Advanced VLSI Design

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Lecture - 01
Historical Perspective and Future Trends in CMOS VLSI Circuit and System Design

I am A. N. Chandorkar from IIT, Bombay, Department of Electrical Engineering. My interest area is VLSI design. We have around 40-hour course in this area of advance VLSI design. I will be assisted with or rather I will be coordinating this kind of course with three other faculties. The details about the course content and the faculty and what they will teach I will speak about in my next talk.

Today, I will start try to talk with you something about historical perspective and future trends in CMOS VLSI circuits and system design. Let us start with the very early 20th century. There were many inventions in 20th century like Airplane, Nuclear Power Generation, Computers, Space aircraft and things of that kind.

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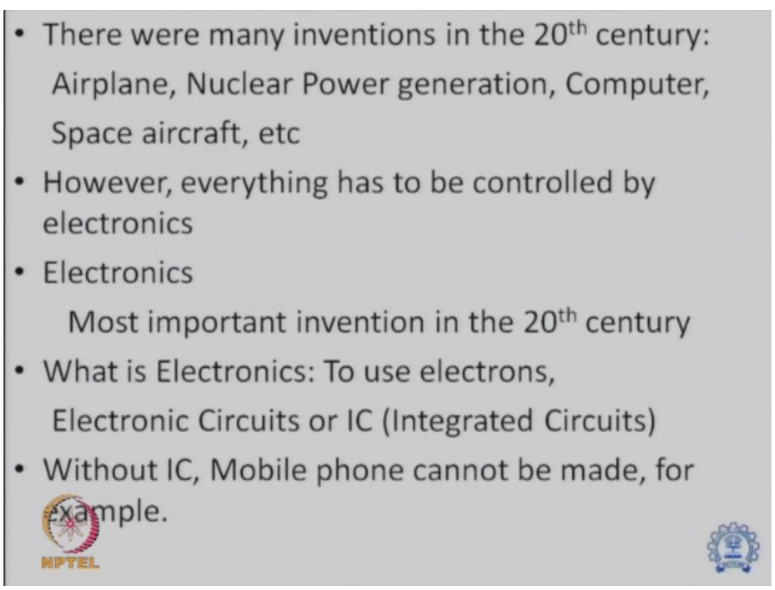

However, everything has to be controlled by electronics as just now known. So, many people ask what exactly is electronics? So, electronics I must say it is the most important invention of twentieth century and it essentially means the flow of electrons in a circuit and therefore these circuits were called electronic circuits. The modified version or the integrated version of same circuit is called integrated circuits.

And this course is essentially talking about vary scale integrated circuit design. Without an IC the present things like mobile phone cannot be made. Just to take you even 50 years before what we were?

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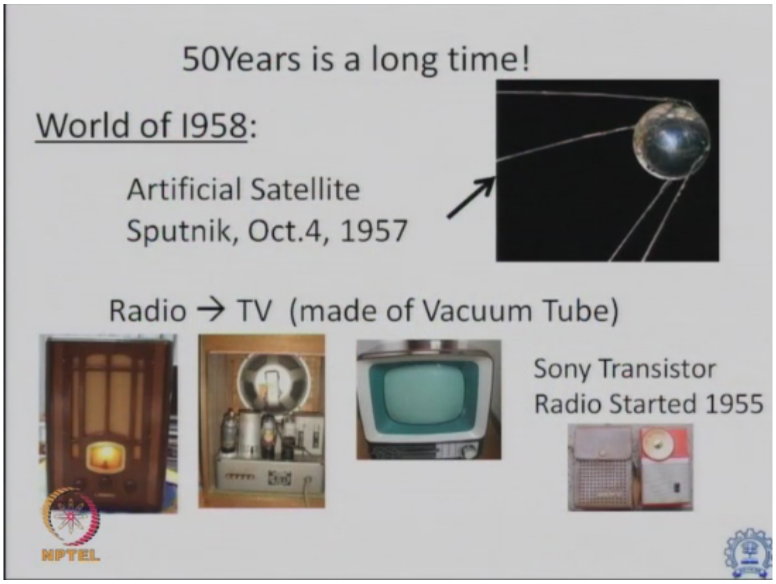

Say for example world of 1958, we have the first artificial satellite Sputnik which was injected by Russian in 1957. We started with radio and today we are at TV. You can see from here initially we started with vacuum tubes. Even Televisions were vacuum tubes as late as 2000 year. Now only we have LCD, LED displays. Earlier we have all vacuum tube based TVs. The first solid state transistor actually appeared in 1955 and the credit goes to Sony.

