Switching Circuits and Logic Design
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Lecture - 10
Emerging Technologies (Part 2)

So, we continue with our discussion on some Emerging Technologies for implementing logic gates. So, we talked about all optical implementations in the last lecture.

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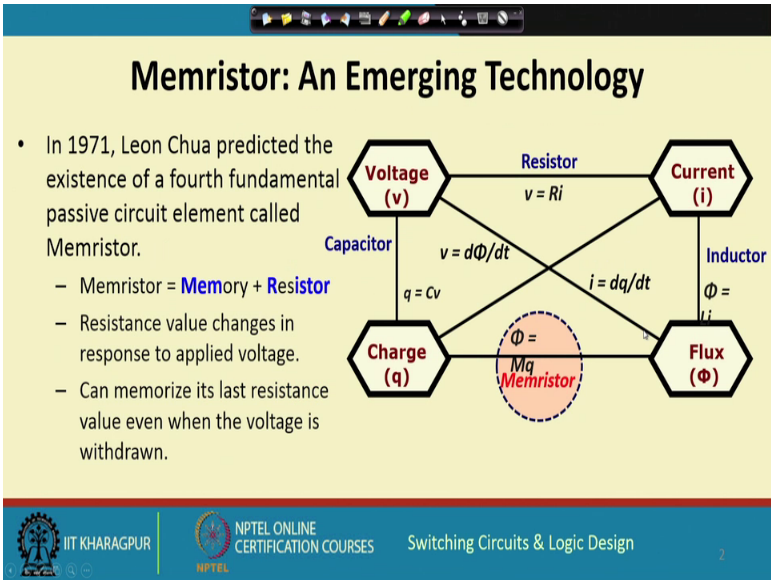

In this lecture which is the second part of emerging technology. We shall be talking about a very interesting technology called memristors. Memristor is actually a combination of the 2 terms memory and resistor, let us try to understand what memristor is.

Well the presence of memristor was first predicted in 1971 by a Professor Leon Chua who considered this device as the fourth fundamental circuit element passive circuit element. Now you know that we have some fundamental circuit element that we know about resistor, capacitor and inductor. And also if you look at the relationship voltage and current are related by v equal to R i, voltage and charge are related by q equal to C v, these are well known equation we have studied in schools right current and flux are related by phi equal to l i and also cross relationship is also there d phi dt is nothing but the voltage and d q dt rate of change of charge is the current.

Now you see we live in a world where symmetry is seen everywhere. So, Chuas first argument was that something is missing, there is a missing link then he theoretically postulated that there should be another such fundamental circuit element have should connect flux and charge. So, this phi equal to M q this was the relationship that this new device should exhibit and this new device he gave the name memristor. But forgetting his theory behind it, essentially speaking a memristor is a device whose resistance changes in response to an applied voltage, not only that it can memorize the last resistance value even when we switch off the power we withdraw the voltage this is a very interesting property let us see.

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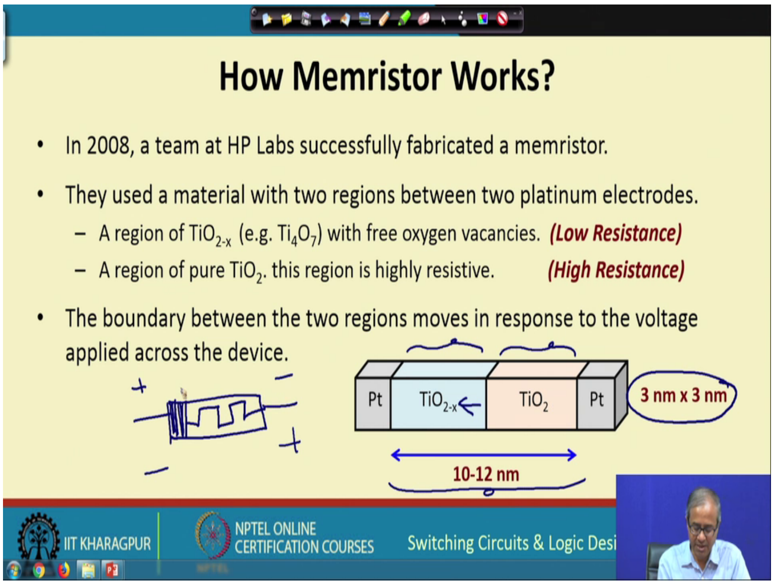

Very briefly speak you see Leon Chua predicted the presence of memristor in 1971, but it was much later in 2008. So, it is about 37 years later means a team from the HP lab USA, they fabricated a device they did not knew what the device was, but they saw that it is exhibiting some very peculiar properties, later on they looked at the paper by Chua and they saw that well the properties are very closely matching with what Chua had predicted. So, they accidentally they fabricated a memristor. So, how did they fabricate the device?

