Electronic Theory of Solids
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Lecture - 27
Spintronics: Introduction and Applications

So, we have discussed the quantum hall effect integer version of it and we found that these is there is completely new physics that appears in presence of strong magnetic field. So, the in the quantum hall effect of course, we did not consider the spins of the electrons because the spins are all because of that large field spins are all sort of quenched they are all in the same direction and the spin degree of freedom was not even considered.

But the fact that spins exist in the axis you can get an electron and the spins can be manipulated in different ways led people to think about changing the way we do our electronic devices electronics as such.

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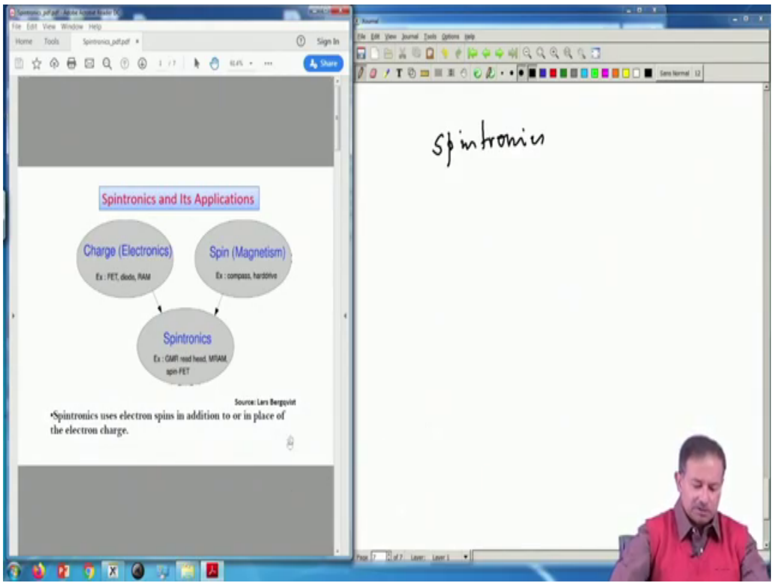

So, what is that and that led to a new area called Spintronics. So, it is a; it is an area which developed it is a long history, but only in the last twenty thirty years one has been able to confidently and reliably manipulate spins for doing what we normally do in electronics.

So, let me just let me just give you a brief overview of what this whole thing is. So, for example, whatever we do rams and things for example memories one and for example one uses for examples chips in a computer. One has to send transport electrons from ones region to the other and transporting electrons in means your transporting charge and that is what electronics is all about that you transport charges. And these charges these electrons carry information and depending on that that information is stored restored and read and so on.

But physically an electron has to move in a circuit to do any electronics that we do or computers and everything which heat up. For example, you see that when you run a computer for a long time it heats up we have fans inside the computer, those are reasons there is those are manifestations of electrons moving and correspondingly joule heat. Everything FET diode RAM everything that you use you need to transport electrons.

Whereas suppose I could somehow not transport the electron and manipulate the system in such a way that spins are moving, I will explain what I mean by spins moving. Of course, the spin is tied to an electron. So, one has to now go to a collective description which I will come back to and spin movement and spin manipulation can lead to no transport of current no transport of charge. But if we can manipulate the spin to carry our information, then that will lead to no joule loss.

And of course you are not held up by the movement of physical movement of charges, which not only heats up it also it is also takes time for electrons to move from one so from place to place. And the scatter of the disorder that is has to be there in the system and so all these can be dispensed with if you could transport your information through spins. So, that the physically nothing moves the spin degree of freedom is being manipulated to take the information for you. One great triumph in this saga of spintronics came from something called GMR is called Giant Magneto Resistance.

So, I will explain what it is basically magneto resistance means your resistance of a system changes by application of magnetic field. So, this is still not only spin transport, this is this also requires charge transport. But it is one of the major breakthroughs which actually got a Nobel prize, where one showed that you can carry selectively pass a particular spin of electron and forbid the others other component of the spin. And that led to a new kind of read heads now we are in we are using which are called GMR read heads and spin correspondingly came spin FET and so on.

