Transducers For Instrumentation
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Lecture - 26
Magnetic Sensors: AMR and GMR

Hello, welcome to Transducers for Instrumentation. Last lecture we discussed the magnetic sensors where the magnetic sensors are made of magneto resistive materials. Magneto resistance is the property when the resistance of a material changes when we apply a magnetic field from outside or it is developed inside. So, the electrical resistance of the material changes and this electrical resistance is easy to measure we apply a certain known voltage across the material and measure how much is the current flowing. So, accordingly R equal to V upon I we can calculate the resistance of the material. Now, ah today we will discuss how do we deposit these materials on some substrate.

We talked about a little bit about substrate and when we deposit these materials on substrate. So, today we discuss how do we decide that how to deposit and how much the material thickness we need to deposit on the substrate and accordingly how much resistance we are going to get for to make a magnetic sensor. So, let us discuss something called sheet resistance. So, when we deposit these materials on substrate we deposit them in the form of thin sheet we sputter the material or there are many ways to deposit the material, but the material is generally a thin sheet on the substrate and then we pattern it as per our requirement.

So, how do we calculate the resistance of these sheets? So, that is called the sheet resistance of the material and that is what we are going to discuss. So, we have something called sheet resistance. So, for this actually we know that all the materials have certain resistivity which is called rho this is the resistivity and this is the material property the unit is ohm meter. So, this rho is the resistivity and the property of any material and the resistance accordingly the electrical resistance r is given by rho L upon A which is the cross section area or we can say T into W. So, cross section area we are assuming that this is like a rectangle.

So, one side is W and other side is T. So, this is the formula of electrical resistance R equal to rho L upon A, A is T into W and we can have certain deposited metal. For example, we deposit something like this so, let us say this is the sheet of metal we deposit on substrate length is this and W is this and T is this thickness from here to here. So, this cross section we have one side is W which is the width of this sheet and T is the thickness of the sheet and accordingly the electrical resistance is rho L upon T into W. In this we can see that this thickness of this material is generally fixed because when we deposit this material on a substrate we generally know how much is the thickness we are going to deposit.

So, this T is generally a constant it is it can be varied but it is most of the time, discrete in nature. For example, we go for 100 nanometer thickness 200 nanometer thickness 150 nanometers thickness. So, generally this T is priorly known to us and rho the resistivity this depends on the material what we choose. So, this is also known to us when we deposit a material we know what is the resistivity of this material. So, this rho and T both are known to us and they are like a constant.

So, this rho upon T we can combine together and give it a different name something called rho square. So, we write it rho square and L upon W. So, this rho square is the sheet resistance and the unit is ohm per square and this is square is a dimensionless unit. And once we have this formula we can just count the number of squares to get the total resistance. So, R is equal to R square multiplied by the number of squares. So, here we have this we deposit this metal with length L and width W and the thickness is already known T and the resistivity also known. So, we write the formula for electrical resistance as R equal to R square which is the combination of rho and T. So, R square into L upon W. So, L is the length of the metal we deposit and width W is the width. If we assume L is equal to W means the length is equal to the width then we are ended up with a square.

If we look from the top this is just a square where the length is equal to the width. So, if length is equal to width it means we are talking about a square and L upon W is equal to 1 it means the electrical resistance is equal to the sheet resistance which is a constant number for a given material and the thickness. So, now when we are depositing we know the sheet resistance rho upon T. So, we just need to multiply by how many squares we are adding up in series to get the total resistance. For example, we are adding up 10 squares a square can be of any length the length as long as the length is equal to width the resistance is going to be same. So, if we are adding 10 squares 1, 2, 3, 4 like that then if we are adding 10 squares the total resistance of this pattern is equal to 10 times the sheet resistance. So, this is very easy calculation to get the desired resistance when we fabricate these sheets on the substrate. So, this is one example where we have this length is L, W and T if we want to add two or more sheets two or more of these blocks together we can also do that. For example, if we if we make like this, this is one slab and then we add one more with it. So, the net net resistance from this side r equal to let us say r1 by 2 where this r1 is the resistance of this sheet. So, if this sheet has resistance of r1 then if we add one block in parallel then the overall resistance will be r1 by 2. So, this is how we can add these blocks together to make a desirable resistance which we can use as a magnetic sensor. So, we have certain sheet resistance known to us for different different materials. For example, if we talk about some typical sheet resistances in let us say 180 nanometer technology node. These are the technology node to use for microelectronics fabrication.