They used a material like here shown in the figure, they created a device where on one side there was a region of pure titanium dioxide and there was a other side this is also an oxide of titanium, but with some oxygen vacancy, this is called oxygen vacancy because in ti o 2 the number of oxygen atoms is double that of titanium, but you see it is TiO 2 minus x sum. So, so one such oxide is Ti 4 O7 something like this was put here and on the both side for connection they used platinum. So, in this device what they found the size of the device is very small cross section area was as small as 9 nanometer square and the length was 10 to 12 nanometers.

Now, they observed symbolically they represented this device like this, this is actually proposed by Chua this side where there is this oxygen vacancy, this part is solidified and this symbol is like this. This is a symbol of a memristor. So, the idea was that if I apply a positive voltage on this side and a negative voltage on this side, then what will happen? This boundary will be moving to the right because oxygen vacancies are positively charged they will be repelled by this positive they will be moving right and this is a region of low resistance and this is a region of high resistance. So, the low resistance region will be expanding the overall resistance will decrease.

But if I apply a reverse voltage, then the bounded will be moving towards this direction. So, this oxide region will be shrinking and the titanium dioxide region will be expanding. So, the overall resistance will be increasing. So, just by applying a voltage of a suitable polarity, I can either reduce the voltage or increase the voltage. Now another interesting property was that this oxygen vacancies has a very unique property that if you withdraw, the voltage they will remain in the position they were the last point in time.

So, they will not change, which means the change in resistance that has taken place is nonvolatile in nature what is meant by non volatile? A some change is said to be non volatile, if it remains even when I have withdrawn the voltage or the power supply. Here it is something like that, I can change the resistance by applying a suitable voltage then if I withdraw the voltage, the old resistance value will remain the device will be remembering the resistance. So, you can understand that I can implement a very simple memory device using this; it can memorize the resistance right.

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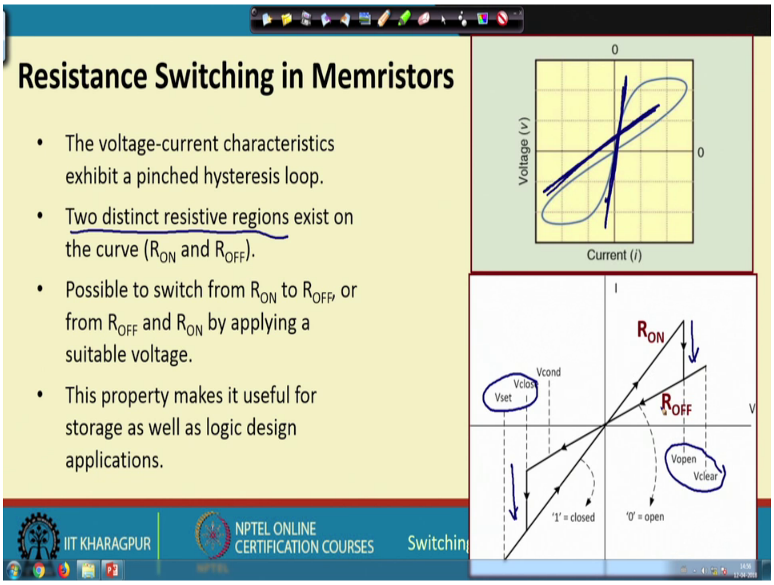

So, very briefly let us talk about the characteristics of such a device, this has been quite widely studied by many researcher voltage and current characteristics exhibits this kind of behavior it is called a pinched hysteresis loop there are 2 region you can see one here and one here.

So, this can be approximate by a curve like this, one with a low resistance. So, see this is voltage and current. So, higher slope means low resistance or this is current here voltage reverse and this will be R OFF is high resistance, because this current voltage slope means current is smaller resistance is higher. So, there are 2 distinct resistive regions low resistance and high resistance and I can switch from one resistance to the other by applying a suitable voltage. If I apply a voltage V open or any voltage beyond that let us have V clear, then it will switch from R ON to R OFF. R ON to ROFF, but if I apply a voltage negative voltage beyond V close, then it will switch from R OFF to R ON. So, I can switch from low resistance to high resistance or high resistance to low resistance by applying a voltage of suitable polarity.