Later of course, an Indian physicist Indian physicist Supriyo Datta and his student Das they divided a suggested another mechanism, which uses something called spin orbit coupling. And so they are you actually manipulate the spin to carry information without transporting the charge. These are called Datta Das transistors they are suggested it is not yet in the market, the still in the state of in the in the on theoreticians papers it has not come to on the drawing board of the theoreticians and it is not yet no devices have come with that. But that is a big breakthrough also in the spintronics.

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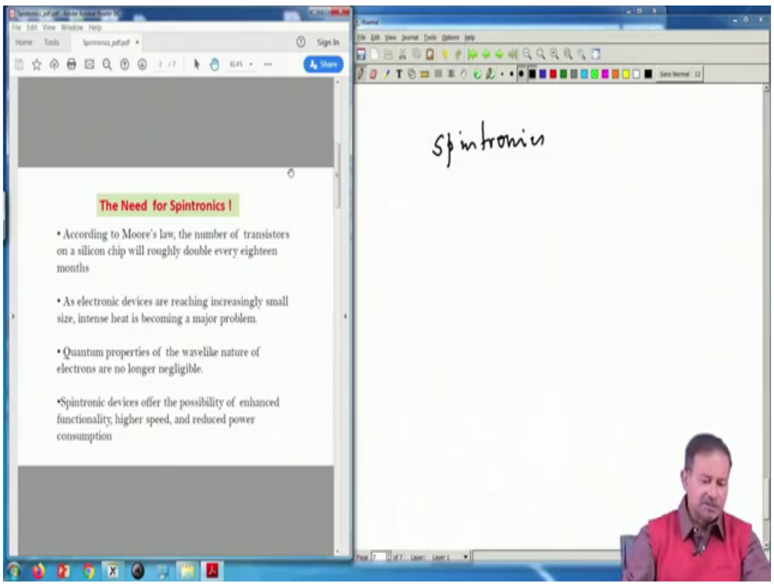

So, so the need for spintronics as I said is that remember Moore's law. The number of transistors on a chip will roughly double every 18 months. So now, if you are transporting currents and electrons between these chips, then of course there will be a saturation at some point, because if you would densely pack one is of course the Quantum limit. But even before you go to the quantum limit if you densely pack these chips in a transistor, then of course we will land up in transporting huge amount of electrons back and forth between these chips. So, that will create a lot of joule heating.

So, there is the size being small, the current density being large the there are there is a large amount of heat that will generate and causing major problem. Also the other important thing is that as the size goes down as I said the quantum limit is being reached and the wave property of the electrons then come into play and one has to really understand at the level of quantum mechanics which is which we have only started doing quantum computing which is a very different ballgame. But that almost I mean every computer that we have in use basically uses this classical transport and that is so that so the problems coming from quantum mechanics we have to be faced as the size goes down.

Where is the spintronics devices offered the possibility of enhanced functionality, higher speed and reduced power consumption. Of course, as I said they can be manipulated easily spins are easily manipulated. They are much higher they have much higher speed, because you are not transferred transporting an electron physically and the power consumption is much much less because you do not have to transport charges from one side to the other or from one place to the other.

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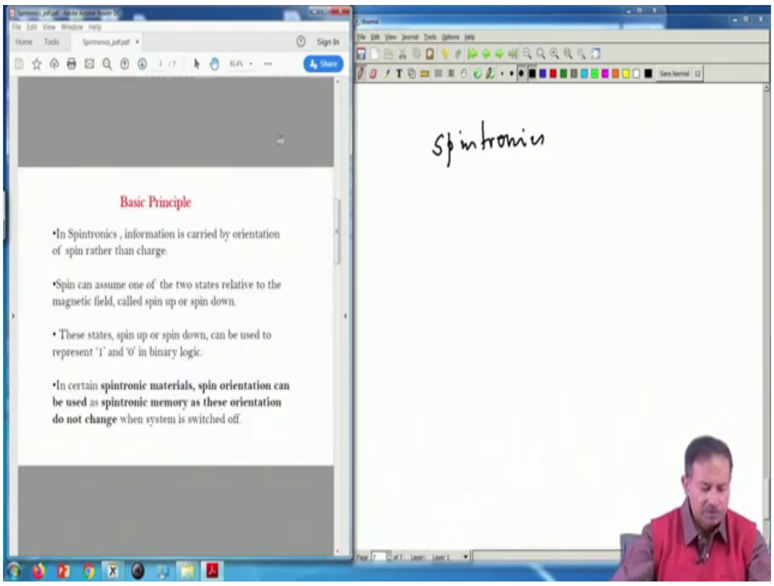

