Digital Integrated Circuits
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Lecture -36

ROM – EPROM, EEPROM and Flash EPROM

We shall continue our discussion on memories. We have studied or seen how the static RAM and the dynamic RAM are realized. In today's class we shall take up another form of memory which is the read only memory. As its name implies, this type of memory is read only memory but although it says read only memory it is not that you can only read from it.

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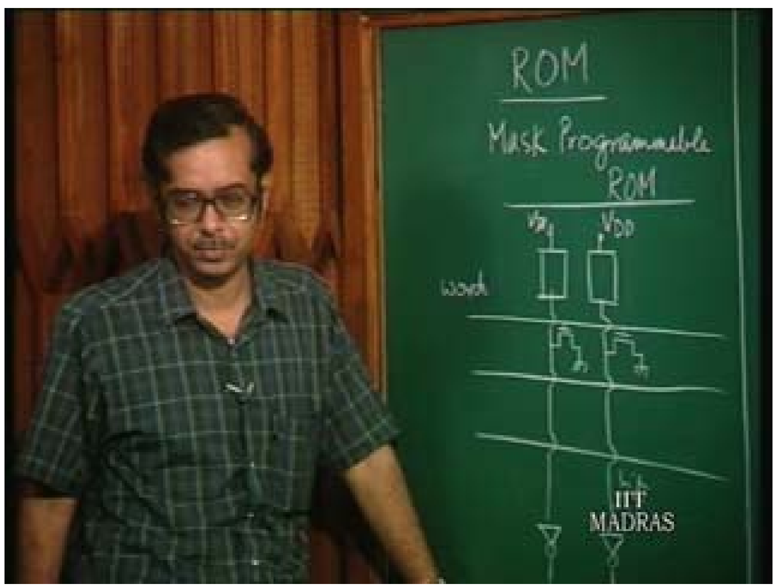

You can also write into it in some forms of ROM which we shall see but the reading process is the most favorable process in the sense that it can be done very fast whereas the writing process is a more cumbersome process in many cases and it takes a much longer amount of time. That is why it is called a read only memory. We shall see the different types of read only memory which are available and see how they are actually realized in practice. One type of read only memory which is called the mask programmable ROM, this type of read only memory can be programmed once in for all and once you program this read only memory, you cannot change it. This is in true essence a read only memory, you cannot actually write. You can write once and for all.

The basic structure of such memory or ROM is something like this, just like we had in the other forms of memory you have the rows and the columns. Again at the intersection of the rows and the columns you have the memory cells. In this case the memory cell consists of just a MOS transistor at the intersection of the row and the column. Here you have the load and this connects to V_{dd} and we have the output that is two inverters. At each intersection you may or may not have a MOS transistor. Usually in actual practice a MOS transistor is fabricated at every intersection. Basically the gate of a MOS transistor may or may not be connected to the word line because it doesn't make sense to actually not to fabricate a MOS transistor because the array is fabricated like straight lines running vertically and horizontally. You have to provide space for a transistor, you cannot have a crooked lines. You are not saving space by not fabricating a MOS transistor, you actually fabricate a MOS transistor at every intersection and the gate of the MOS transistor may or may not be connected to the word lines. These are the word lines and these are the bit lines say the vertical lines.

Now what happens is only one word line can go high at a time. When the word line goes high then all the transistors on this row are selected, if there is a transistor there and if there is a transistor there, the transistor turns on and when the transistor turns on the bit line is pulled to low and the output goes high. Of course depending on whether you have a transistor connected here or not, if there is no transistor at this intersection what happens is this bit line is going to remain high and the output is going to be low. Basically by connecting a transistor here or not, you have stored a one or zero at this particular location. The location means the address corresponding to this particular intersection of the word line and the bit line. Once you have fabricated the chip, the programming is over, you cannot change it anymore. This case you want to have some storage which you don't want to change over and over again. Whatever is there once and for all, you want to use it.

For example you want to make a controller program of some system. You know that this program is fixed and you want it in large volumes, maybe you can fabricate a ROM which contains that program and then use it. Once you do it, it cannot be changed. That is an advantage to some extent because if you are programming in a RAM, it may get changed again and in which case you have to reprogram it again. That is a mask programmable ROM but this has an inherent disadvantage is that once you program it, you cannot change it. There are other types of ROM's available which remove this drawback, in the sense that you have the flexibility of programming the ROM.