Now, this property that a memristor can remember the last resistance value, it makes it very useful for implementing memory devices storage and we shall see it can also be used for implementing some gates logic gates logic design. So, we shall very briefly look at this technology.

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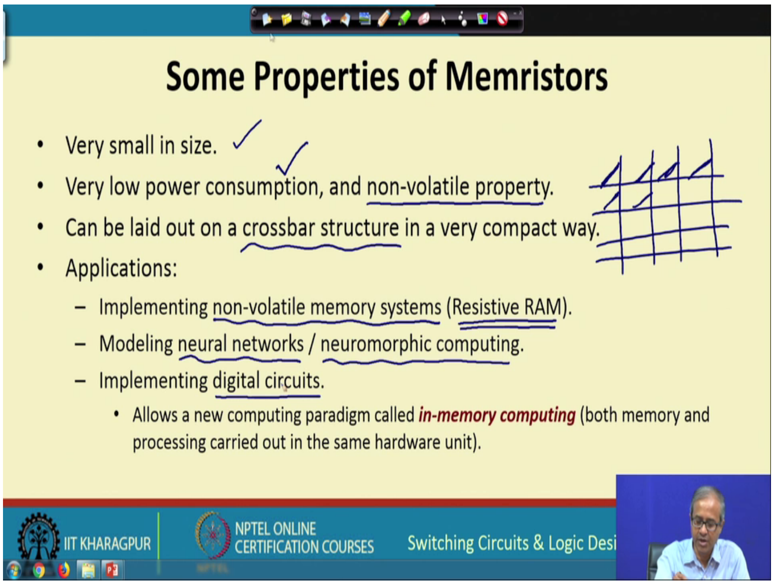

So, we had already said memristor is something which is very small in size much smaller than the current CMOS transistors.

Well, it consumes a little power only during operation, but when you are not means operating you can withdraw the power. So, there is very low power consumption it can remember the last resistance non volatile. Cross bar structure means you can have a compact implementation some rows and columns. These are 2 different rows and you can connect the memristor between rows and columns like this very conveniently etcetera this is called a cross bar structure some of the application just to name one is we can use this to implement memory systems nonvolatile memory systems. This is called resistive random access memory resistive random access memory resistive.

We can model brains there is also some work where some neural networks or some neurons were implemented using memristors and of course, we can implement gates some digital circuits ok. So, we are not going into the detail of this because this is slightly beyond the scope of discussion here, I just wanted to name a few application.

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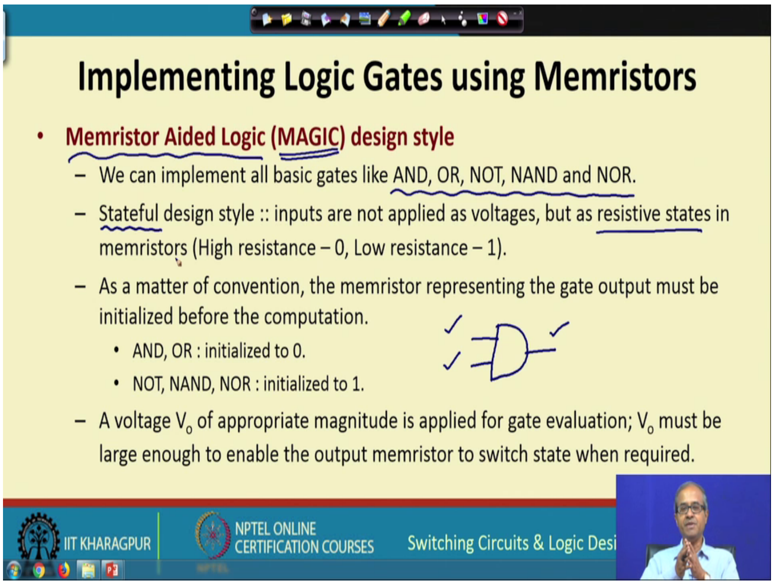

Now, let us briefly look at how we can implement logic gates is a minister without going into much detail. We shall be talking about 2 broad techniques one is called memristor aided logic in short magic. Now using magic you can implement any of the gates AND OR NOT NAND NOR and in this method you see for a conventional gate when you had implemented using TTL or CMOS this inputs we were applying as voltages and the output we were getting as voltage.