So, the basic principle is that as I said information will be carried by the orientation of the spin rather than movement of charges. So, that is the underlying basic principle. Spins for example, for an electron spin half system the spin can have either plus of or minus of components and you can flip the spin using a magnetic field.

So, that is called the spin up and spin down states. Now, you two if you two you have two states then of course your binary logic is easily set up, because your binary logic will be now spin up will be called up state 1 and spin down state will be called 0. So, these are the two states that these are two binaries, they these are the two states that will represent your 1 and 0 and your computer logic algorithm will again go through.

So, that is a that is very straightforward and that is being used and that is; that is something that people are trying to use. Of course, the real systems still do not use it only the quantum computers have started use these quantum states as replacing your logic gates. In certain Spintronic materials spin orientation can be used as spintronics memory as these orientations do not change when system is switched off.

So, this is another interesting thing that the memory is retained at infinitum, because you if you spin suppose spin up state represents something and a series of up states. For example, represents some information and when you switch off the computer, the system will just retain it as such nothing changes it is up state from up to down unless there is a strong magnetic field which you it will be shielded from. And then there is; then there is no way you can you can change the orientation of the spins, that means your memory remains stored the moment you switch on the computer whatever memory you had will be there.

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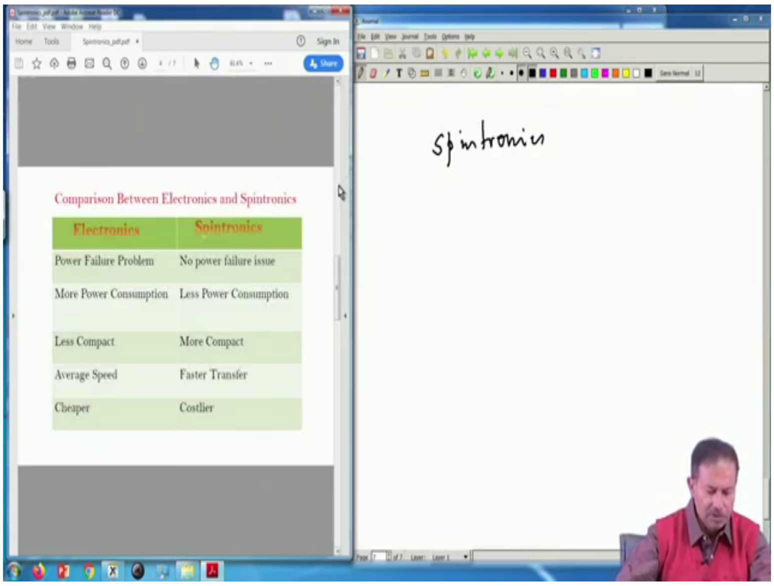

So, this is a comparisons with electronics and spintronics, no power failure problem issue of course, because the memories are always retained and the power consumption is much less, because the little power you require is to is to manipulate only the spins, it is very very compact system because as I said you are not going to transport the charges. So, you can pack as much as you want in a as much as physically possible in a small chip.

So of course, for much faster because again physically nothing is moving, what is moving is the spin orientation is being is being transported and that transport does not require this the physical movement of an electron. And of course, the thing that is mentioned at the last is of course, at the moment it is going to be costlier, but with that we know is not in our hand and that some at some point the cost will become much cheaper.