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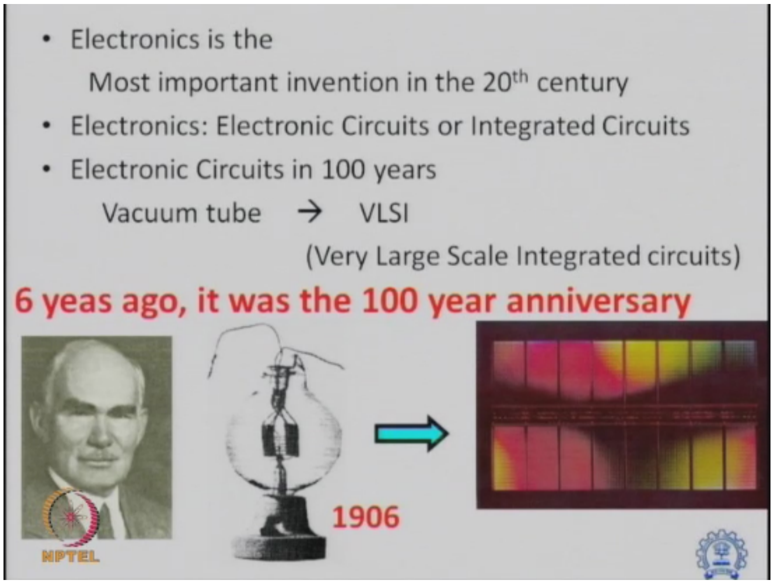

So, as I said electronic is the most important invention in 20th century. Electronics are integrated circuits how they actually are progressed in last 100 years? We started with vacuum tubes and today we are at very large scale integrated circuits. Just to tell you 6 years ago it was 100-year anniversary of vacuum tube. The first vacuum tube was made by Lee de Forest and it look like something like this and today when we are talking of a VLSI.

This is the SRAM which we are showing you. This is a 64 KSRAM from Intel and you can see the change in the structure, change in the operation of a single vacuum tube compared to what today we call memory semiconductor memories.

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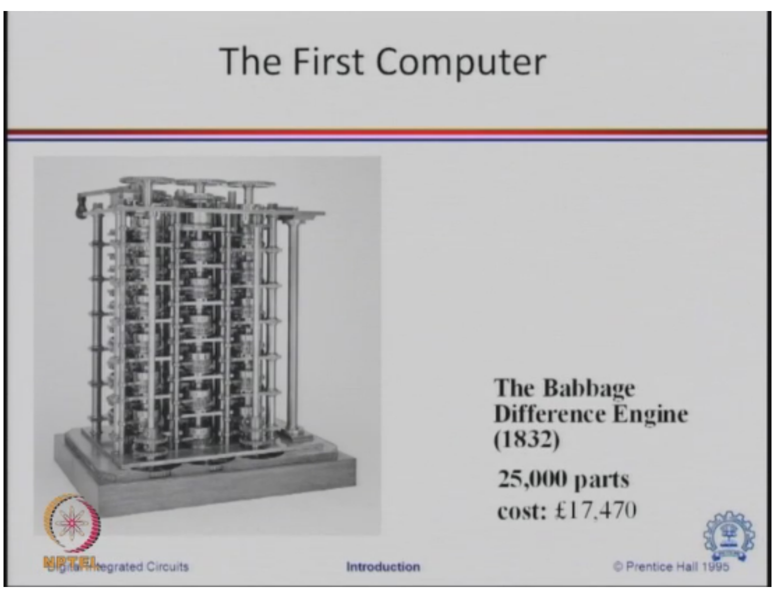

The first computer which appeared in the scenario of 2000, it was even before 2000 was credited to Babbage this is called Difference Engine which was proposed by Babbage in 1832 and it has 25,000 mechanical parts. And in those days it cost something like 17,470 Pounds. In today's, money it may be millions and millions of dollars equivalently or may be crores of rupees in Indian money.

So, this kind of a mechanical system was first though which later on become regis track as some kind of register system. And please remember the first register system was used or rather popularized by the most famous company in computer, the IBM. Actually, they also have their first machine which was mostly mechanical system.