That is basically you can write it or you can erase whatever is stored in the ROM and rewrite into that memory and then you can use it as a ROM and again maybe you want to load something else into that ROM, you can do it once again. That type of memory is called an EPROM which stands for Erasable Programmable ROM. There are different types of Erasable Programmable ROM, how you going to erase that we shall see so that it gives rise to again different types of EPROM's and we shall discuss that.

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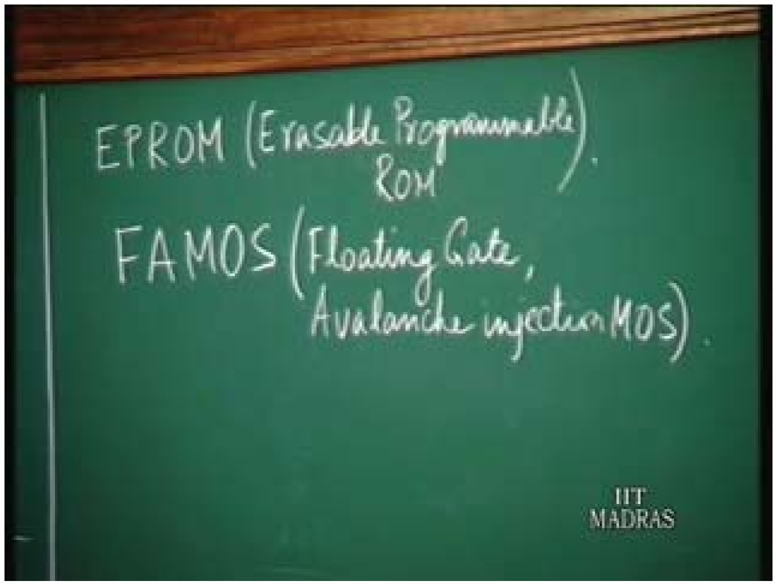

Now the basic transistor or basic active device in an EPROM is slightly different from the normal MOS transistor here. What you use is in an EPROM is what is called a FAMOS device. The name of the device is called the FAMOS device which stands for Floating Gate Avalanche injection MOS transistor. That is the type of device which we use. I just draw the cross section of that device and say how it looks like. It is just like a MOS transistor, n plus, n plus, p but what you have here as the name implies is a floating gate.

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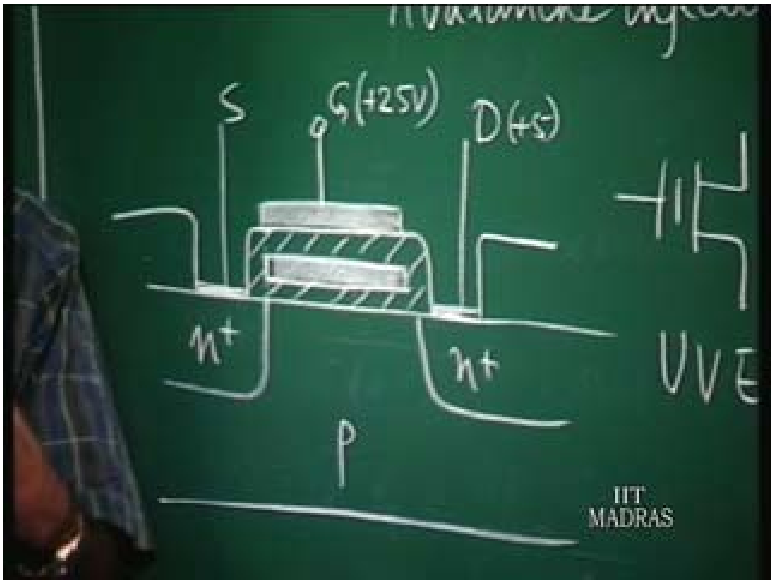

Basically this is the oxide, this is a gate and this is the source and drain contact and this is a gate and this is another gate. This is the gate, this is the source, this is the drain, this is the FAMOS device (Refer Slide Time: 10:40). There are basically two gates to this MOS transistor and one gate is a floating gate in the sense that you have no electrical connection to that gate. You cannot access that gate electrically that is why it is called a floating gate and the device is called a floating gate MOS transistor. Basically the symbol for that is something like this (Refer Slide Time: 11:12) which implies that you have a floating gate here that is one gate which cannot be accessed.

