Materials Chemistry
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Module - 5
Lecture - 4
Spintronic Materials III Tunneling Magnetoresistive Materials

In the last 3 lectures, we have been looking at, the issue of Magnetoresistance and any material which loses its resistance in the presence or absence of magnetic field becomes very interesting.

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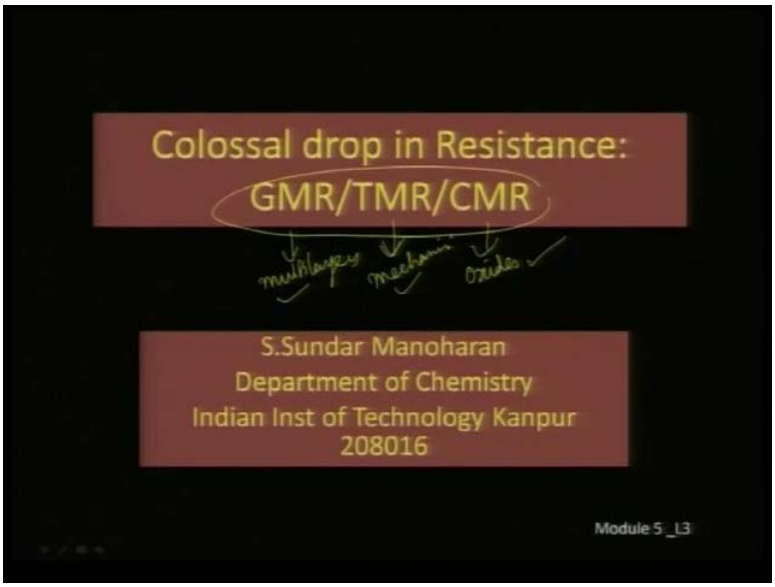

In the first example, we looked at rare earth manganites, which actually has a gene inside the lattice, the magnetism controls, the electrical conductivity and as a result, there is a huge drop in resistance when you try to disturb the magnetic ordering there. And in the next example, we saw it need not be a ferromagnetic material in bulk, but if you can make stack layers of ferromagnet and antiferromagnet or ferromagnet and a spacer layer, then you would expect a colossal change in the resistance.

So, we looked at the few examples of this metallic multi layers, we are actually looking into the theme of, the various aspects of magnetoresistance, we call it G M R, we call it T M R, C M R. G M R and T M R are predominantly involving metallic ferromagnetic layers, whereas C M R is confined more to oxides. So, we looked at the example of C M

R, we looked at example of multilayers of G M R and we looked little bit into the mechanism of T M R, which brings about a colossal change in resistance.

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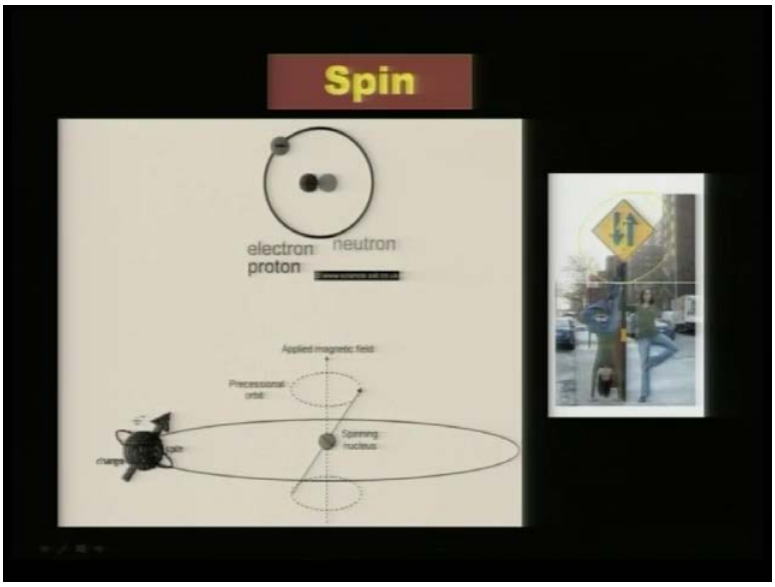

Just to give you a recap of what is the central issue, the issue is to make use of the electron spin, electron has a down spin and electron has a up spin; therefore, you can try to exploit, the orientation of this electron spin up or spin down and you can try to moderate the electrical conductivity.

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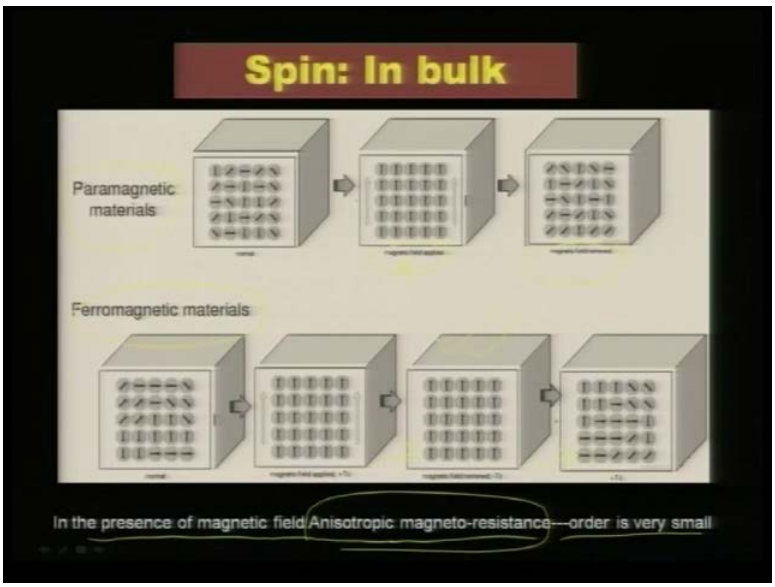

In the bulk, there are ferromagnetic materials, as you know paramagnetic material is best exemplified in this fashion, when magnetic field is removed, the moments are oriented in random way, whereas if when they are aligned, when applied magnetic field is stronger and it can reorient all this in 1 direction. So, this is the situation of a paramagnet and then we also looked at a typical ferromagnet, typical ferromagnet gets ordered below T E C, they are ordered like this and above T C, they get reoriented into a paramagnetic phase.

Now, the point is the presence of magnetic field produces only anisotropic magnetoresistance and the order of such change in resistance is very, very small, as a result, you cannot bring about a colossal change in resistance, when you are looking at anisotropic magnetoresistance. Therefore, you need to use the same ferromagnetic material, but you should align it, in different way, you should stack it in different way, then you can induce a colossal drop in magnetoresistance.

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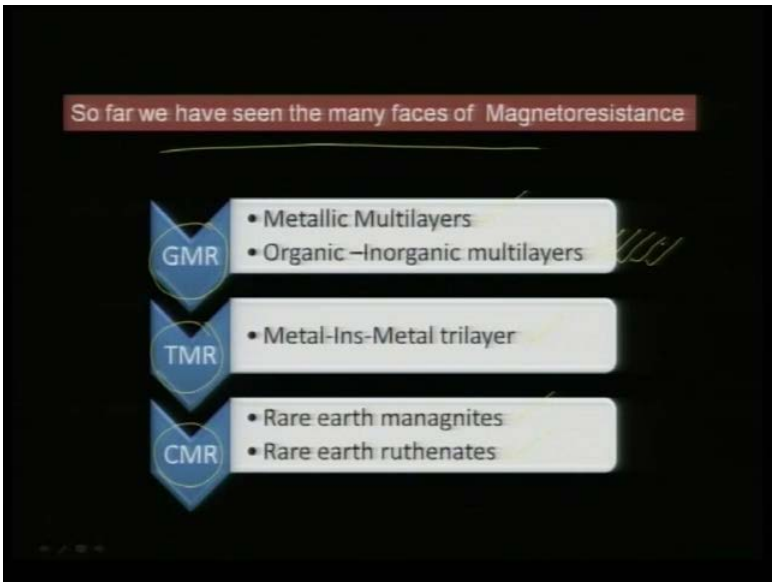

So, far we have seen the many phases of magnetoresistance, we call this as G M R, we call this as T M R and we call this as C M R. A G M R predominantly, we are talking about metallic multilayers and organic inorganic multilayers, in T M R we looked at metal insulator metal trilayers and C M R predominantly rare earth manganites and ruthenates. Today, I am going to spend little bit more time on this issue, of organic inorganic multilayers and why it is advantageous, why we need to go for such a combination of organic, inorganic multilayers.

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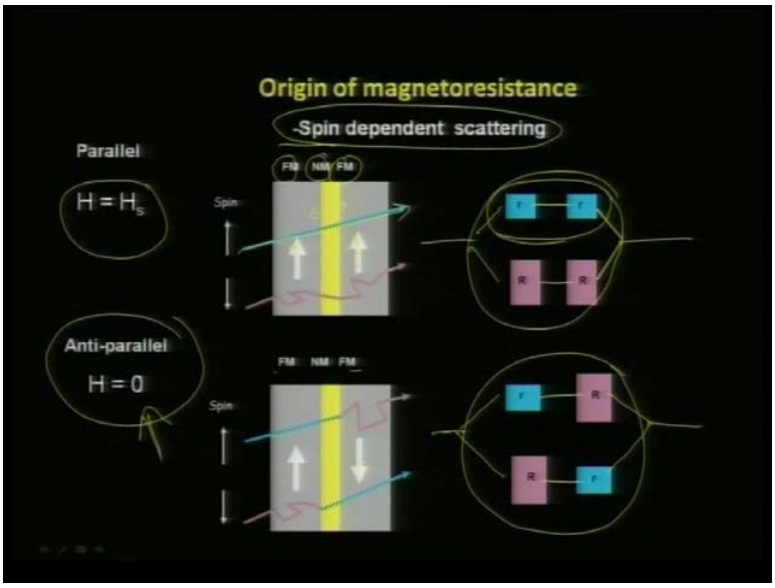

Now, just to bring back to focus, the 2 important mechanisms, that governs, we said if there is a ferromagnet here, which is aligned in this direction, ferromagnet here, which is aligned in this direction. And it is separated by a non magnet of this dimension, then you have 2 different resistance pathway, one is if the up spin electron is going from here to here, then you have a resistance pathway in this form and if you have a down spin, then you have a resistance pathway in this form.