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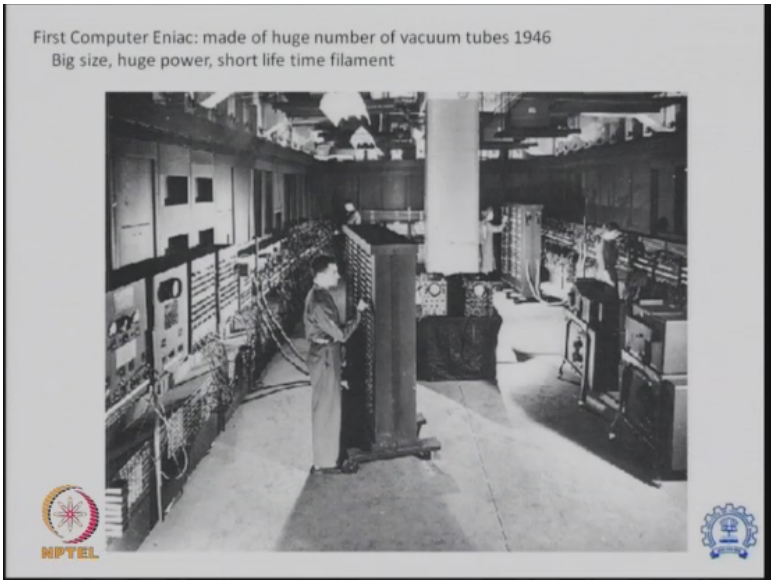

The first electronic computer came in 1946 was named as ENIAC. Essentially, it was electronic calculator some kind of equivalent. But it was made out of vacuum tubes you can see this has been put into a garage of a huge building, the basement of a huge building and even it was doing only four small operations but it requires such a large area, large systems, large in size. It consumed hell of a power and it has a very short life filament available on the tubes.

So, you have to keep changing the tubes. Let us take a comparison if for this ENIAC equivalent if I now make a Pentium four in ENIAC equivalent circuit or equivalent system it will be at least to height of an Empire State building in New York and will require for to cool it almost two

Niagara Falls every minute to throw on it. So, the kind of system from where we started in 1946 and the kind of system now talking in 2012 is hell of a difference.

Large improvements something which can do many more functions then what we thought in 1946.

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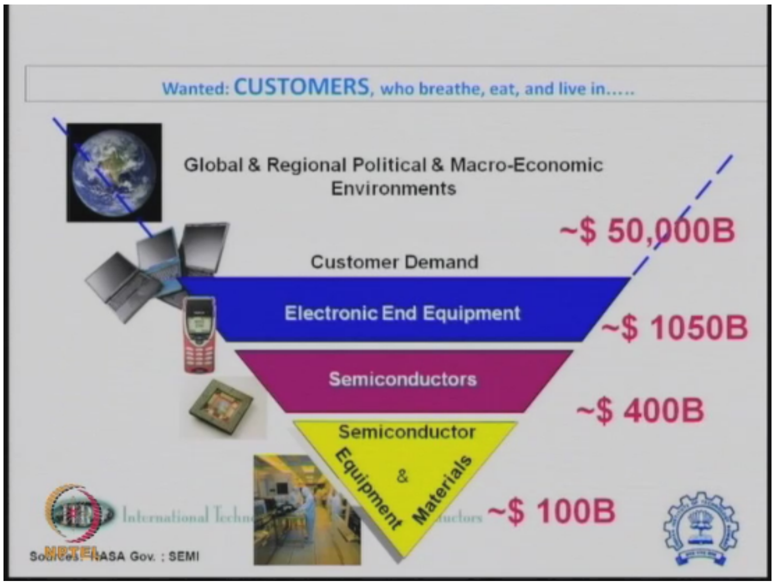

Please remember in life whether we talk about circuits, we talk about anything at the end of the day anything can be done if there is money. After all economics matters on money matters so for you those who are money minded and may be one should be at these days let me show you some kind of a view graph which says we are looking for customers who breath, eat, live only electronic systems.

So, as I was talking to you about economics in case of semiconductor industry economics is related to what we say. If you see the lower most angle inverted pyramid, the lower part the semiconductor equipment material requirement is around 100 billion dollars. The semiconductor itself is around 400 billion dollar market. Electronic equipment is around 1050 billion dollars and overall impact on political micro economic environments which uses these kind of electronic components and system have around 50,000 US billion dollars.