So, let us say for 180 nanometers process we are talking about and this side is the layer which layer we use and here is the sheet resistance. And if we talk about let us say diffusion the silicided one then the sheet resistance is typically 3 to 10. If diffusion without silicide no silicide the resistance is typically 50 to 200 the sheet resistance actually increases. Similarly, if we talk about polysilicon this is silicided one this is again 3 to 10 and the polysilicon with no silicide then the resistance varies from 50 to let us say almost 400. And then again we have certain metals metal layers. So, metal layer one as like sheet resistance 0.08 typically metal two is 0.05 metal three is again 0.05 ohm per square metal four is typically 0.08 metal five is typically 0.02 ohm per square and metal six let us say is roughly 0.02 ohm per square. So, if we see we have multiple layers in microelectronics fabrication which we can use as a to make a resistor. The first one is the diffusion when we diffuse certain area this also act as a resistor and there are two types in this one is silicided one one is the non silicided one. Silicided one is the one where we put some more metal and make some sort of alloy in that region.

So, that is the silicided one. So, accordingly the sheet resistance decreases around 3 to 10 and if we do not have this silicidation then the roughly the sheet resistance is higher little bit than 50 to 200. Similarly, with polysilicon polysilicon is generally used as a gate of mosfet and this also has two types one is the silicided one where again we make sort of a alloy. So, the sheet resistance is lower 3 to 10, but if we do not do silicidation then the resistance is roughly 50 to 400. So, if we want to have a resistance in our the requirement of our resistance is higher for example, we want to make 1 kilo ohm of resistance. We want to go for non silicided polysilicon or non silicided diffusion because the sheet resistance itself is very close to 1 kilo ohm for example, 200 or 400. So, we will need to add less number of squares to get 1 kilo ohm because 1 square is already give us giving us 400 ohm. So, we just need to add 2 and half square 2 square and then half. So, that the total resistance comes out 400 plus 400 plus 200 all together 1 kilo ohm. So, if we want a resistance with higher value, we go for non silicided materials non silicided diffusion and polysilicon.

However, if we want to have a resistance with lesser value for example, 0.1 ohm or 0.2 ohm then we would like to go for let us say metal 1 metal 2. These are the metal layers when which we use for fabrication. So, we have a substrate silicon substrate on top of this we use metal 1 for interconnection then metal 2 then metal 3 4 5 something like that and when we are going higher the thickness of these metal layers increases. So, because this thickness or the T of this of these layers are increasing the sheet resistance R square is nothing, but rho upon T. So, if the T increases the thickness increases the sheet resistance goes down this we can see in metal 1 as well as metal 6 metal 1 has higher sheet resistance 0.08 and metal 6 has lower sheet resistance 0.02 that is because the thickness of the material is increasing in metal 5 and 6. May be the material is still same for example, copper or something, but because of the deposition thickness which is higher in metal 6 the sheet resistance of metal 6 is lower. So, if we want to go for smaller and smaller resistance value we want to go for these metal 1 2 whichever is appropriate for our calculation. So, this is how we decide which one which material to choose for making this sheet this appropriate resistance. So, now we see how do we fabricate and we measure this sheet resistance. So, the fabrication process we discussed last lecture that we take substrate and deposit the metal on this. So, for example, we have just deposited some material with certain thickness on a substrate.

So, this is our deposited material now. Now we need to measure the its resistance which we do using 4 probe method. So, 4 probe method is something like this. This is our deposited substrate deposited magnetic material. Now, we put 4 probes on it. So, this is pad 1 and this side we put pad 2. These are the 2 pads to apply the voltage and then we have 2 more pads here which are generally to measure the voltage. Let us call these pads A and B. So, this is called Kelvin connected anisotropic magneto resistive sensor. Or we call AMR in short. So, in this sensor we fabricate we deposit certain material magnetic material on the substrate which is shown here in gray color. This deposited material now we put 4 pads on top of it to measure the electrical resistance. However, we just need only 2 pads for normal measurement we apply a certain known voltage across these 2 pads and calculate how much current is going flowing through accordingly R equal to V upon I we can calculate the resistance. But generally the resistance change in these type of sensor is very small. So, for very precise measurement in fact, whenever we want to measure a resistance very precisely instead of going for 2 probe measurement, we go for 4 probe measurement which we are going to discuss in a minute. This 4 probe measurement is also called Kelvin connection and that is why this whole sensor is called Kelvin connected anisotropic magneto resistive sensor AMR sensor which is Kelvin connected. So, this easy axis of the material is in line with the mechanical length. So, this mechanical length is in X direction which is the easy axis of this material now which we discussed in the last lecture as well. So, easy axis of the material is in line with the mechanical length of the resistor the material for example, material is Permalloy changes its resistance and we measure the change in the resistance per resistance. So, we measure delta R upon R the change in the resistance divided by the total resistance is measured.