So, if you are, if it is an antiparallel direction, your ferromagnets are antiparallely aligned, then you have a different pathway for resistance and this is the model that, we proposed. So, overall if you have a antiparallel situation, then you have larger resistance and if you apply a magnetic field, you have a smaller resistance, specially via this form, which we call it as short circuit therefore, you can see a change in the magnetoresistance, this is mostly a spin dependent scattering, which happens across the interface.

The other one, we also told about the mechanism of a tunneling magnetoresistance, in the aligned case, you actually have the spin up electrons going from here to here, when they are aligned parallel. And in that case the spin sub bands, both are same, whereas when it is aligned in antiferromagnetic fashion, the spin up band is located here, whereas in this case spin up band is located here. Therefore, there is a reluctance for this electron to go here and therefore, this resistance is going to be greater in the antiparallel way. So, these are 2 important considerations, for the resistance across multilayers.

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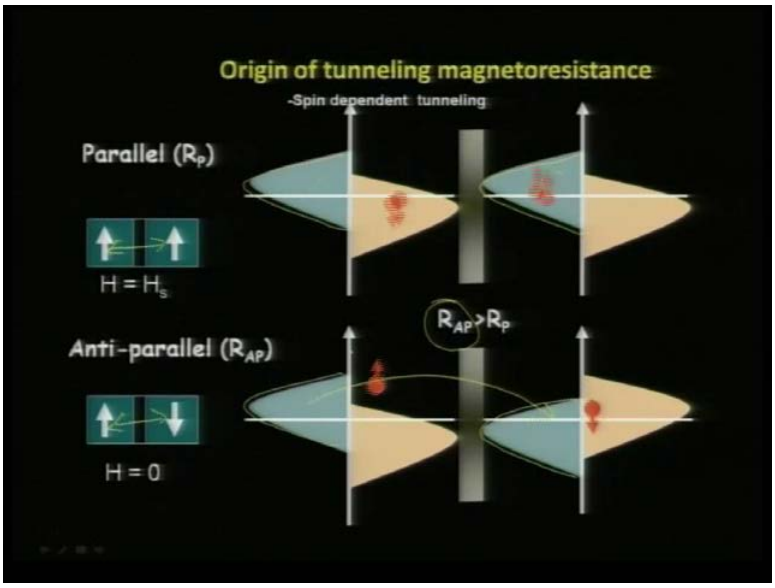

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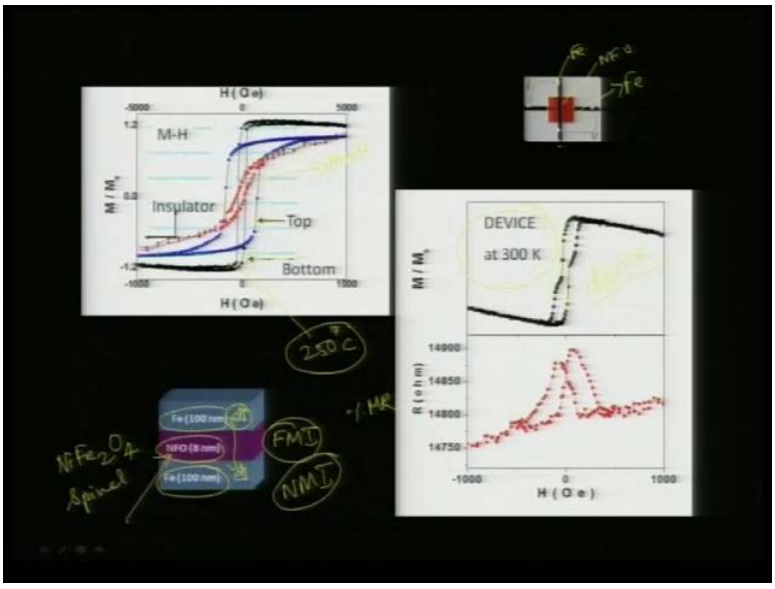

Another example that, we can think of is instead of a insulator a nonmagnetic insulator, you can try to replace that with a ferromagnetic insulator, what would happen, if there is a ferromagnetic insulator, then electron when it goes from here to here. If suppose, it is up spin and then it has to retain, it is spin memory, when it goes to this layer and in that case, if there is a ferromagnetic ordering or if there is a ferromagnetic alignment, in this insulating phase. Then the spin up can have the, this electron can have a spin memory, which can be retained as it goes to this layer.

So, this is also a useful concept instead of using a nonmagnetic insulator, you can go for a ferromagnetic insulator, to maintain the spin memory, as the electron goes from one electrode to the other electrode. So, in that case, what is a situation, this red M H loop, M versus H loop, what do you see here corresponds to nickel ferrite, N F O is nothing but N i F e 2 O 4, which is a spinal, spinal ferrite and this is ferromagnetic.

And this is a insulator, typically it gives magnetic hysteresis loop of this fashion and you also have the hysteresis loop of the unsintered iron layer, which is having a rather different coercivity compared to the bottom layer, which is actually grown at a 250 degree C. So, you have essentially, same thickness of iron, but with different coercivity, because in one case you grew the film at 250 therefore, the coercivity changes and other case, you have iron, which is deposited at room temperature therefore, it has a different coercivity.

So, you have 2 different coercive ferromagnetic electrodes and separated by a ferromagnetic insulator, typically you would see, the device showing the M versus H loop in this form. So, what is unique about, this you have this staircase, you have this staircase type of hysteresis loop, which is typical for a device. So, if a device is performing, then you have the staircase sort of feature and then the magnetoresistance also shows a pronounced activity, you can see although the order of percentage M R is rather low.

But, you can clearly see this butterfly shape, butterfly wing shaped M R curve, which clearly shows that, this sort of magnetoresistive feature can be accomplished with a ferromagnetic insulator. So, this is another example, one can think of you can make this device in this fashion, you first put iron electrode and then this is your N F O layer and then you put another stripe of F e, then you can measure the voltage, that develops across this interface.

So, this is one example where, we can show that you can use variety of spacer layers not just nonmagnetic layer, you can use M G O, we have already seen one example of M G O, which is neither magnetic nor it is metallic, but it is a antiferromagnetic insulator and this is also showing a pronounced tunneling magnetoresistance.

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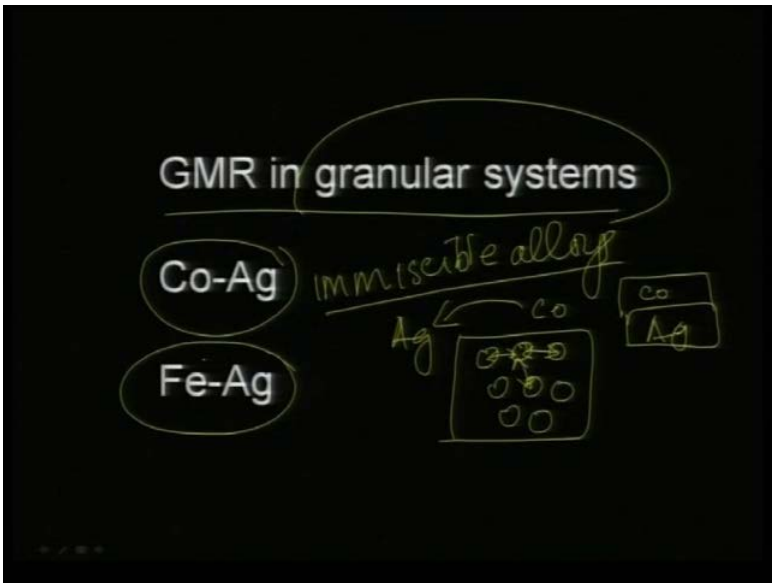

Now, G M R can also be seen in granular systems, what is granular system, for example if you take a cobalt silver, these 2 are not miscible, in other words, we can say they are immiscible, they are immiscible alloys. So, if you actually deposit say silver layer and then you try to put cobalt layer, it would not grow as a silver layer and then as a 2 dimensional cobalt layer. What would happen, because of the immiscibility all the cobalt will actually form clusters, they will form clusters of cobalt atoms and it will be deposited on the silver matrix.

Now, the interaction between these clusters will determine, what sort of magnetoresistance that you can get and this is also called as granular system, one drawback about the granular system is the field sensitivity is less, we can also achieve that, using iron and silver. Now, you can make several, such composites, for example, one can run through nickel ferrite P P Y, this is a example of how this G M R can be seen, even in bulk, because your N F O is nothing but ferromagnetic insulator. You can try to provide the conducting pathway by coating, it intimately with the polypropylene, so or polypyrrole. So, in this case you take pyrrole and you try to polymerize in situ with suspended nickel ferrite.

