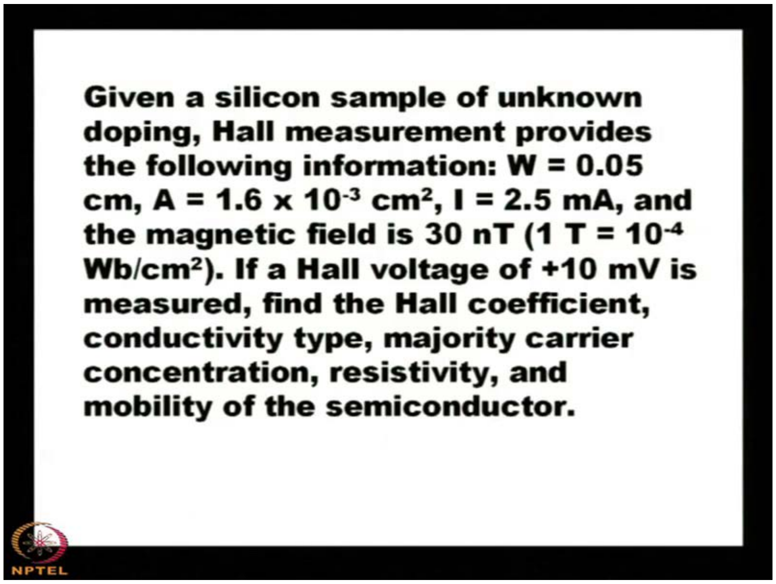

Then, there is another problem, which is this one that given a silicon sample of unknown doping, Hall measurement provides the following information, you just write down the data. W equals to 0.05 centimeter, A the area equals to 1.6 into 10 to the power minus 3 centimeter square, I the current is equals to 2.5 milliampere and the magnetic field is 30 nano tesla and 1 tesla is given it is 10 to the power minus 4 weber per centimeter square.

If a hall voltage of plus 10 millivolt is measured, find the Hall coefficient, conductivity type, majority carrier concentration, resistivity and mobility of the semiconductor. Many things we have to determine. It is given that w equals to 0.05 centimeter area is 1.6 into 10 to the power minus 3 centimeter square, I equals to 2.5 milliampere and magnetic field is given 30 nano tesla. And Hall voltage is given. You have to calculate R H Hall coefficient, conductivity type, majority carrier concentration, that is a naught p resistivity and mobility.

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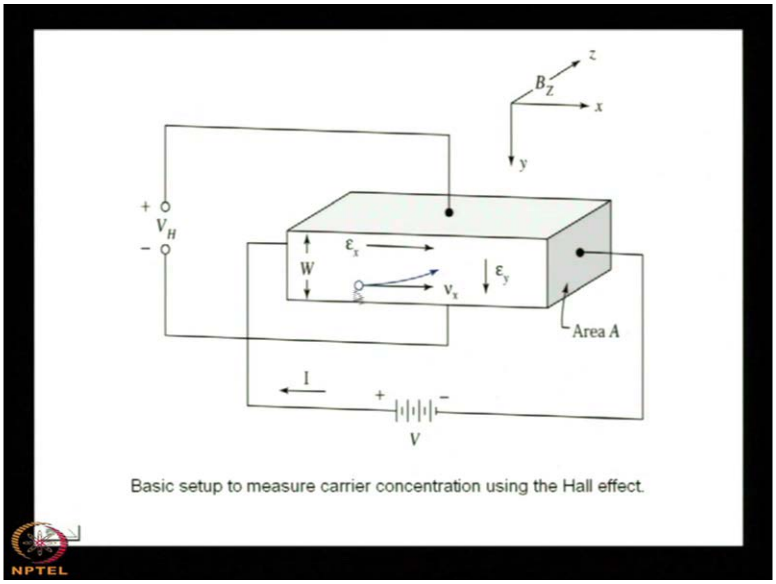

So you try. Yes, what is W and what is a it is given you see, which it is related to this figure. A is the area and W is the (( )) thickness basically here. Now first tell me, what is the carrier type, it is p or n.

Student: It is denoted by R H.

Yes.