Now how does this work? What happens is basically there is a gate here and this is the silicon dioxide underneath it. This is a very thin layer of silicon dioxide and if you apply a normal source and drain potential, may be slightly higher what happens is electrons will move from the source to the drain. The gate voltage if it is made very high, normally what is done is if the gate voltage is say plus 25 volts say and the drain voltage is say plus 5 volts, what would happen is normally if this gate voltage is higher than the threshold voltage, you have a channel and electrons flow from the source to the drain, for a normal MOSFET operation. What happens is because of very high gate voltage in this case some of these electrons acquire very high energy and they have sufficient energy to overcome this silicon silicon dioxide barrier and these electrons gets implanted in to the floating gate.

Many of these electrons because of the very high electric field, because the gate voltage is made very high, many of the electrons which are floating from the source to the drain have very high energy and they get implanted into the floating gate. What happens is basically you have a negative charge on the floating gate. Now what is the effect of a negative charge on the floating gate? If this is for programming, you have put a 25 volts and 5 volts while normal operation you will have normal voltages, a gate voltage 5 volts or so. When electrons are getting implanted into the floating gate, what happens to the threshold voltage? The threshold voltage is going to increase because you have a negative charge on this gate which is going to result in positive charges in the silicon and in order to overcome that you have to apply a much larger gate voltage on this gate which is called the control gate. You have a flowing gate and the control gate, you must apply much larger voltage at the control gate to create the channel, basically in order to overcome the effect of negative charges on the floating gate.

Basically the threshold voltage is increased by this process of implanting negative charges on the floating gate. Now if you come back to this circuit here, in a mask programmable ROM you either have a MOS transistor or you don't have a MOS transistor. Now suppose if you consider two transistors here may be the FAMOS type of transistor and one of them has been programmed by introducing charges into the floating gate and the threshold voltage of that MOS transistor has increased to above 5 volts. The threshold voltage has become say 7 volts because of that process.

Now when you put 5 volts on the word line, for this transistor the threshold voltage is less than 5 volts. What happens this transistor turns on and this bit line voltage becomes low, whereas this transistor suppose the threshold voltage is 7 volts this is not going to turn on. It is as if this transistor does not exist here. This line voltage is going to remain high. By this process in a FAMOS transistor by changing the threshold voltage by implanting electrons into the floating gate, we can alter the threshold voltage of the device. Basically we can increase the threshold voltage of the device so that this transistor does not turn on at normal gate voltages.

We can program the memory ourselves that is basically if you want to program this here we have to apply 25 volts on the word line and the 5 volts on this bit line. We must be able to do that in which case this particular transistor will get programmed and for all the other transistors although you have 25 volts, you don't apply 5 volts drain voltage here. It does not get programmed, this is how you can have an EPROM. We can basically program it but the point is erasable I mean what's the use of programming is if you can't erase it. You must be able to erase it and then program it. Now what happens is once electrons are implanted into the floating gate, these electrons can stay there for many years. Once you program it, the program is not lost in fact tens of years I mean you can have that program, whatever maybe your program. To erase it what has to be done is you have what is called UV erasable programmable ROM.

Basically what you do is you expose the memory chip to ultra violet lights, these memories uv erasable programmable ROM's they come with that is they have a particular package where there is a glass window on top. You can expose these memory cells to ultraviolet light. Basically what you have to do is you have to take this chip and expose it to ultra violet light and once you do that these electrons which are in the floating gate, they get excited because of the high energy they acquire and they may overcome again the silicon dioxide barrier and they move over to the silicon substrate or the control gate and once they do that you are basically reducing the threshold voltage again.

It takes a lot of time, may be half an hour you have to expose it to ultra violet light after which the electrons move out from the floating gate and then again it is ready for reprogramming. The point here is that in this case, you cannot erase part of a program, a part of the chip. When you erase, the entire memory has to be erased and then again you have to reprogram the entire memory. It is not that if you have a part of a memory that you can erase or anything. Whatever you had in the chip is removed and then again you have to reprogram the whole memory. That is the problem and what we have to do is it cannot be programmed in the circuit itself.