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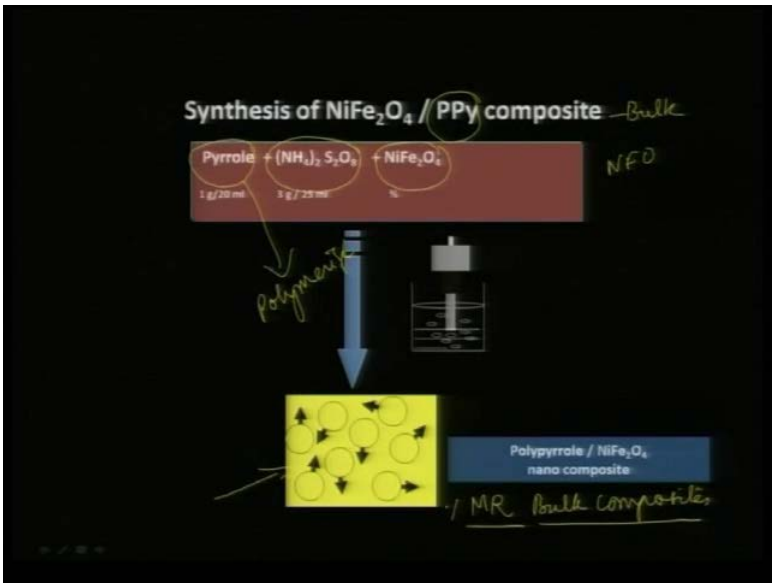

So, as pyrrole is getting polymerized, you will see that, these nickel ferrite particles are coated intimately by pyrrole polypyrrole, as a result you get a conducting matrix like this. So, the moments are actually aligned randomly and you have the polypyrrole matrix, which is actually holding all these nickel ferrite clusters, now this can give us some clue whether, we can achieve magnetoresistance in this sort of bulk composites. Because, so far, we have seen whether, there is pronounced m r in metallic multilayers, now we can also see whether, there is any faint chance of harvesting a large percentage magnetoresistance in bulk composites.

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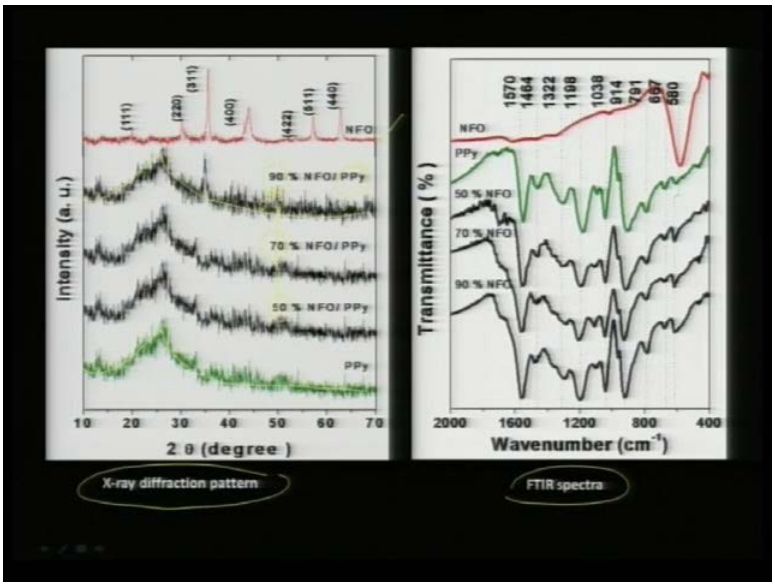

If you actually take a look at the infrared spectra and the x-ray diffraction spectra, you would find, it is very interesting that, the pure N F O, that is nickel ferrite gives a typical spinal pattern whereas, the P P Y, which is a polymer gives you amorphous pattern.

Now, if you keep loading nickel ferrite in P P Y to the order of 50 percent 70 percent or 90 percent, in spite of loading that much of nickel ferrite, even with little percentage of P P Y, you can see still the faint amorphous pattern dominates over the crystalline nickel ferrite. What it suggests that nickel ferrite can be intimately coated by polypyrrole, as a result you can try to measure the magnetoresistance in bulk, in such composites.

The infrared spectra also gives you clue about the this particular band, which is propping up with the increasing N F O, because this is a characteristic nickel oxygen bond, which can be seen in this N F O P P Y matrix. So, one can actually make quite a bit of composite materials with the wide range of loading capacity.

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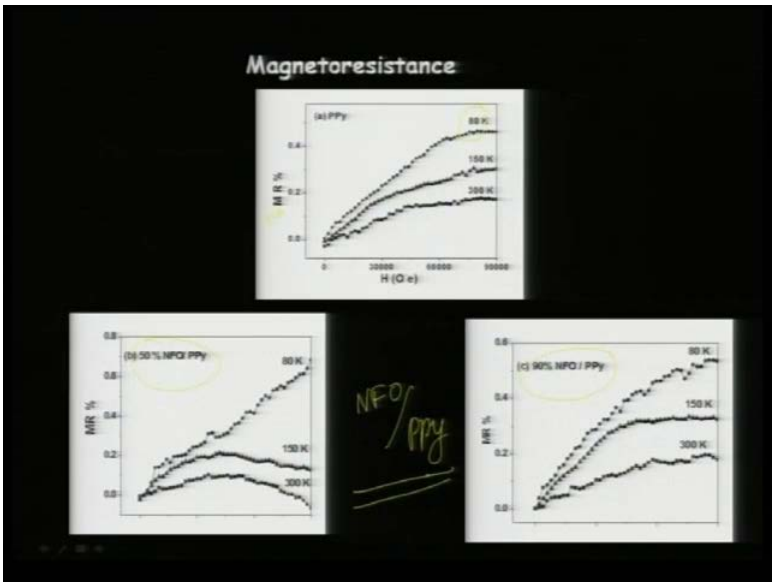

And one can see, whether this also gives pronounced G M R, if you actually take polypropylene itself, which is a metallic polymer, you would see that, there is a positive magnetoresistance and it is of the order of less than 1 percent although, but it shows a more significant M R at 80 K.

But, what we find here for a optimum composition of 50 percent N F O, which is a N F O P P Y composite, we see M R is much more higher than, even the 90 percent. So, there

seems to be some influence of the N F O loading, on polypyrrole and there seems to be some way, that we can look for a magnetoresistance, even in these bulk composites, although the magnitude is less.

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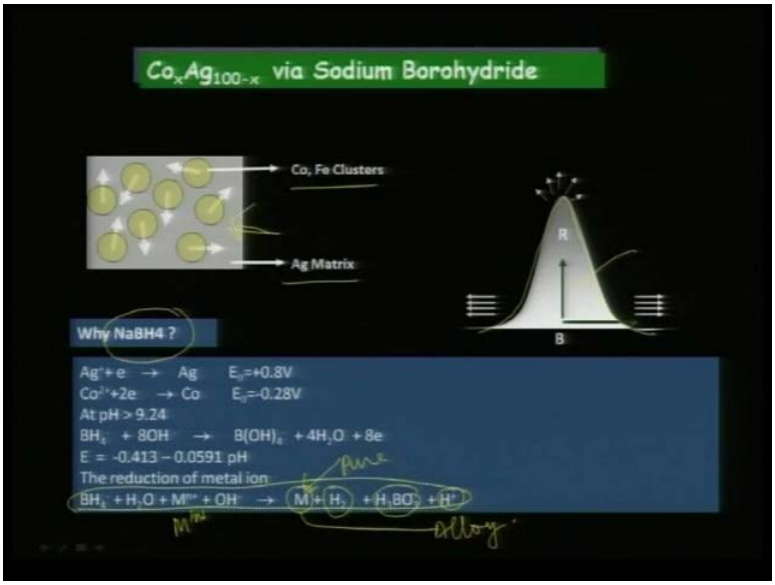

We can also look at the other granular system that is cobalt silver, again in this case you have the iron or cobalt silvers, which is dispersed in the silver matrix and we can achieve this sort of cobalt silver alloys by using sodium borohydride as the reducing agent. And this is the overall reaction, as to what happens sodium borohydride reacts with metal salts and it releases metal and boric acid and all this can be easily removed filtered, therefore essentially, you get a pure metal.

If you are going to take 2 metals M N and M prime N plus, then you can actually get a alloy and this alloy can be nano in size, as I told you, if it is a granular M R, the feature is something similar to this. Where, you have the saturation value is rather high, because the switching phenomena of this randomly oriented moments takes larger field, as a result you have a very low saturation effect.

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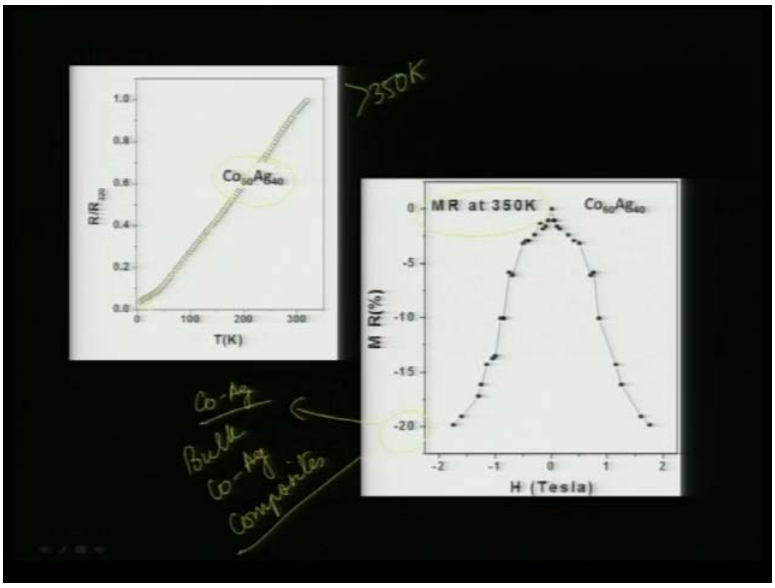

Nevertheless, we can see for a 60 percent cobalt doped silver alloy, in other words 60 40 alloy, we can say, you see a very nice trend of a metallic behavior down to 4 Kelvin. And we have tried to measure the magnetic property or the T C, for this alloy and this is reported to be above 350 Kelvin.