So, this is the kind of money in which electronic is now involved and therefore one should not take things very lightly. Why we are progressing so fast? Because somehow we want to see that we do much profit then what we have been today. Many students have asked me over the years that how do we really know before you start a particular system on chip that is you want to fabric a chip.

What will the cost of production? So, I have actually taken it as an old data 2005 data, not that it is the current value system but the idea of evaluation of any product money is shown here. Say for example 1000 wafers per month if that is what your company can manufacture.

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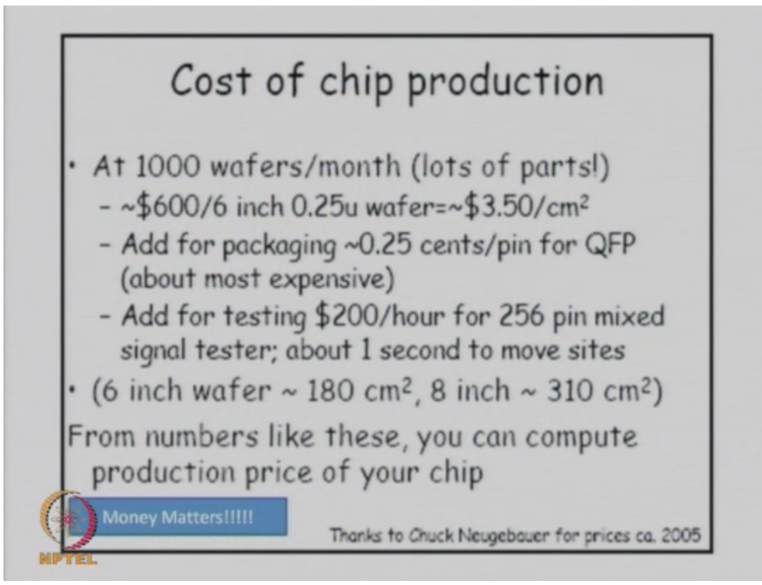

Of course there are large numbers of parts. 600 dollars are actually required for 6-inch quarter micron wafer thicken wafer. So, therefore it is roughly for the lot you are talking it is 3.5 dollars per centimeter square is the charge you require for the silicon. Add for packaging around quarter dollar pin for Quad Flat Package. This is the most costliest part per pin because it may be 100 pin, 200 pin package so lot of cost actually goes per pin on the packaging.

Then you add around 200 dollars an hour for 256 pin mixed signal tester about 1 second to move sites. 6-inch wafer and 180 centimeter square 8 inch which is one 310 centimeter square is the area typically I am talking and from this numbers then one can probably evaluate, please remember I have not added the design the cost which at times may be larger than this.

But generally it is now found that the cost of chip is actually goes in the testing which is the highest amount of money one spends just to say that my chip is working or working well to the specifications.

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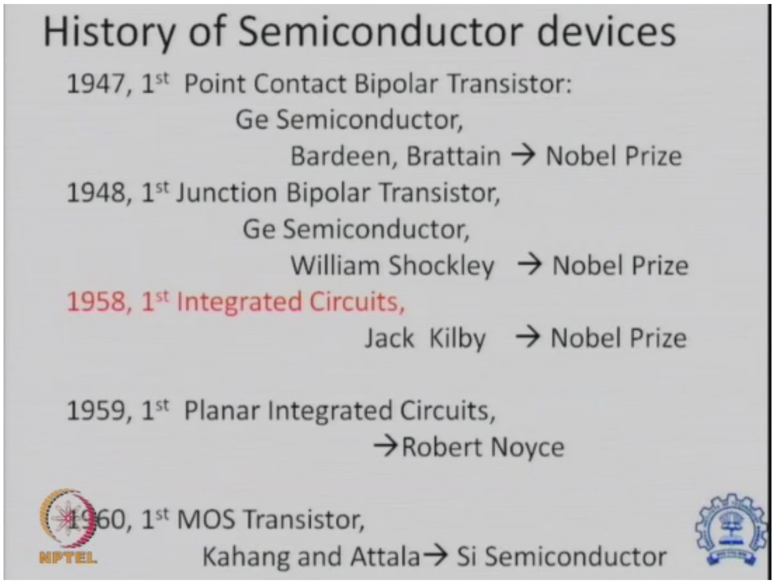

Coming back to what I was talking I just thought these two slides to show you that why? Semiconductor industry is doing well or why so much effort is put on the semiconductor industry? Why Intel, IBM, HP are known or Tech transistor is known world across. The simple reason as I say is the amount of money which they are generating or spending on people as well as on systems.