I mean basically if you want to change whatever is the content of this memory, you have to take out the chip from the circuit, expose it to ultra violet light to remove the memory and then again you have a special mechanism because we have to apply very high voltages 25 volts or so. You have a programmable kit for example where you do the programming and then again you have to put it back into the circuit. Basically the writing process is a very cumbersome and again that's why it's a read only. It's basically a read only memory, you can read from it but writing you can do once in a while. You cannot do it all the time, it doesn't make sense. That is the EPROM. Obviously we would like to have something which is more flexible that is you can do the writing operation may be inside the circuit itself or it can be a faster operation. You need not have to take out the chip from the circuit that's the type of thing led to what is called an electrically erasable programmable ROM. This is electrically erasable programmable ROM. Now the device which is used actually in the EEPROM is similar to this FAMOS device but it is slightly different.

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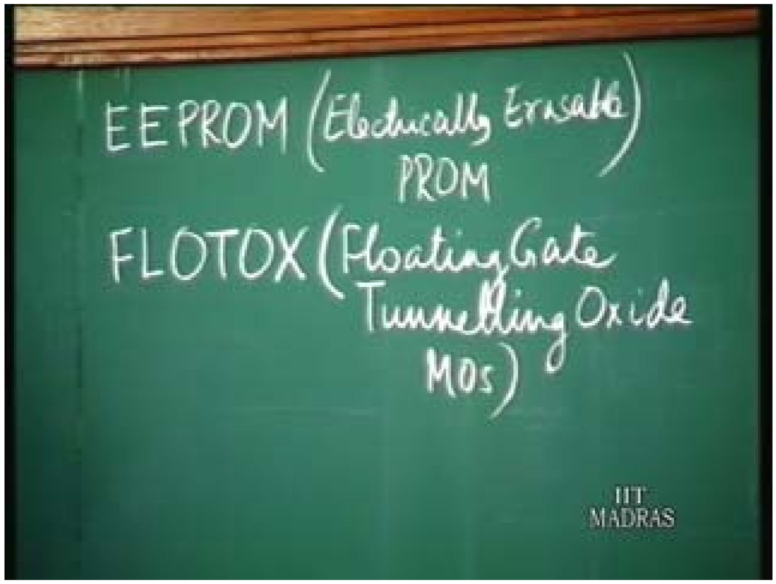

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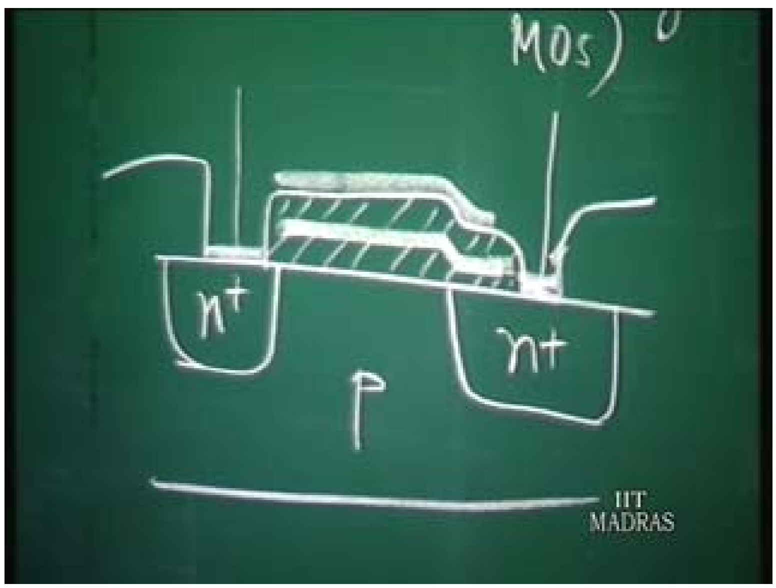

The device which is generally used nowadays is called the FLOTOX or which stands for Floating gate Tunneling Oxide MOS. Basically the device structure is something like this, you have a floating gate again and then you have a control gate on the top, this is source and drain, n plus, n plus, substrate. This is the floating gate and then you have the control gate and then of course you have the source and drain contacts. Basically the difference here is that what you have is over the drain you have the floating gate and here the oxide thickness is very small, much less than 100 angstroms of oxide. Here if you apply a large positive voltage on the control gate with respect to the drain here, what is going to happen is the electrons will tunnel through the oxide here and will get implanted into the floating gate because this oxide thickness is very small here.