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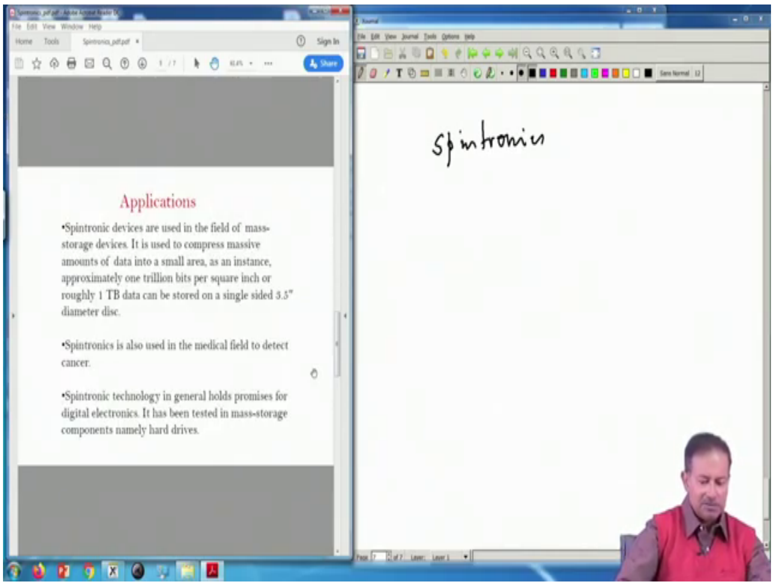

So, as I said they applied their applications using field of mass storage devices, massive amounts of data can be compressed in a small area. One trillion bits per square inch or roughly one TB data can be stored in a single side sided 3.5 inch diameter disc spintronics is also used in the medical field to detect many medical conditions including cancer. For example, because you know again if you have information coming in terms of the spins, then of course you; actually MRI signal sort of does that it manipulates the spins of the hydrogen atoms in the water molecule.

And so in a way if you can store your information or you can detect things by manipulating the spin, then you are home you actually do not do not need to again have a huge set up to create a large transport of charges and so on and so forth. So, it holds a lot of promise it is still not fully the way we want it GMR red heads are there, but in GMR you still have to transport, but you can transport it spin selection.

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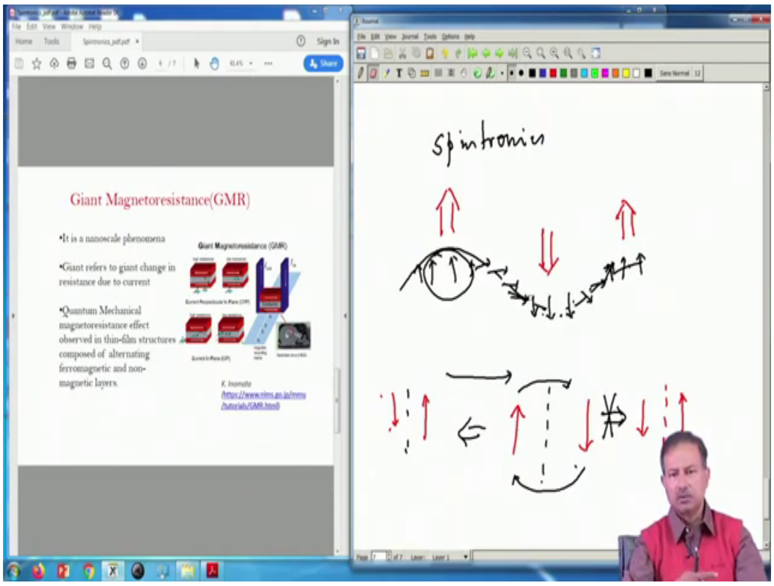

So, for example, it is a nano scale phenomenon giant magneto resistance. So, basically it uses the fact that your resistance depends on the on the magnetic orientation of your spin. If it is you can selectively take choose the resistance to be lower for one particular spin channel rather than the other one, the other one can have a higher resistance. So, that is the main mechanism that is used in GMR.

So, the set up looks like this it is a series of materials, it is a sandwich basically a series of them can be used also. And they selectively transport one particular direction of spin and makes the resistance to the other direction of spin much higher.