So, let us go back to say history. How is semiconductor device started way back in 1947? First point contact bipolar transistor in Germany was made and the credit goes to Bardeen and Brattain and they won Nobel Prize. In 1948, actually it was not 1948, in 1948 he started. In 1956 the first Bipolar Junction Transistor and not the point contact transistor was actually first suggested and is grouped then manufactured or fabricated was due to William Shockley.

There is an interesting story on Shockley as I proceed ahead I will talk about that. He also on same time 1956 Nobel Prize was rewarded to Shockley, Bardeen and Brattain for invention of transistor. In 1958, the first integrated circuit was suggested and was actually made by Jack Kilby then he was at the Texas Instruments, he is late Jack Kilby now and he won in 2000 the

Nobel Prize.

In 1959, the first Planar IC came and that credit goes to Robert Noyce and he is the most famous person in integrated circuit. I will come to it when it comes to next slide. And major invention of today, came through the efforts of Kahang and Attala at Bell Labs and they make first MOS transistor.

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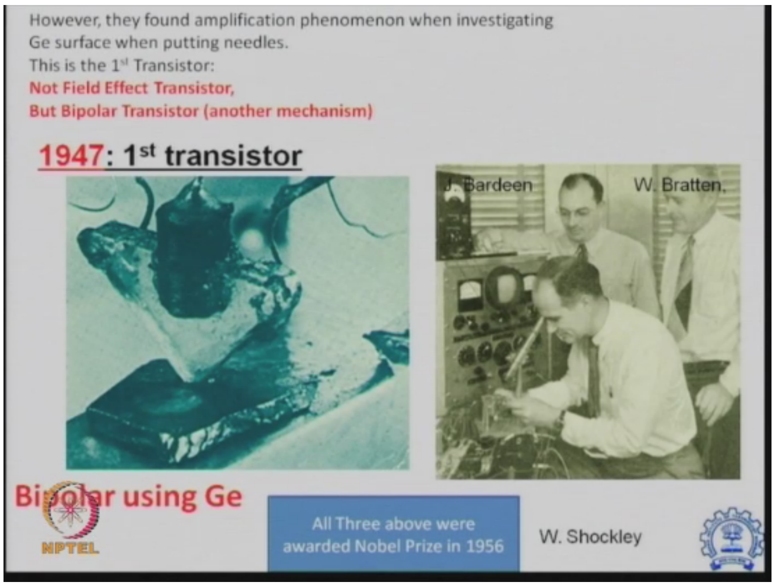

Here are some interesting photographs. The first point contact transistor shown on your left is a point contact done by Bardeen and Brattain. You will be surprised what they were actually trying on a simple germanium piece they were putting two probes and trying to feel whether it can amplify a signal. So, it was quite trivial when they started. But when they started bounding it they suddenly realized just they got some kind of amplification and that made sudden change in thinking of most people.

That simple material with two contacts can actually do amplification which was vacuum tube required a huge area, huge power, 300-volt supply, contrast to this it require hardly 5-volt supply and a very small current, low power and it was still doing amplification for signals. So, this was an invention of 1947 which made the today world whatever we see most of the integrated circuit area is essentially due to the first such invention by Bardeen and Brattain.

On your right, you can see there 3 people sitting one is Bardeen on the left, the right is Brattain and the lower one is the famous person William Shockley. He was the head of the group which was supposed to –government of United State that time asked them to actually make some kind of replacement for vacuum tube and he was heading that group and Shockley went in 1947- 1948 he was in Kelty as a visiting faculty.

And during this time Bardeen and Brattain actually invented. So, when the patent was filed by Bell labs about this point contact transistor it did not put Shockley's name and Shockley was furious when he came back he said this is unfair because most of this discussion which went through before 1947 was with me by both Bardeen and Brattain and he had a tough fight with Bardeen. Bardeen.