Student: If R H becomes positive then it will be (( )) now (( )).

Now, what is what is there for R H what are the…

Student: One thing u y by d x and now E y is (( )).

No, you see that the polarity of R H is depend on which factor. You see the equation.

Student: (( ))

You see the relation.

Student: Sir it is v s into w into v upon I is (( )).

Then on which factor the polarity of R H will depend.

Student: I and I N R (( )).

It will depend on the v H hall voltage. It will depend on the hall voltage. Now hall voltage is given how much it is?

Student: 10 millimeter.

It is plus or minus.

Student: Minus.

So.

Student: p type.

It is p type; obviously it is p type.

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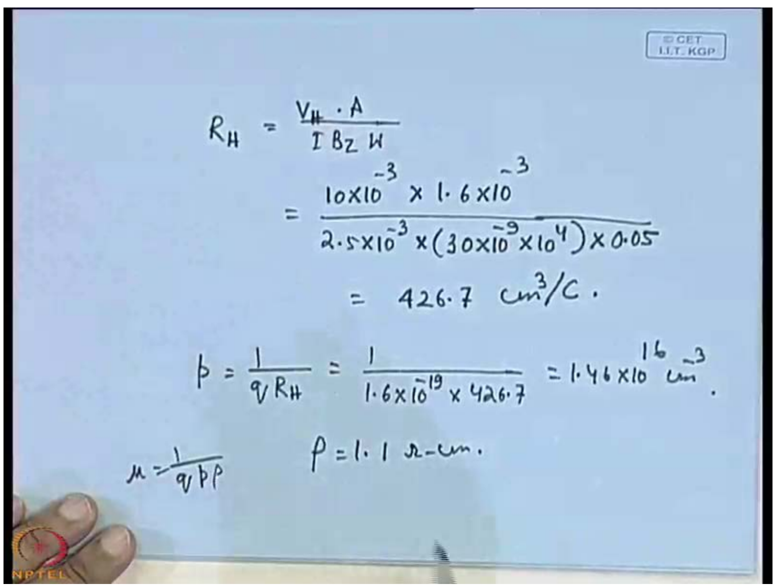

You see that it is R H is equals to, V H into A by I B z into W. Can we write? R H equals to V H into A by I B z W with reference to with reference to this figure you see.

Student: Sir 1.07 into 10 to the power V.

I can write. So that means V H is ten milliampere what is the area 1.6 1.6 into 10 to the power minus 3, current is 2.5 magnetic field is 30 nano tester; that means, 30 into 10 to the power minus 9 tesla into 10 to the power 4 Weber per centimeter square, into W is 0.05; that means, it is 426.7 centimeter cube per coulomb. See here R H is positive, so the Hall.

Student: Hall effect (( )).

Yes, that means the carrier concentration is equal to that means sample is p type and the carriers are holes. Then what is the hole concentration? R equal to z upon a 3. This 1 p equals to one by q into R H. So 1 by 1.6 into 10 to the power minus 19 multiplied by 426.7 and it comes out to be 1.46 into 10 to the power 16 centimeter cube inverse. We have done?

Student: Sir 1 tesla equals to 10 to the power minus 4 by (( )).

Plus 4, plus 4. Tesla is high; 10 kilo gauss is equal to 1 tesla. So three things we have calculated, one is the Hall coefficient the type and the carrier concentration but for the determination of mobility you must know the resistivity. And the resistivity is not given.