So, that the base value of resistance does not impact the calculations. So, that the base value of resistance does not impact calculations. Now this above figure shows picture how do we measure this resistance. So, this use 4 point Kelvin contacts to minimize the effect of contact resistance between the Permalloy and connecting metals. So, we have this metal deposited and we put 4 probes on it the easy axis of the material is in line with the mechanical length and now if we apply a magnetic field on this assembly the resistance is going to change. We may generally measure delta R upon R instead of just measuring the change in the resistance which is delta R we measure delta R upon R which is the actual value of this resistance. So, that the base value does not impact our calculation we are just focused on how much change is there in per unit resistance. So, for example, percentage change in the resistance is what we are looking for. So, for that actually we measure delta R upon R for the measurement. Now this figure shows the how we do the measurement which is basically 4 point measurement and this is called the Kelvin connection.

So, instead of using just 2 pads we are putting 4 pads here and by the way why do we use 4 pads because whenever we have a material for example, here permalloy which is deposited here. Now we need to apply a certain voltage across this material permalloy. So, that we do using some external probes these probes are made up of some material for example, copper. So, when we connect these copper probes on the permalloy which is a different material nickel iron alloy. So, as soon as we connect this these different materials together there is a contact resistance which comes into picture.

So, we know that resistance of copper stand alone that is known to us we know the resistance of permalloy that is also known to us, but when these 2 different material joins that resistance the contact resistance is depending on which metals we choose and this is different for all the different combination of materials. So, when this contact resistance comes into picture this is also creates some extra resistance in the assembly which is not required or which is kind of extra to our system which should not be there. So, to deal with this contact resistance we go for Kelvin connection or this 4 point measurement. Let us see a little bit how do we do this 4 point Kelvin measurement. So, why Kelvin 4 probe method used? So, drawbacks of 2 probe method. So, is the error due to contact resistance. So, let us say we have this material which is deposited here. Now we apply a certain voltage and we have another source. So, this is the assembly this is point x and this is point y and this length is L. This is the current measured and this is the voltage measured. So, here we have this permaloy which is deposited I want to measure the resistance of this permalloy. So, what I do I apply a potential across these x and y point and the distance between them in length L. So, this potential is applied through this battery which is E here and now I measure 2 parameters one is the current flowing into this loop and one is the voltage measured across these point x and y. So, this voltage and the current flowing into this circuit it depends on how much is the resistance between x and y of this permaloy. In fact, right starting from these 2 points which is let us say I start calling x dash and y dash. So, between x dash and y dash whatever is the resistance that will dictate how much current will flow and how much voltage will build up.

Now between x dash and y dash there are 3 resistances one is the resistance because of the permaloy which let us say I call by this red resistance symbol. This is the resistance of permaloy which is known to us because we know which material we use and we know the resistivity. But at point x and at point y where this copper metal which is shown in blue when this copper metal is contacting this permalloy that time this contact resistance is not known to us how much it is that we cannot measure. So, I represent this resistance let us say by this green symbol resistance here and resistance here. So, now if we see overall between x dash and y dash we have 3 resistances one red and two green these resistances because of the contact resistance. And these contact resistance are always there because of this 2 different materials. So, we want to have only this red resistance which is due to permalloy, but these 2 resistances are always there and this is an error in our measurement because of this contact resistor. So, this is the problem with going with 2 probe method because the current need to flow in through this through these materials and these resistance are always there. So, they are going to give us a certain voltage across them and that is an error to our measurement. So, we go for a 4 point measurement where we put 4 probes one for measuring of voltage and one for the current.

So, current is in the total loop and voltage where we measure the voltage we do not actually flow any current into that. So, that the contribution by contact resistance is 0 if there is no current flowing into this contact resistance they are not going to provide any error in the measurement. So, this is what we do in 4 point measurement let us see how that happens. So, Kelvin 4 probe method produces 2 probes for supplying current and 2 probes for measuring voltage. So, in Kelvin connection we have like this. The first 2 probes 1 and 2 they are used for applying current. And the other 2 probes let us say A and B they are used for applying current. So, they are used for measuring the voltage only. So, this is how we do the measurement by 2 probes we apply this current which is independent to the measurement of voltage and these 2 inner probes A and B they do not carry any current because the impedance of voltmeter is very high. So, there is no current effectively flowing in A and B probe.