Because of the measuring constraints one cannot measure magnetoresistance beyond 350, so for this reason, we have tried to measure the M R at 350 and we see that, near to T E C. This sort of granular alloy show a pronounced effect of up to 20 percent M R in this bulk, cobalt silver composites, this is new, because there are no reports where, cobalt silver alloy is known to show such high values. It is possible from this work, that one can try to prepare by either sputtering or other methods to prepare cobalt silver films and try to look at the T C close to sorry, M R close to the T C.

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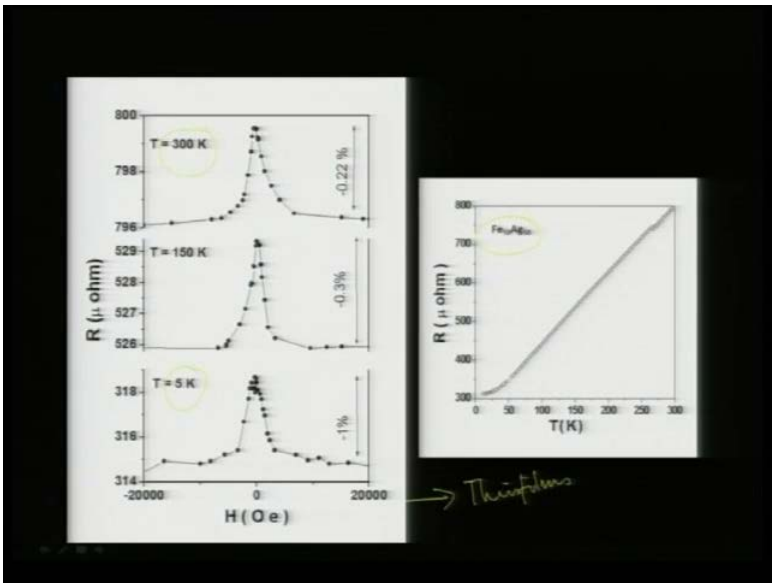

We can also try to do this with the iron silver alloy composites where, you see again a clear metallic behavior down to 4 Kelvin and one can see that, with increasing temperature the resistance increases and M R shows a very clear feature. Although the M R percentage is significantly low, but it is showing higher proportion at 5 K compared to 300 K.

So, you have another composition iron silver 50 50 alloy, which also shows similar trend where you, see lesser M R percentage at room temperature compared to 5 Kelvin and this can be engineered for applications, if we can translate this composites into thin films.

So, I have shown you a variety of combinations of alloys, which show M R behavior, just to sum up at this stage, what I have shown to you is that, this stacking of multilayers is very important. And one can try to engineer a variety of combinations, as spacer layers and we can try to observe significant M R, in cases of metallic multilayers and there is lot more work to be done for spacer layers, which are not traditionally metallic.

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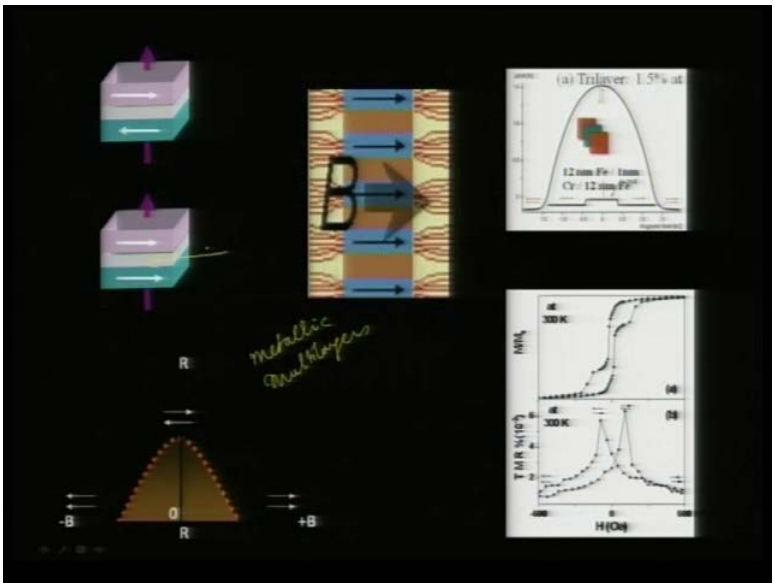

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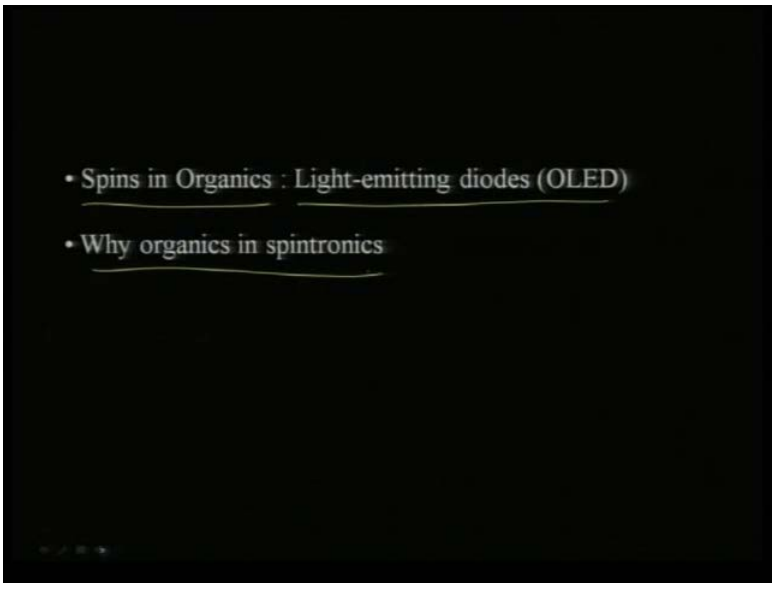

So, we will go to another important issue of organic multilayers, we can start from the origin where, exactly this idea stems from this is known as a dominant feature in organic light emitting diodes. In organic light emitting diodes, we have almost all the layers, which are organic, but for the anode and the cathode. So, why these organics can be brought into spintronics, what is the need and what are the advantages over the metallic multilayers is the question.

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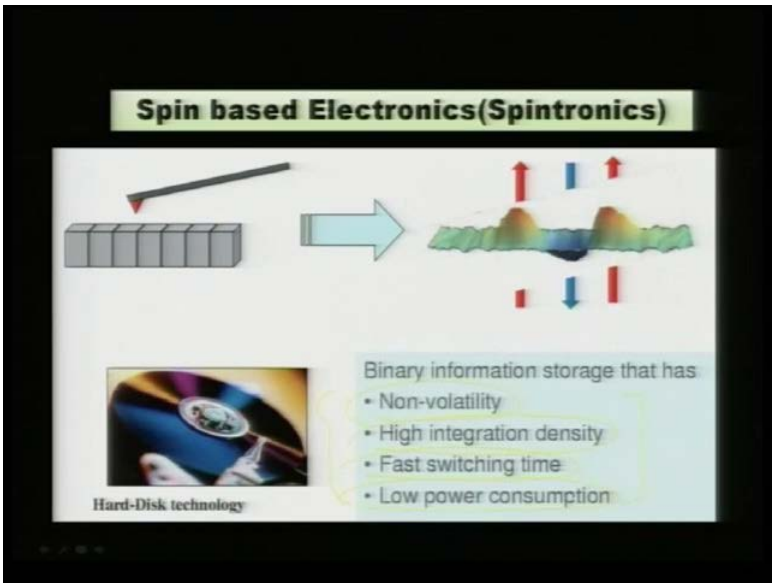

Now, spin based electronics as you know, we can try to read the information of each of this domains, if we can look at the spin orientation. So, depending on the spin orientation, you can have a binary information storage, that has non-volatility, it can have high integration density and fast switching time and low power consumption. All these are advantageous for spin based electronics, which are obviously, absent or a incurs costly penalties when you think of the regular semiconducting industry. So, for this reason, we need to a look at new possible avenues where, we can try to look for wider applications involving organic spintronics.

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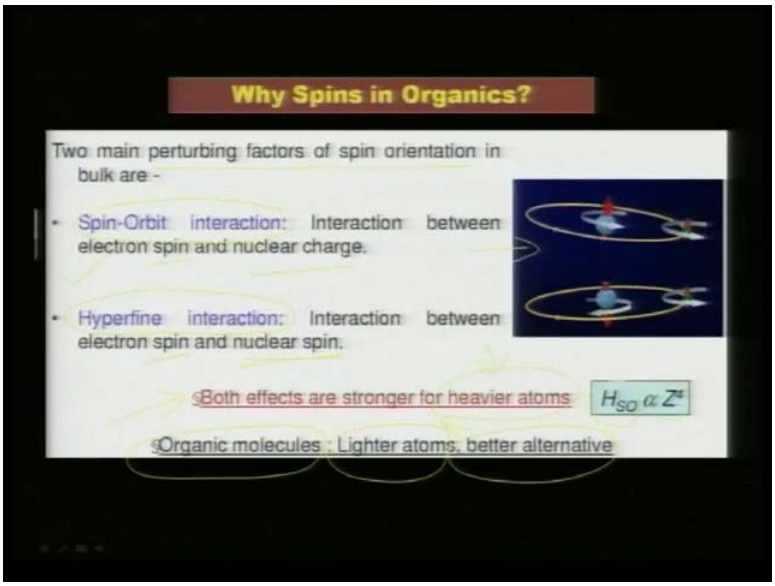

Now why spins in organics, there are 2 perturbing factors of spin orientation in bulk, number 1 you have spin orbit interaction, in this case interaction between electron spin and nuclear charge are becoming important. And this is more pronounced for heavier atoms, the spin orbit interaction is more pronounced for heavier atoms. And then you also have another competing interaction, which is hyperfine interaction, this interaction is between the electron spin and the nuclear spin.