So, these are basically very thin films which one material sandwiched between the two or is a combination of these sandwiches one of the other, so that the efficiency increases. So, they basically transport one particular direction of spin over the other and that. So, that that allows us to selectively choose the direction of a particular spin component of the electron. So, one electron of a particular spin component say up will transport and the other will not.

So, if you if you code your information’s in such a way that the ones are being transport and zeros are stopped. That means, you are storing once somewhere reversely you can do the other way depending on how you put your magnetic field and you can allow zeros to go and stop the ones up spins the down spins are going. Then of course, you have the zero states that are passing.

So, that is how you can manipulate the 1 and 0 selectively by and by not electronic mechanism, but by storing the information in the spins. But as I said we are not yet in the stay at the stage in GMR where we need not have to transport any charges. So, that is the goal and that is what one suggestion is as I said Datta das transistor and that is what one is after.

So the of course, the explanation as to why one particular spin goes and the other can be halted comes from more detailed calculations. In these physics is beyond you say here for examining GMR system something called RKKY interaction is used. Where, the spins are selectively aligned by a spin exchange process, so that is beyond the scope of this course.

Whereas there are nowadays one is talking about systems with strong spin orbit coupling as the Datta das transistor suggests, where the chances of not transporting an electron and transporting the information in the spin is possible. Now as I say as I have been saying that spin of course belongs to an electron. So, how is it that you can transport the spin and not the electron?

So, let me just show you an example. For example, if you have a collection of electrons which has a spin density which is like this, these spins are rotating they are up here and they become slowly sorry and so on. So, this will be sorry this is let me just draw it again the spins. So, the spin degree has a modulation which is somewhat like this for example. So, the spins are up here and they are down here. So, the net spin is up here net spin is down here, let me draw it in a different color. Spin component if you measure you will find that they are up here, the sum of all these spin components of the all these electrons is up here it is down here it is up here and so on.

So, supposing this whole thing can be moved. So, so it is a spin wave it is called a spin density wave, spins are aligned in such a way that it goes from up to down and then again up and then down periodically. Now, you can suppose you encode a information in these spins, for example these are and then you allow the spin density to be like a plane wave it moves and it is a move traveling wave then this set of spins can actually nothing moves no electron is not moving electrons are still here ah.

But the profile of the spins can move and you can encode your data into this profile of the spins. And then of course, nothing no electron is required to remove and you have transferred an electron. A very simple example for a is for example, if you have an up spin and a down spin and you have a barrier some kind of barrier to a barrier in between. And suppose now I transfer the up spin to the right hand side and the down spin to the left hand side.

So, physically that that means I will end up with a situation which is down and up. But do I need to physically transport an electron to do it actually I do not. All I can do is there is a magnetic if there is a magnetic interaction called exchange interaction between these two which we will learn in magnetism, then I can simply flip the spin.

Instead of doing this by physically moving an electron I will not do it what I will do it is I will use a magnetism and magnetic exchange between the two and I will just flip the spins. This spin goes to up from it is earlier position which was down. So, I have flipped it to up position and the electron with spin up I have flipped it to down.

So that means, I now have a situation which is down here and up here. And this is a; this is the left hand process this one does not require any electron to move. But the information for example zeros and once if up is one and down is zero then zeros and ones have moved and that is the way we spin. That is an example of how spins can carry information without moving the electron from one side to the other.

So, these are the techniques that are being mastered and it varies this is a simplest possible example. But one actually uses the spin density because you have large number of spins, in a system you do not manipulate single spins in spintronic devices those are done in quantum computation devices. So, those are not what we are interested in at the moment. But at least here for example, a large number of spins in one direction the spin direction can be moved like in a spin density wave as I showed in the top and that that allows me to not transport the electron.

But transport ,send the information across without transporting the electron, but changing the spins of the of the number of a large number of electrons together. Like a wave I can move or I can just move the domains with one particular domain moving on to changing it is spin on the other side and so on, without physically transporting any electrons.