So, whatever is the contact resistance in probe A and B that does not impact the reading of voltmeter. So, we can precisely measure the potential across these 2 probes A and B and to calculate resistance we simply need to divide the this voltage divide by the total current which gives us the value of R. So, this is a 4 point Kelvin measurement and this inner probes does not draw any current. So, let us write this as well inner probes does not draw any current does not impact the measurement. So, this is what we have shown the anisotopic magneto resistive sensor where we deposit this permaloy and we apply a magnetic field and the resistance of this material changes that resistance we can measure directly using 2 probe or 4 probe.

So, we go for 4 probe measurement because these give us the more accurate result compared to the 2 probe measurement. So, this is AMR sensor the magnetic AMR sensor. Let us discuss now the GMR sensor which is called the giant magneto resistive sensor. So, the principle behind this GMR sensor is if we have 2 magnetic materials which are polarized in one direction then if there is a layer in between which is carrying current this current or this the resistance of this material is actually dependent on what is the polarity of the other 2 layers. So, let us discuss this GMR sensor the giant magneto resistive sensor.

So, in this type of material for example, we have 2 layers which are having one other layer in between. Let us say this is first layer in between we have a sandwich layer. So, let us say this is the first layer in between. So, let us say this is the first layer in between. So, this is the assembly of GMR sensor where we have 2 different magnetic materials shown by this red let us say this is A and the other one is green which is B now.

So, these 2 magnetic layers they are polarized in opposite directions red is polarized towards the towards the right and the green is polarized in let us say in the opposite direction. And if there is a current flowing in the middle layer which is this blue layer we are applying a potential across this through this battery and there is a current flowing this current get scattered by this opposite polarized magnetic materials and the current sees more scattering and the resistance seems to be higher in this case where these materials are oppositely polarized. So, 2 different ferromagnetic materials sandwiched by thin conductive layer and the mobility of electrons with the parallel spin is higher than those with anti parallel spin. And these magnetic layers are typically 4 to 6 nanometer and this conductive layer is typically 3 to 5 nanometers. So, here we have these 2 ferromagnetic materials and one conductive layer is sandwiched between them. Now the mobility of these charge carriers in the conductive layer this blue is the conductive layer. The electron mobility in conductive layer depends on how the other 2 layers are polarized if they are in opposite direction then the mobility of electrons is lower and if they are polarized in the same direction then the mobility of these electrons are higher. So, this can be easily detected using the external circuitry and we can check whether the both the materials are same are polarized in the same direction or the reverse direction. So, depending upon this we can find multiple applications of this kind of sensor or devices one application of these is the hard disk, where we have this magnetic material coated on the disk and the head which reads the data on this hard disk that is kind of GMR sensor.

Other application is making logic gates using these materials. So, for example, A and B layers if they are similarly in the same direction they are polarized that can be a one state if they are oppositely polarized that can be treated as a sec the second state. So, we can use these kinds of GMR sensors as the logic devices as well. So, this is the case shown here where the the both the metals both the materials are polarized in opposite direction and in the same direction, we can have the higher mobility. So, we can plot that as well. So, this is the lower mobility case where we have this scattering and lower mobility.

In another case if both are polarized in same direction. So, this is the case shown here where the both are polarized in opposite direction this green is also in the same direction this is A this is B and this is conductive layer and we apply a voltage across it. So, because of these two layers polarized in the same direction we have lower scattering and higher mobility. So, this is what the thing is GMR sensor or giant magneto resistive sensor and this is how it works. The typical applications are in the magnetic hard drives which we use in computers.

There we have a disk which is coated with these magnetic materials when we write on these magnetic disk the the head actually polarize the magnetic material in a certain direction and while during reading head reaches to this location and check whether this is polarized in the same direction or in the opposite direction if it is in the same direction the current of in this head increases if this is polarized in the reverse direction the current in the head decreases.So, this is how we do reading and writing in typical computer hard drives. This is the one typical application of GMR sensor. So, today we discuss two magnetic sensors one is the AMR sensor and one is the GMR sensor.

So, this is all for today.

Thank you.