So, you have 2 issues that, you confront in the multilayer systems, specially when you think of spintronics one is electron spin interacting with nuclear charge, another one electron spin competing with nuclear spin. As a result you have the spintronic values or the magnetoresistance values are considerably low, specially when you involve a heavier atoms, because the spin orbit coupling contribution is of the order of Z to the power 4.

Z is the nuclear charge, as a result, since this is dependent on a Z power 4, the contribution of spin orbit coupling is usually dominating and that is why, we should try to see whether we can completely ignore this contribution, so that you can maximize on the G M R or the magnetoresistance ratio. There comes the issue of organic molecules, if I need to subdue this both these effects, then I should look for organic molecules, which are lighter atoms. And they are better alternatives, because you can minimize both on spin orbit coupling and hyperfine interaction to a larger level as a result, there is a search for new compounds.

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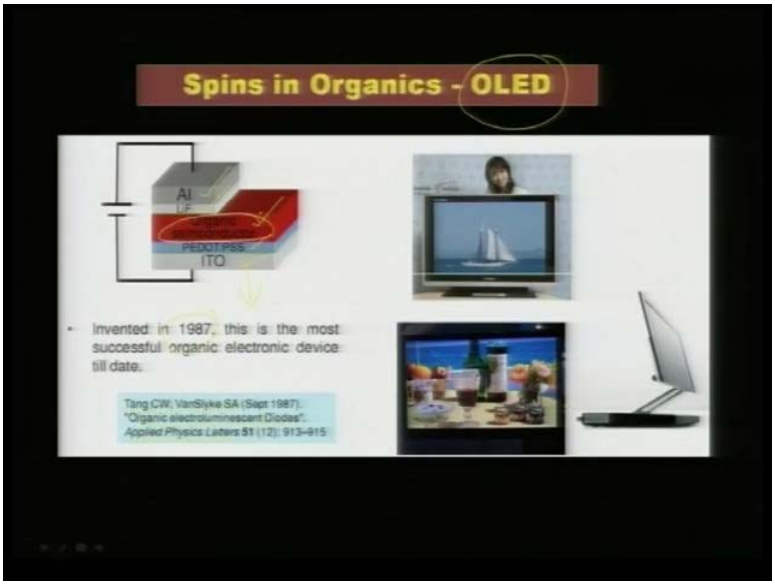

Now, where does organic come into picture in electronics, the classic example is that of organic L E D, because in the year 1987, it was van Slyke and tang, who actually reported organic electro luminescent devices, a which appeared in applied physics letters. And a typical organic L E D configuration is like this, you have the transparent I T O, which is compounded, which P dot P S S, which is a whole doping layer and then you also have aluminum as cathode with a small barrier lithium fluoride.

Now, if this is sandwiching a organic semiconductor, then light comes out of the I T O layer, which brings about a new generation of display devices. These are all the oled devices, which are presently coming into market, you can bring down the screen size, because you can go for large area and also you can minimize on the deposition intricacies. So, organic semiconductors brings about, a new generation of devices, which involves a spin 2.

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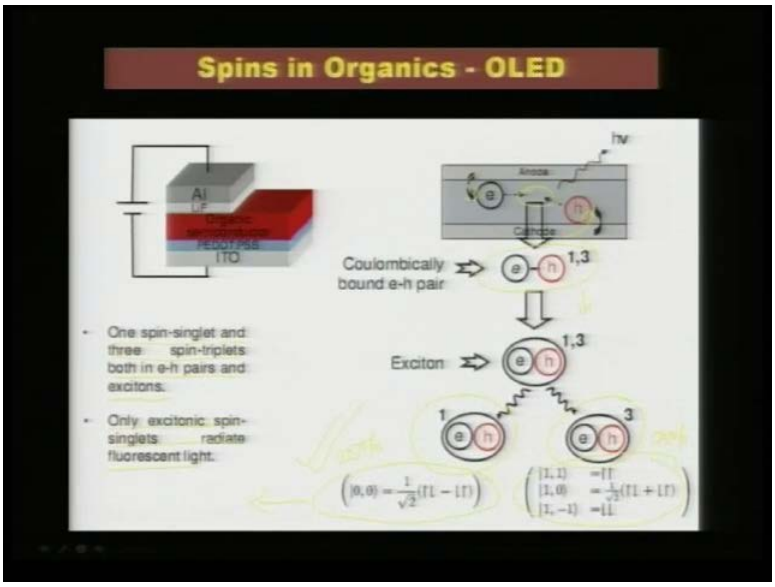

Now, spins in organics is construed in this way, what is the mechanism of this organic L E D, as you see here electrons come from, the anode and then holes go from the cathode and they do combine here. When they combine first they are held by a coulombically bound electron hole pair and this value 1 3 specially, refers to 1 spin singlet and 3 spin triplets, both in electron hole pairs and they together combine as excitons. So, as electron hole pair, the proportion is 1 spin singlet and 3 spin triplets.

Now, they together combine to form a exciton with a singlet proportion and a triplet nature. So, you can actually have the singlet exciton and the triplet exciton, of which the excitonic spin singlets are the ones, which radiate the fluorescent light, in other words, if you look at the spin statistics, you have 25 percent or 1 4th of the possibility is the singlet exciton and 3 4th of the possibility is the triplet exciton. And because of spin rule, spin selection rule, only the singlet excitons are allowed to radiate and therefore, they account for the light that, you see in a organic LED.

In other words of the of the excitons, that are produced due to electron hole combination, you have only 25 percent, which is responsible for the light emission and 75 percent is spin forbidden. There are ways to harvest this, if you can annihilate this triplets, then you can convert this into singular pair and thereby you can increase the efficiency of this singlet excitons, which radiate florescent light.

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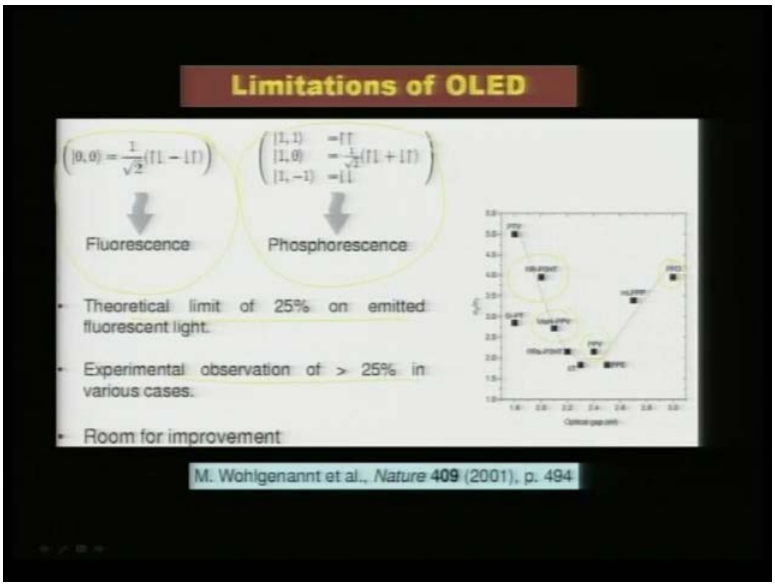

So, this is what, I said the singlet, which is responsible for the florescence and the triplets excitons, which are responsible for the phosphorescence, this is the theoretical limit and the experimental observations are slightly higher than 25 percent in various cases. Now, these are some of the organic molecules, which are used in the current oled devices and mostly, these are all polymers P P V P F O M E H P P V and P 3 H and so on.

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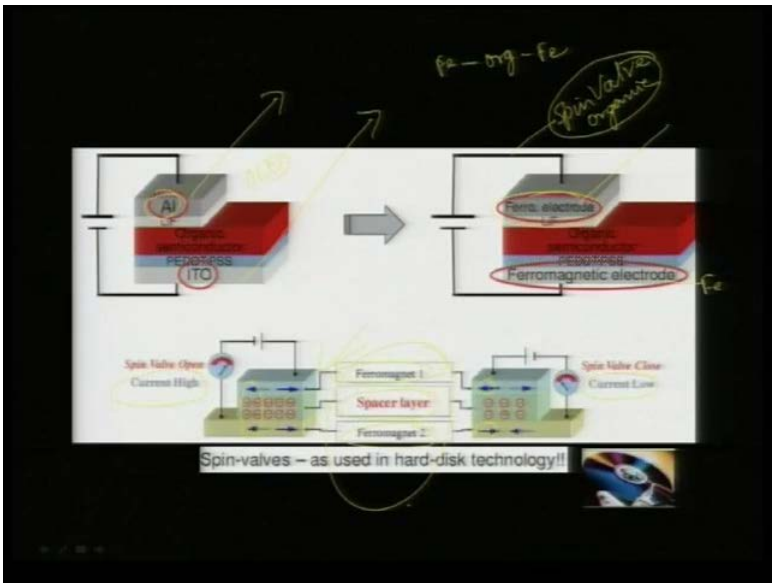

Now, how do how can, we translate the spin L E D into a spin magnetoresistive device, if you carefully look at this configuration, this is your oled device. And if you want to convert, it into a spin valve all you need to do is replace this anode a cathode and anode by ferromagnetic electrodes. So, if you replace I T O with a ferromagnetic electrode, if you replace aluminum with a ferromagnetic electrode, then you are essentially making a spin valve device, which involves a organic layer.

This ferromagnetic electrode can be a metal inorganic metal, such as say iron or it can be cobalt, so essentially you are making a iron organic iron electrode or device, where you can look for this spin valve operation and this is typically, the way we can cartoonize the spin valve structure, that involves a organic where, you have a ferromagnet 1 and ferromagnet 2, this is the organic layer.

And as you see that, when they when the ferromagnets are aligned, then there is more of electron mobility as a result, you have a current high situation when the spin valve is open. Now, if they are antiparallely aligned, then you have current low and therefore, even with this sort of a configuration, ferromagnet organic layer ferromagnet device, you can essentially bring about a spin valve response, using organic.