Actually you will not believe but in 1951 Bardeen left the group and actually started working on some other area which is called superconductivity and he won his second Nobel Prize in 1959. So, Bardeen was the very furious person that Shockley wants all credit but Bell lab did not fill a patent along with Shockley. So, Shockley started working on germanium junction transistor instead of point contact and in 1954 he first time actually showed how a junction transistor can work.

And for this invention of his along with Bardeen and Brattain all three were awarded Nobel Prize. There are interesting history about Shockley please go through some Wikipedia kind of things to know how Shockley really believed in his life.

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All said and done this is slightly magnified version of the same transistor point contact, germanium transistor which was made in 1950 for display this photograph is actually taken from Bell Labs museum where this transistor is still actually shown.

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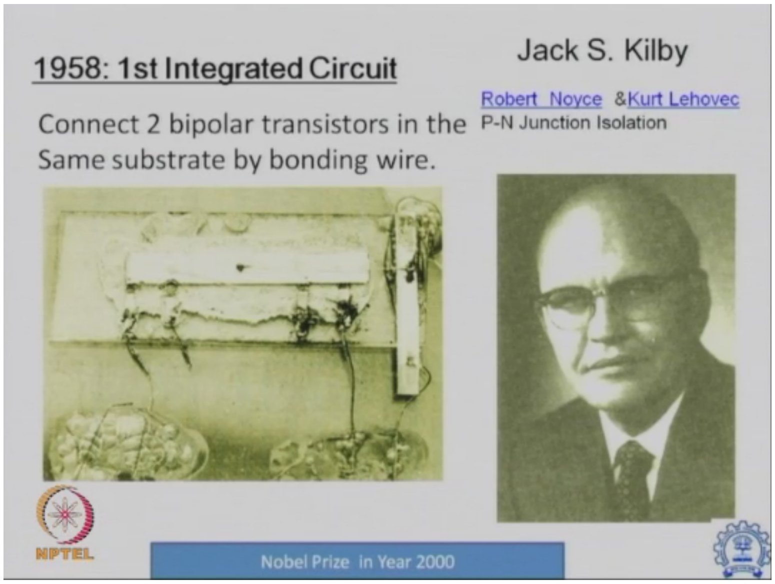

In 1958, you know the another young engineer then Jack Kilby joined Texas Instruments and the way he was he was actually asked to help people in making some CRT tubes kind of way circuits and he has much more time to while away. So, he was sitting alone he use to find that why you know only transistors have been put separately then you put on a board something resister. Why not I can make all components in silicon or in one same material?

And then if I join it will be a universal kind of circuit in which everything is made out of a semiconductor. This idea not only thought but he also actually introduced that itself on a board and on your left the first integrated circuit as made by Jack Kilby is shown to you. Though it looks far away from today's integrated circuit but the main important point that this was the first IC which has two register, one capacitor, one transistor all together on a circuit and that has worked.

The importance is it was working circuit. Please remember Jack Kilby was not assigned this project even after this invention by Texas Instrument. So, that is the irony of life that he was asked to do something for which you think you know more. However, Jack Kilby invention was never treated very high till so late as 2000 in which he was then awarded Nobel Prize. Simultaneously, when Jack Kilby was doing something on kind of things he showed Robert Noyce then at Fairchild who started company along with others Intel.

They actually were thinking of making all components in silicon and they called PN Junction based silicon device, isolation technique which allowed components to be separated in the silicon. There was another scientist or another engineer called Lehovec who was that time at Sprig Electric and then joined USC as very distinguished professor at University of Southern California.

They also worked on PN junction isolation theory and that allowed us to actually separate components inside a silicon block. Unfortunately, both died before Kilby got the Nobel Prize probably he would have to share the money as well as the credit if had they been allowed in 2000. So, here is the first planer integrated circuit.