It's a tunneling oxide basically, this process is going to be quite fast and in the reverse process again if you make the drain voltage very high and the control gate voltage is zero then you have a reverse field and the electrons implanted in the control gate can be removed through this tunneling oxide because this is electric field which is aiding the tunneling. If the oxide is very thin and if you have a large barrier but if the barrier thickness is quite small, electrons can tunnel through the barrier with the help of an electric field. If that is utilized in implanting or removing charges from the floating gate and that is type of a system. What you have in an EEPROM, the structure is something like this. It's quite similar but with a small difference which we shall see, we have basically a two transistor cell this is one select line and this one is the floating gate transistor and this one is a normal MOS transistor.

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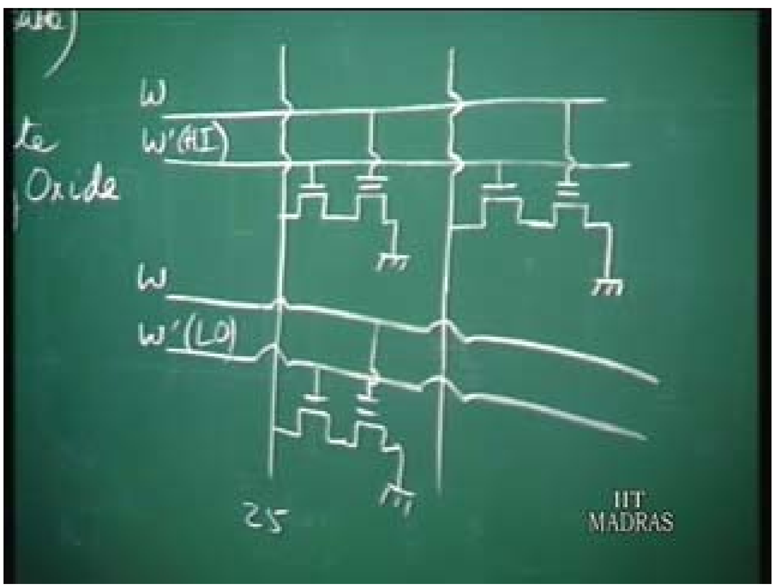

Again at every intersection you have a cell. This cell is basically a two transistor cell unlike the other ROM which are one transistor cells. It is something like this and of course at every intersection you have this. Now what is the purpose? Here you see one is the word line, you have two word lines in fact.
The purpose of this is when you want to program the memory what you do is you have to make the gate voltage much high and the drain voltage zero. What you do is you have to make a gate voltage high and the drain voltage zero. When you want to erase it, erase the cell you have to make the drain voltage very high say 25 volts and the gate voltage 0. Now what happens is if you didn't have this extra transistor here, what is going to happen is when you make the drain voltage 25 volts, all the transistors connected to this particular column is going to have a 25 volt drain voltage. That may

alter the contents of that particular memory, that may erase the contents of that particular memory cell. What you do now is with this extra transistor which is called the select transistor, you can select the particular transistor in a column which will have the specified drain voltage. That is suppose you want to erase this particular cell, you apply 25 volts here on this line but what you do is you select this w prime which I have put here.

One of these w prime is selected that is here you have number of rows, each with w and w prime. Now only one of these w primes is selected. You have another cell here say, now when you apply 25 volts here and this is high and this is low. What happens is this transistor is on, only this cell, drain voltage gets 25 volts. All other cells in this column is disconnected. Basically you increase that voltage of one particular column and you select the transistor on that column which you want to erase. Basically what you do is you can erase a single bit of memory unlike the previous case, uv erasable programmable ROM you have to erase the entire memory at a time. You cannot erase bit by bit, it is not bit erasable where as this one is bit erasable. That is you can erase one bit at a time. That is advantage of this.