But for circuit using memristor it is different, we call it stateful design style where we apply the inputs not as not as voltages, but as resistive states of the memristor the meaning is something like this, suppose I am implementing a gate with 2 inputs there will be 2 input memristors by applying a suitable voltage, I shall be initializing those memristor to either the high resistance or the low resistance states right. If it is high resistance I call it logic 0 if it is low resistance I call it logic 1.

So, the inputs I am not applying as voltages, but I am applying as resistance values in the memristors this is called stateful logic ok.

So, this is the convention and in memory stated logic, when you carry out a gate operation you have to initialize another memristor, where the output will be stored. So, we initialize it to either 0 or 1 depending on the type of the gate and some voltage has to be applied on the input site to evaluate the gate, I just show you how this circuit looks like.

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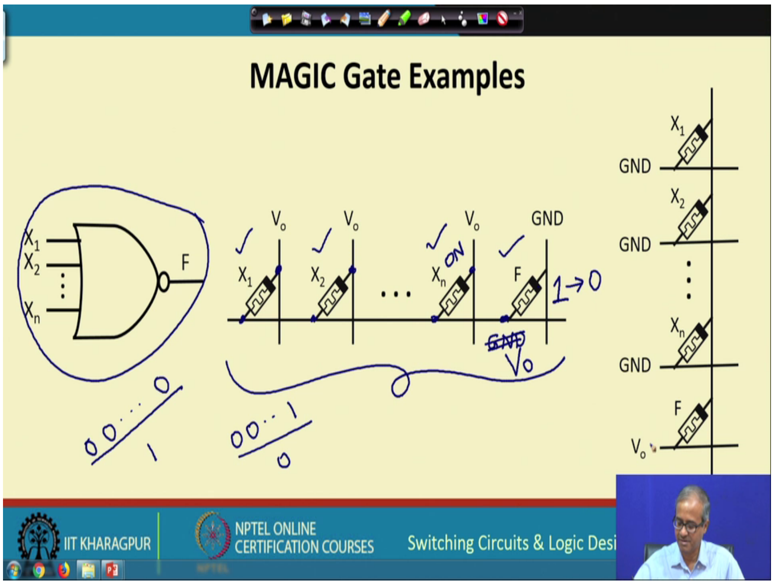

Here I have just taken an example of a NOR gate, this is an n input NOR gate there are n number of inputs and one output. Now you can very easily implement it using memristor like this, there are a number of memristors x 1, x 2 to x n which represent the inputs and one memristor representing the output and the previous slide we mentioned for NOR gate this output memristor must be initialized to the one state which means on and depending on the inputs we will have to initialize these input memristor.

Suppose the inputs are all zeros because it is a NOR gate when the inputs are all zeros the output has to be 1; if the inputs are all zeros means what these are all high resistances. So, this V 0 is connected to this point V 0 is connected here, because this is a high resistance very little current will be flowing and these are all connected on this side and because this high resistance no current will be flowing and this point is grounded and this point will be approximately at the ground potential ground. So, on the output memristor there will be no current flowing and it was one it will remain as one. So, it remains as one.

But let us say at least one of the input is that 1 let us say the last input is 1. So, for a NOR gate the output should be 0 let us see how it happens. Let us say one of them is one may this xn let us say this is on; this is the on means V 0 will be connected through this is a low resistance and this will not be ground, this will now be V 0. And this V 0 will be applied across this memristor see this part is ground, this point is V 0. So, you are applying a higher voltage on the other side and a lower voltage, on that ti 4 or 7 side. So, this will be reversed biased and the output will be changing to 0 to off. So, this is how it works.

Now, not only like this you can also connect it like this in a different way, where of course, the connections will be different, but I have just shown this to you just for your convenience ok. This is one way you can implement some gates using memristors just to give you an idea.

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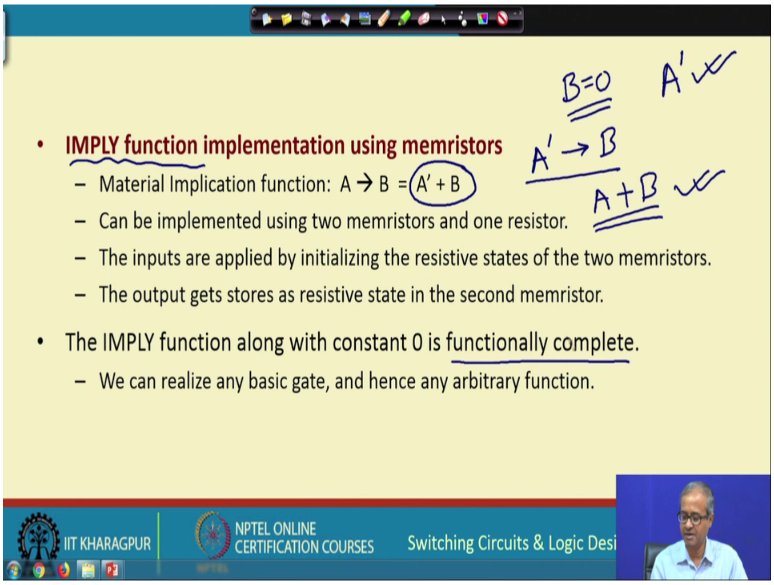