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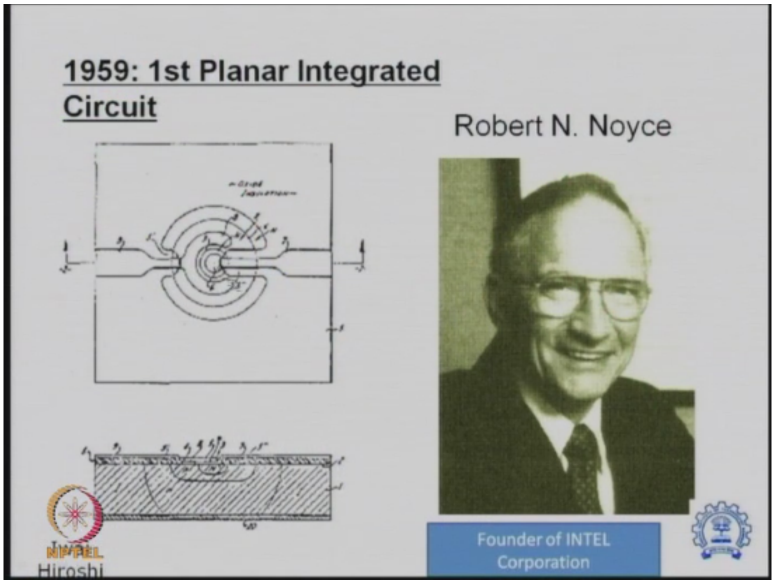

You can see from here. There are three parts annular form one this, one downwards and one center and these are contacts. So, PNP transistors were first made by Robert Noyce inside the silicon itself or diffusion inside all contacts in the top and this was the major invention I must say which allowed integrated circuit to manufacture in large number of densities and very cheap methods.

This so called planar techniques still stands and this is the way almost every semiconductor chip is made. Here is the photograph of Robert Noyce who also working with—that was called 8 dirties among them is Gordon Moore, Intel Noyce then their use be Chong. All these were working with a new company in Menlo Park in California under headship of Shockley. But as usual Shockley never wanted to be credit to any of them.

Therefore, they all 8 dirties left and started a company Fairchild and this Fairchild was a camera company. They did some work and then they realized that in a camera company they were only making CCDs. So, they left Fairchild and started their own company and then called Intel Corporation. What today you all see is because of probably Shockley because if Shockley would have been a good man probably Intel would never started.

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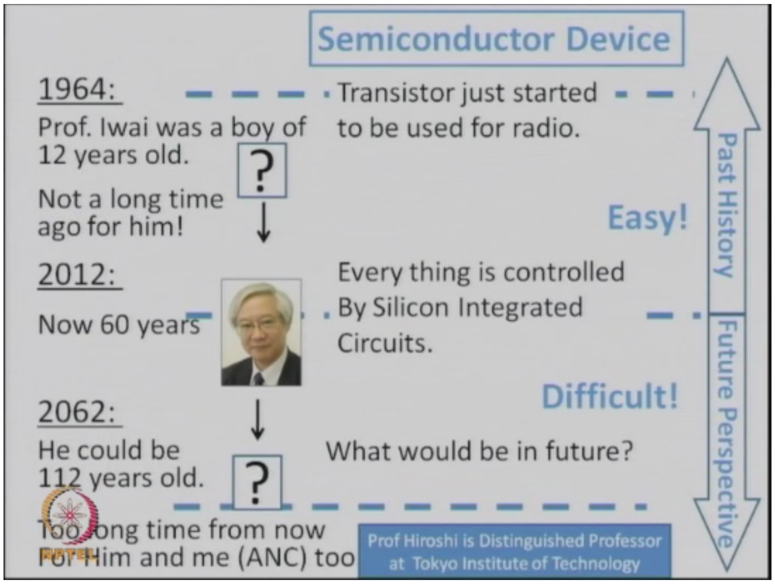

To sum up on this kind of device I have an interesting slide you know one of my very famous distinguished colleagues at Tokyo Institute of Technologies, Professor Hirose and this slide actually was made by him. So, I thought I always show it everyone. He said how the devices technology had progressed over the years. To your left you can see Professor Hirose was a boy of twelve years in 1964.

However, in 2012 this is how he looks. He is 60-year-old and in 2062 another 50 years you add he will be 112 years and I do not know how will he look? Too long a time for anyone for him as well as for me. So, what has happened in 1964? Transistor just started to be used for radio. Yeah, most people though amplifiers is all that you need. So, small logic was made and the history shows that this part was though noble but was not difficult.

It was rather easier to actually achieve successes faster. Slowly, when you say every system became based on integrated circuits particular silicon integrated circuits over the years last you can see 2000 onwards, 2012 and now onwards till 2062 any progress in silicon IC industry or in silicon technology will be very, very difficult. So, for us it was a nice time we could do small things and get credit for it probably in future when you start doing work in this area.