Similarly when you want to program it, you have to put 25 volts on the control gate and only one of the cells is selected again by this w prime line here w and that means only one drain voltage is going to be 0, other drain voltages are floating. You can program only one of the cells at a time. That is the advantage of an EEPROM. You have two transistors per cell instead of one transistor per cell. The density of an EEPROM is slightly less compared to the normal UV EPROM, other types of ROM where you have one transistor per cell but the advantage here is you can erase it bit by bit. You can erase one particular bit, it is bit erasable and you don't have to take it out, you can do it internally.

In fact many of these EEPROM chips, these high voltages are generated internally by a particular circuit called charge pumping circuits which actually generate this 25 volts internally from the 5 volt power supply. You don't have to have an external 5 volt power supply, because you require them just for a short interval of time. You don't require 25 volts for long period of time, you just require it for the writing time which may be a few micro seconds may be. For that short period of time you can generate large voltages and that is done internally inside the chip, when you want to do an writing operation or an erase operation but even then for these EEPROM's the writing time is much larger than the writing time or the erasing time in case much larger compared to the normal reading time.

That is if you have stored any information in the ROM and you just want to read it, that operation is very fast but if you want to alter the contents of the memory, it will take much longer time. Usually that is of the order of tens or microseconds whereas the reading time may be in the order nano seconds. You see that there is still a lot of difference between the time required to write into this memory and the time required to read from this memory. That is why it's still a ROM and it's not a RAM as such. There is another type of memory which is called the flash EEPROM.

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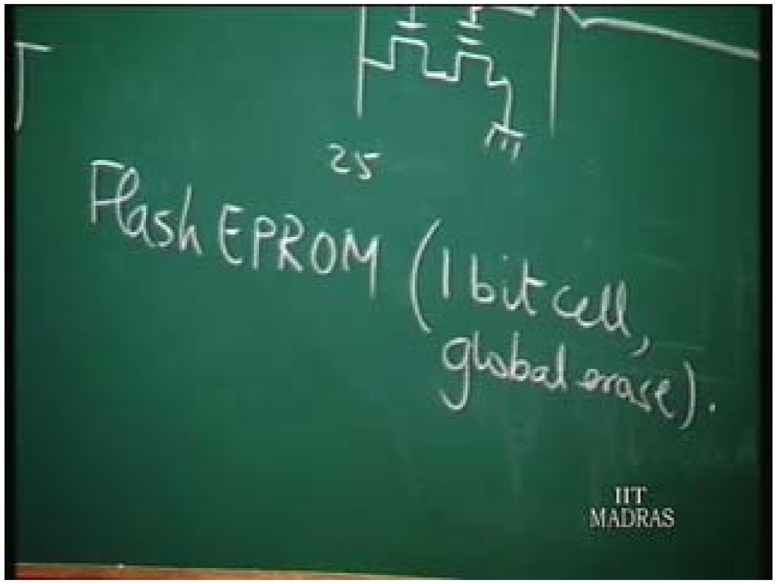

This is also an electrically erasable programmable ROM which is available that the difference is you have a single transistor cell that is also electrically programmable but in that case it is not bit erasable. When you erase you have to do a global erase because of this problem. If you do not have the select transistor you cannot do a bit erase, you have to do a global erase. This is also available, a flash EEPROM this is a one bit cell but global erase. These are the types of electrically programmable ROM's which are available at present. Just to summarize the section on memories, we have seen all different types of memories now static ram, dynamic ram and programmable ram. If you look at the different characteristics of this memories, the desirable feature which one would expect in a memory is for example whether the memory is say non-volatile.