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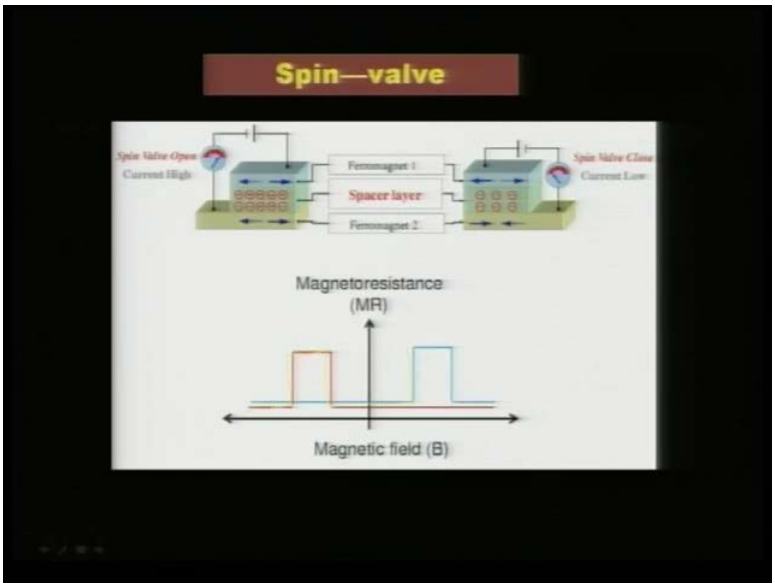

And this is the way that a spin valve will work, if you have this sort of a configuration, then you will see a sharp rise in the resistance, as a result you can imitate this to be like a inorganic spin valve.

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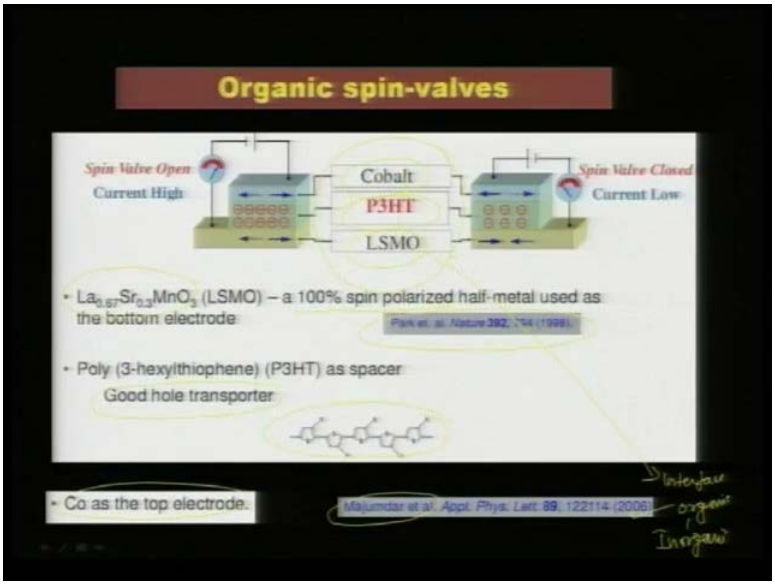

So, in organic spin valve, what are the examples park, actually reported, this first work where he used L S M O and cobalt as the ferromagnetic electrodes, one of the reason why L S M O, which is lanthanum strontium manganese oxide, which is used is because this is known to be a 100 percent spin polarized half metal and therefore, we can use this

as a bottom electrode and the interface also can by and large can be moderated, if you are going to put a organic layer.

P 3 H T is nothing but a thiophene moiety with substitutions and this is a good hole transport layer, as a result we can try to have this, in between 2 ferromagnetic electrodes and the cobalt can be used as a top electrode, which is reported by majumdar and coworkers and they have reported this in 2006. So, this is a typical configuration of a organic spin valve, where you are essentially using ferromagnetic electrodes and your middle layer is your organic, but what are the problems here.

Problems in making this is to do with the interface, because to grow a organic and a inorganic interface, it is very, very difficult, because this organic layer should be good enough to wet the inorganic layer or the inorganic layer has to be atomically flat. So, that you can make a very thin 2 dimensional layer of your organic, which is the challenge, otherwise many such structures could have been realized by now. So, far the limitation is you cannot grow a good interface here, because of the roughness that is coming from the inorganic layer, and because of the growth mode, which can vary for the organic layer.

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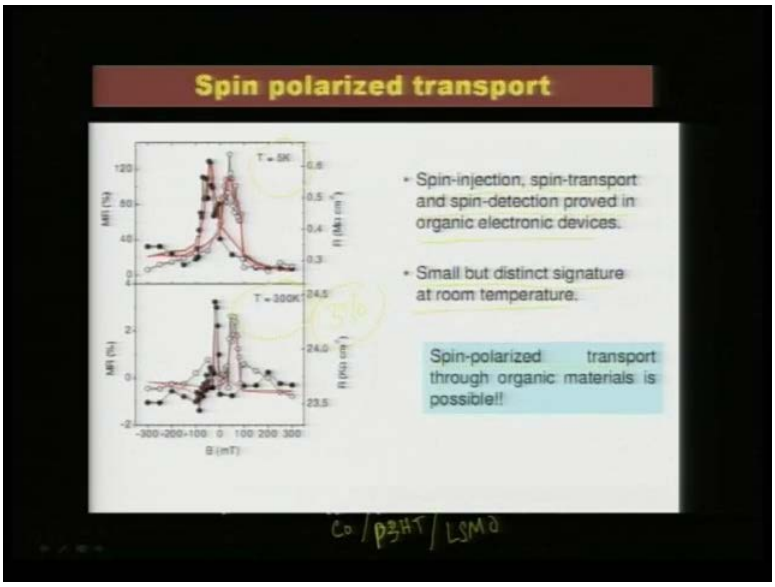

Never the less you for the device that, we saw which involves cobalt P 3 H T L S M O layer, you can see here, the magnetoresistance at 300 K and magnetoresistance at 5 K, it is sufficiently remarkable response is there. In this case, you can see at 5 K a very large response and in the other case, you see a faint response of above 3 percent at 3300 K,

which is not a bad number, considering the metallic multilayers, at room temperature definitely, there is a good response for this device. A spin injection and spin transport and spin detection seemingly are proved in this organic electronic device, these are small, but distinct signature at room temperature therefore, spin polarized transport through organic multi materials is therefore, possible.

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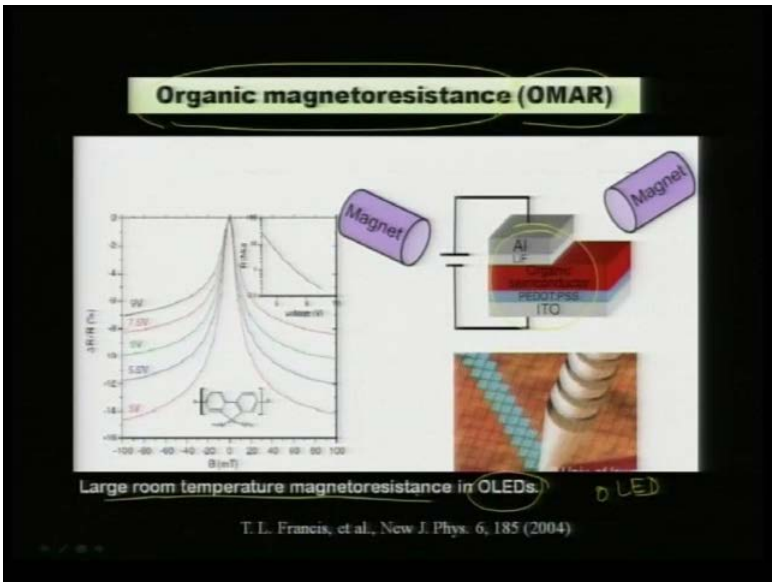

So, what is this organic magnetoresistance, which can be called as OMAR organic multilayers, first even before a typical organic spin valve was done, a typical oled device was taken and magnet was kept in closer proximity. And this is the response, that you would see a huge change in the resistance with the driving voltage is realized, when you have P F O as the organic layer. And therefore, a typical oled device, can also give you a large magnetoresistance, it need not necessarily involve a ferromagnet organic ferromagnet trilayers, even a typical organic L E D can give you large room temperature response.

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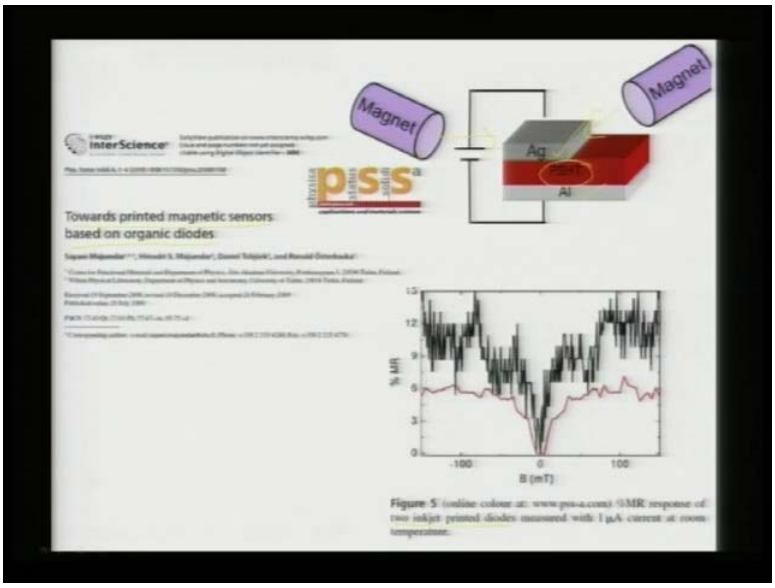

Because of the spin statistics, that are involved in such phenomena, using this as a clue, towards printed magnetic sensors based on organic diodes. Majumdar group have come out with another structure, which involves, silver aluminum and P 3 H T and put it between the magnets and then you can see a clear M R behavior that can be seen. This gives us the challenge to go for printed electronics, which is another good development in this field using organic layers.