And there is another kind of a logic design style which is also quite widely explored, this is called imply function. An imply function is defined like this you take the not of a variable A and then do a or this is defined as imply function. Now using memristor you can very easily implement imply function also. Now, it can be shown that imply function along with constant 0 is again functionally complete. Like for example, if B equal to 0, if B equal to 0 then you can implement what A bar or 0 means it will be A bar; that means, you can implement not operation.

So, since you can implement not operation then you can just apply the input A was that, you apply A bar and then imply B, this will become A or B which is or operation. So, so you can implement a not, you can implement an or this again is a functionally complete set as we shall see later. So, you can realize any arbitrary function also using imply. So, here I am not going into detail, just to give you a basic idea that this memristor is a very promising technology and you can use it for designing logic also.

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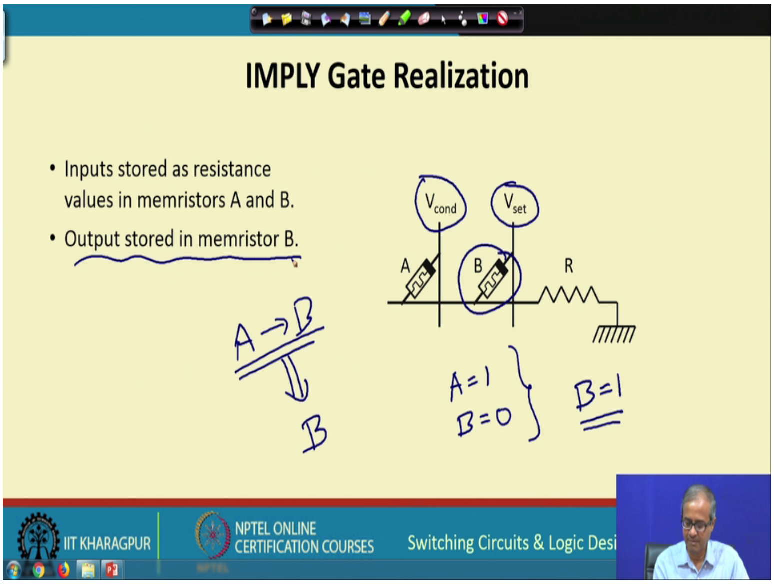

And imply gate can be realized like this 2 memristors and one register, the convention is that the input should be stored in A and B and after operation the output; that means, now this A implies B this will be the output, this value will get stored in B.

So, the value in B will be overwritten. So, again the voltage we are applying here is V cond and V set, I am not going into the detail here. So, the basic concept is like this that you have a circuit comprising of 2 memristors and one register. So, whenever you want to carry out some logic operation for some given value of A and B let us say A equal to 1 and B equal to 0, then you will have to initialize the values of A and B appropriately.

Let us say I initialized A to 1 I initialized B to off, then I apply V cond and V set then this A bar or B will be 1. So, what will happen is that after computation B will become 1 this will be the output because output will also be stored in memristor right. So, actually this is how the imply gate works. So, I here in this lecture we have given a very brief idea without going to the detail regarding how this emerging technology memristor works. So, if some of you are interested to know more about memristors, you can read the literature if you do a Google search you will get lot of material about memristors a lot of interesting applications that people are talking about.

So, a few things people are predicting that the first kind of application of memristor that you will see in the market will be some non volatile memory devices like your the pen drives, USB drives that we use today. They will be of much higher capacity much faster as compared to the present day USB drives. So, let us hope that we get to see such devices in the market very soon in the near future.

So, with this we come to the end of this lecture, now from the next lecture onwards we shall be starting our discussion on so called switching functions and switching expressions, how do we represent such functions, how do you manipulate, how do you minimize. And later on we shall see how do we implement them using gates and various other circuit modules, digital circuit modules to implement the desired functionality. So, we shall be starting this discussion from the next lecture.

Thank you.