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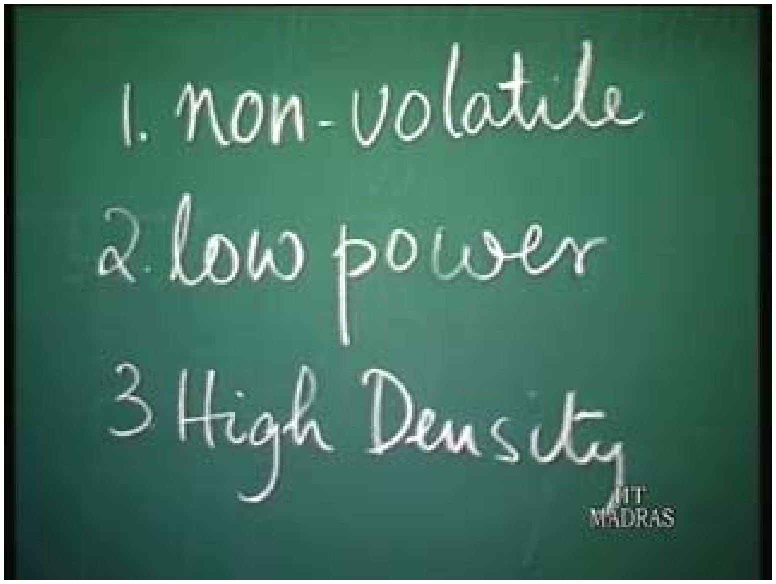

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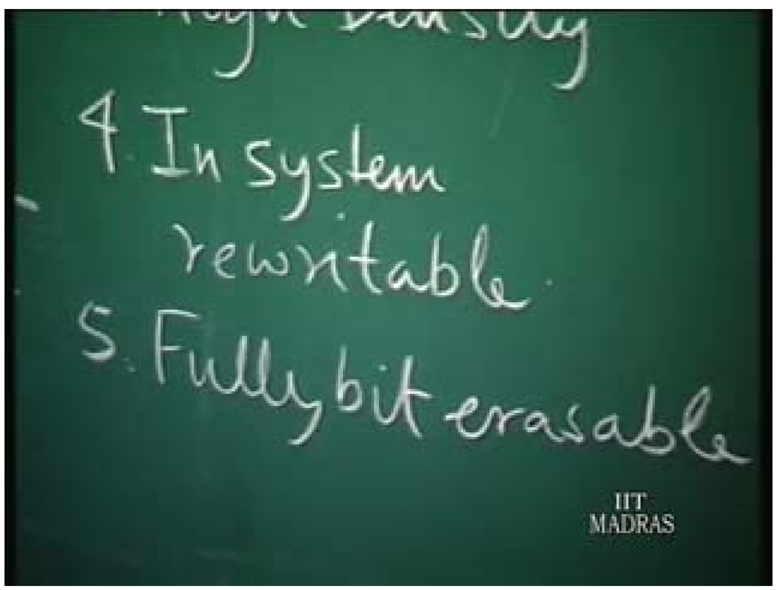

Non-volatile means that is the memory contents are retained even without the help of power supply. That is a desirable property and of course the ROM's will come under this category but the RAM's they are not nonvolatile, they are volatile memory. Then low power, the ROM's for example they don't require any power to retain the memory. The static ram requires much more power, the dynamic ram requires much less power. I think all this things you see basically the ROM's are having the advantage. High density, here again the ROM's of course the dynamic ram with its single transistor cell is a very high density memory and also the ROM's if you look at the EEPROM, just two transistors per cell it is also a very high density memory. Of course the static ram is not very high density memory because it uses 4 to 6 transistors per cell. In system rewritable, of course EEPROM's the newer versions one can actually do that but we must say that it is a very slow process compared to the reading process. Here of course the RAM's have a greater advantage over the ROM's. Fully bit erasable, this is of course EEPROM, all the memories except the flash EEPROM would have this advantage.

Basically an ideal memory would be one which has all this good properties. Now of course none of the memories amongst all the memories have all these properties. Of course there is lot of work going on to realize the ideal memory. That is for example may be a static ram which is say for example has a single transistor cell and its non-volatile may be, it would be an ideal memory or for example an EEPROM where the writing time or the flash EEPROM may be.

The flash EEPROM which is bit erasable and where the writing timing is as small as the reading time. Or for example the EEPROM which has a longer writing time about microseconds, if that can be brought down to the order of nano seconds that would be a very good memory because it has almost all. It is non-volatile, low power, quite high density just two transistors per cell and it is fully bit erasable. In fact there is lot of work going on may be to realize this ideal memory. We have to wait for the future for that. With that we come to the end of this section on memories where we discussed the different types of memories, the static ram, the dynamic ram and the EEPROM and we have seen the characteristic of the different types of memories and some of the future directions also.