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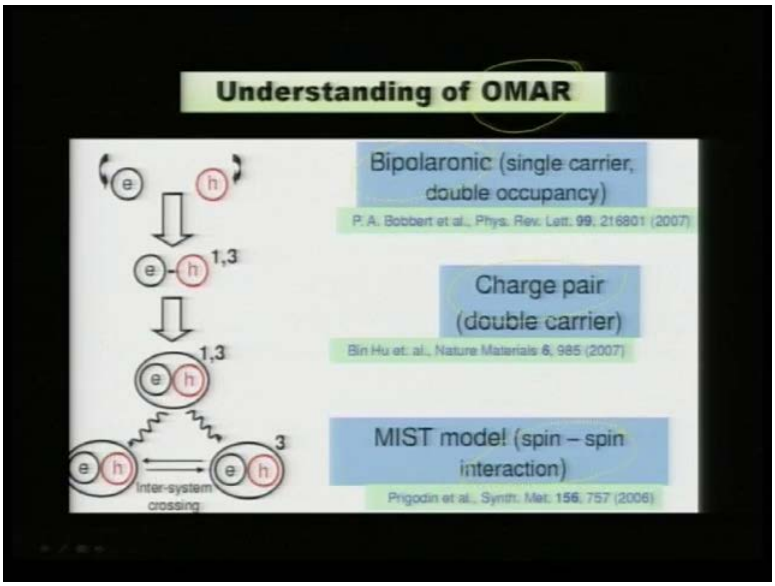

So, one can go for different models and how do we understand the organic magnetoresistance. There are several issues, that are being addressed one is the bipolaronic issue, then the charge pair issues and also this spin interactions, all this are discussed in different examples, which are quoted in the recent past.

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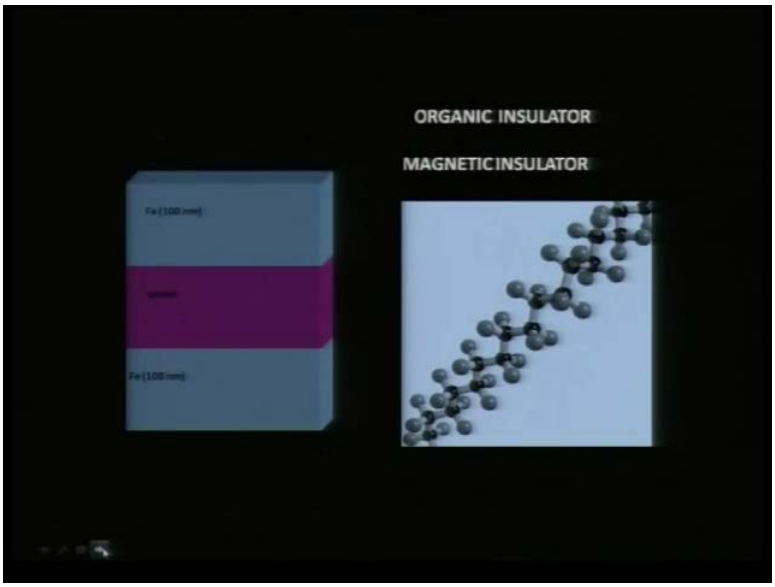

I would like to leave with the one more example on organic insulator, we can take 2 ferromagnetic layers and we can put a spacer. And the spacer can be a nonmagnetic insulator, which is a organic layer.

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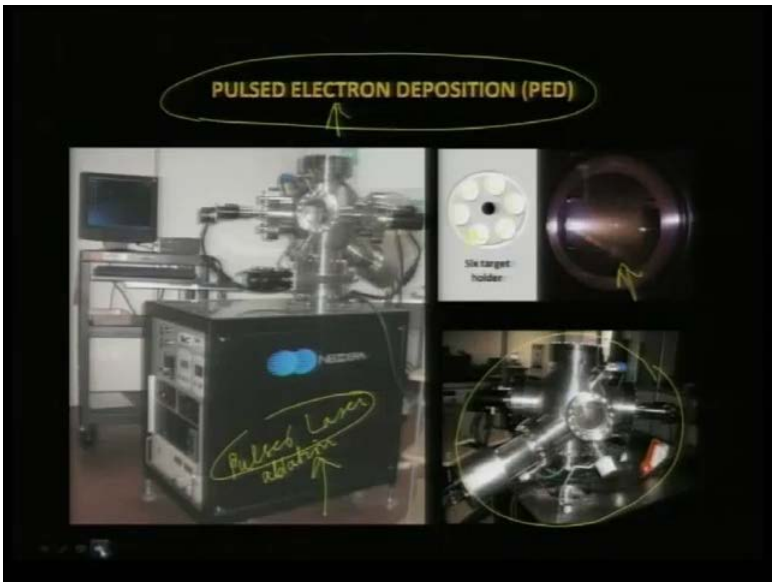

And what would happen in such situation, we can try to make this sort of organic layers using, pulsed electron deposition, which is a rugged facility and this is a typical pulsed electron deposition chamber, which has facility for a 6 target carousal. And you can use this pulsed electron beam to ablate the material from the target and typically during a ablation protocol, you would see the plasma, that is coming out.

Because, you can essentially use this pulse beam, for any type of material not only metallic, but you can use organic material, you can use insulating material to ablate this sort of compounds and this is the over all setup while in use. So, we can see some examples as, to how we can look for magnetoresistance using organic layers in the next slide.

So, this is a very good facility for making organic trilayers, mainly because the insulating organic material can easily be ablated, this is very different compared to pulsed laser deposition. Pulsed laser deposition is a technique, where laser plume, laser light falls on the target something like this and then it ablates the material, but if the material is insulating and it has a wide band gap, then it is difficult for the laser light to be absorbed by the material and ablation will be remarkably low. So, for this reason, you can replace that with a electron beam, then you can try to ablate any material, either metallic or insulating material.

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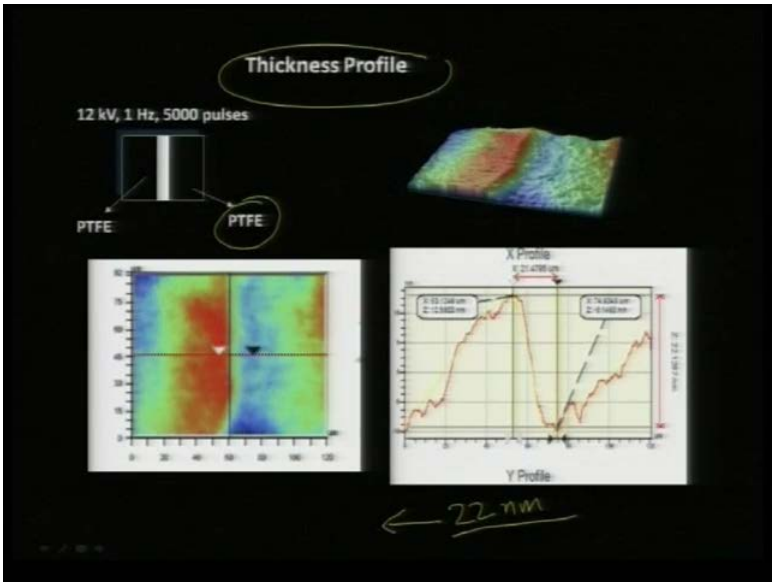

So, you can make any device applications and this is typically for the compound P T F E, which is commercially known as Teflon. Teflon is a good insulator and we can use Teflon as a organic layer between 2 ferromagnetic electrodes and typically, if you have the P T F E deposited, using P E D. You can see the thickness profile and this thickness profile is evaluated from a profilometer and you can actually go up to 21 22 nanometers, thick P T F E layer can be deposited. And this is how you can look at your thickness profile, one can also go down up to 5 nanometer comfortably with a continuous deposition of this film in 2 dimensional way.

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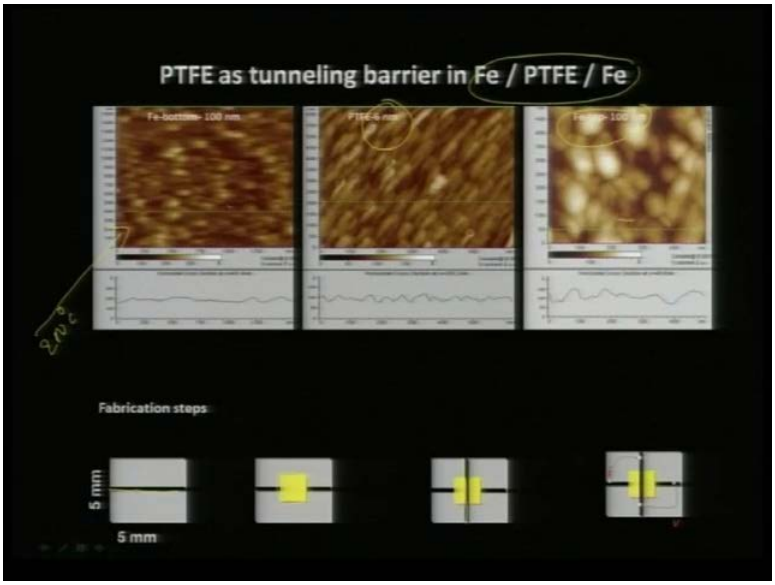

So, after ensuring that, it is possible for us to make a device structure of this configuration iron P T F E iron trilayer, how do you go about it, first you put a iron stripe like this and then we can put the organic layer. And then you can put one more metallic layer on the top and you can measure across the electrodes and then you can also see the A F M images of the iron layer, which is deposited as a bottom electrode.