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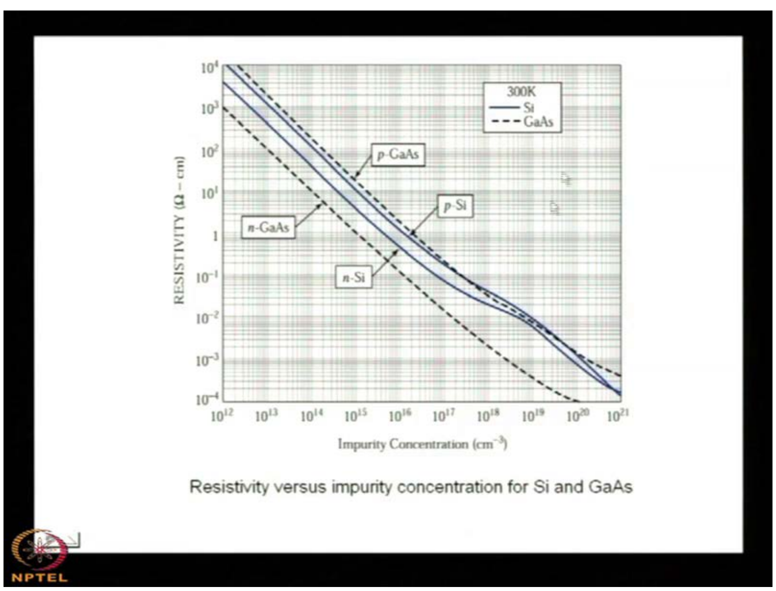

So basically, there will be a chart like this from where you can calculate the resistivity. Here, what is the carrier concentration? 1.46 into 10 to the power 16, 10 to the power 16; that means, this is 10 to the power 16 and what is this sample Silicon or Gallium arsenide.

Student: Silicon.

Silicon; so that means, this is p type silicon this is p type silicon. So it becomes normally from the graph, we find that it is one 1.1ohm centimeter precisely. Rho is 1.1 ohm centimeter. In exam such graph will not be given, so the value is provided. Otherwise, we have to take the value from a graph but, data sheet is available, for all material data sheet is available. So if you know the impurity concentration, from the impurity concentration you can find the resistivity and from the resistivity you can measure the mobility, mobility is equals to mu equals to one by q into p into rho.

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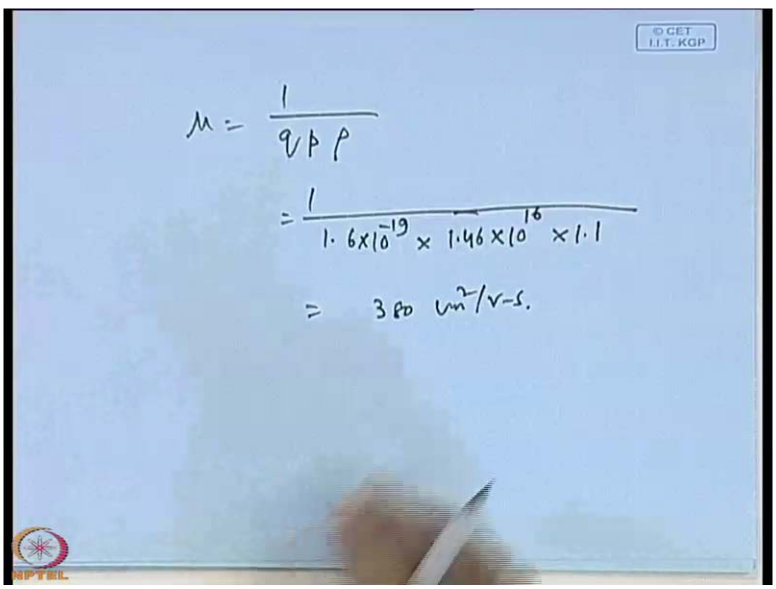

Now what is q? q is 1.

Student: (( ))

Yes, mu equals to 1 by q into p into rho, 1 by 1.6 into 10 to the power minus 19, p is 1.46 into 10 to the power 16 and it is 1.1 rho, that is equals to 380 centimeter square per volt second. So this is an example, using which you know that you are in a position to determine the material parameters of p or n type semiconducting sample, which is essential for the for its application in electronic industry.

So that is very important. Suppose, we have grown very good Silicon you claim that, it is good Silicon, and you find that its mobility is in place of 1300, it is say 800. So that means, what is that? It is very bad material. It, it is of no use; it has no use, you cannot use that material, because the standard Silicon has 1300 centimeter square per volt second is the mobility and your grown material is 800 only; that means, it is it is a bad material; some impurities are there, right? So, with this, we conclude our discussion for today. Next day we shall concentrate on the optical characterization of the materials.

Thank you.