This is actually deposited at 200 degree C and then you can put a 6 nanometer thick P T F E film, the surface looks like this. And then the top layer, which is actually deposited at room temperature shows a much larger grain size compared to smaller grain size for iron electrode.

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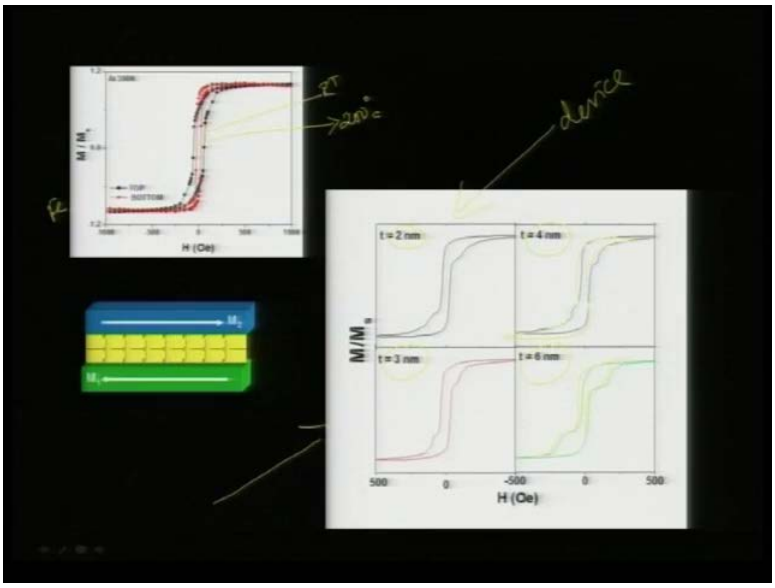

Now, how does the device respond, if you individually take the top and the bottom electrodes iron electrodes, you can see the coercivity is different, because when you deposit the iron at 200 degree C or so then the coercivity shrinks whereas, the top layer shows higher coercivity, which is deposited at room temperature. And this is the typical signature for the device, when device is there, then you would see, this 2 step hysteresis loop, which is showing the clear device operation.

Now, you can vary the thickness, we can go down to 2 nanometer, 4 nanometer, 3 nanometer and 6 nanometer and as you increase the P T F E thickness, you can see that this step is more resolved, compared to smaller one thicknesses. Now, the question is when you can achieve such small thickness of this P T F E layers, whether the device can clearly show magnetoresistance is the question, you would see that in the next slide.

When you have 3 nanometer and 4 nanometer although, you have this 2 step hysteresis loop, which is characteristic of a device, but when you look at the magnetoresistance, they are essentially showing negative magnetoresistance, negative M R, which means, the top iron layer is actually getting coupled with the bottom iron layer. Only then you will see a negative magneto resistance, but if they are clearly separated by P T F E layer, then you should actually see, positive magnetoresistance, which is nothing but the response for tunneling magnetoresistance device.

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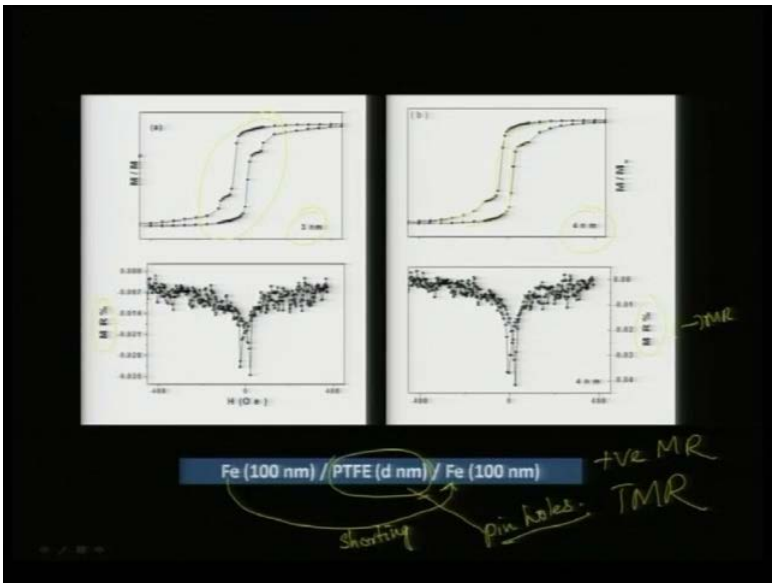

So, what does that mean, even though you have a 2 step magnetic hysteresis, there is shorting between the bottom and the top iron electrodes, it is short circuiting, as a result. We can say that this layer is not flat or it is not fully covered, there are pin holes in this layer, which is actually bringing about a short circuit between the top and the bottom electrode.

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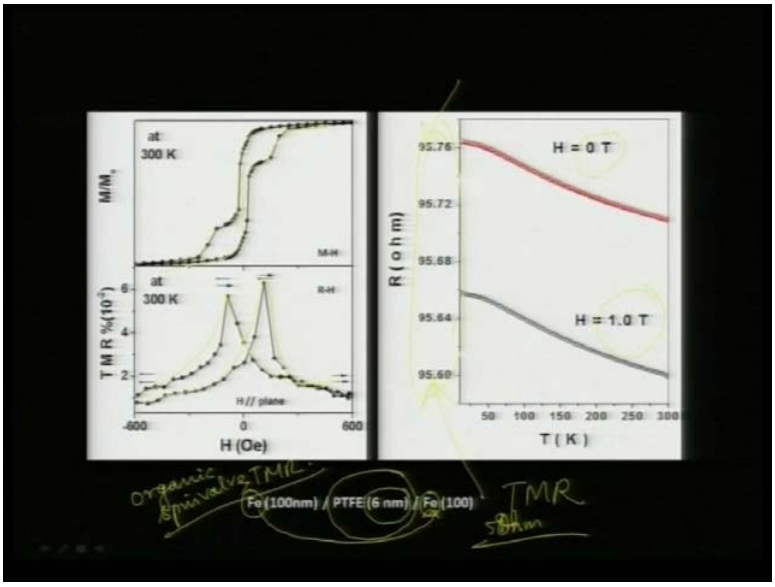

So, what do you do if you go further to 6 nanometer, if you go to 6 nanometer, then you see this response is much clearer and if you look at the magnetoresistance, compared to

the previous one. In previous one, it is a inverted response whereas, when you go to a higher thickness, you see that the response is now positive. So, what does that mean, at critical thickness of say 6 nanometer, you are able to clearly demonstrate a tunneling magneto resistance behavior, as a result you see a positive M R although the value is very less, still it is appreciable to show that organic spintronic can be demonstrated.

Now, what is the clue for whether this device is working, if you look at the resistance value, for such a device, you can see in the presence and absence of field, the resistance is varying and the value of resistance gives you a clue as to whether, such a device is working. Suppose, the top electrode and the bottom electrode are short circuiting, then the value of this resistance will be less than 5 ohms or this may be in milliohms.

Because, it is essentially coming from iron electrode the fact, that you are seeing a very high resistance, it means the organic layer is able to decouple the bottom electrode from the top electrode, as a result you see a pronounced T M R value. So, this is another example, that we can look more positively into making organic spin valve or organic T M R junctions, which can give you pronounced G M R behavior, there are lot more things one has to do, specially in understanding, how the inorganic organic surfaces work.

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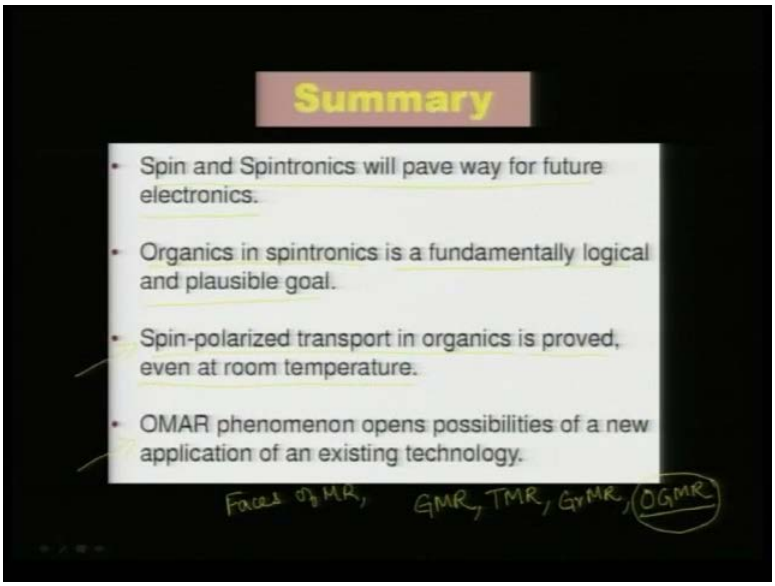

Just to conclude, what we have seen, so far, spin and spintronics will pave way for future electronics, number 1 and organics in spintronics is a fundamentally logical and plausible

goal, provided you have a ways and means to deposit, these organic films in a very sequential way. And spin polarized transport in organic is now proved, even at room temperature, if you can carefully look for a suitable combinations, then you can achieve maximum spin polarized transport via organic layers.

And we can also say organic magnetoresistance phenomenon opens possibilities, for a new application of this existing technology. So, we have actually in essence seen different phases of M R, phases of M R 1, we saw about a G M R, which is in stacked multilayers and then we saw some examples of tunneling magnetoresistance in trilayers.

We have seen some example of granular M R in bulk composites and we have also seen organic G M R where, we are bringing the hyperfine interactions and the spin orbit coupling interactions into focus and we have tried to see whether organic spintronics can become a vital tool, to address to the issue of magnetic storage. So, with this I will stop and we will continue with other examples of electrical conductivity, in inorganic materials in the next lecture.