You will find very difficult to progress as the pace with which we all progressed or the technology progressed.

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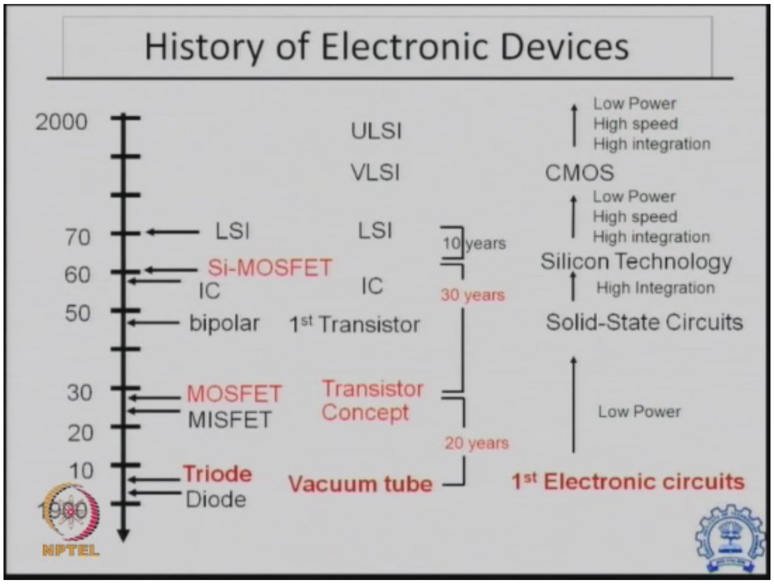

So in nutshell in 1900 diode came, then 1906 triode came Williamson invention. In 1926 MISFET and MOSFET were first announced never made but announced first bipolar transistor came in 1947 to 1950 both part in Bardeen and Brattain, Shockley inventions. First IC came in 1958 Kilby, Noyce and Lehovec. First MOSFET appeared in 1960 by Kahang and Attala and first largescale integrate circuit appeared in 1970.

The names were given because we started looking for the number of components on chip. So, first we started the vacuum tube first 20 years it took us to reach to transistor concept. Next, 30 years we could make ICs and last 10 years up to 1970 were spending on largescale integration and I do not next last 30 to 40 years we are in the era of VLSI Ultra-large-scales. What was the difference from 1900 to 2000 otherwise in this performance wise?

The first electronic circuit was huge power and very slow, a huge power consuming and comparatively lower speeds. We wanted to look for lower power dissipation so we went from vacuum tubes to solid state now silicon technology allowed high integration and when we went to CMOS we have a low power high speed very high integration devices put on a simple chip and we are still continuing for high integration very high speed and low power.

They remain the same parameters in which integrated circuits are being advancing now.

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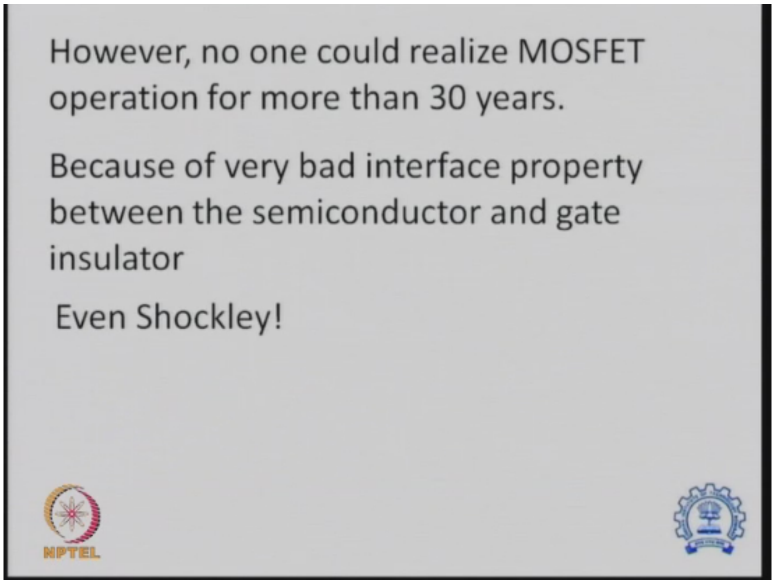

Please remember that in 1925 to 1933 twice there was a research done on MOSFET including Shockley was actually working on MOSFET and Shockley has a legal fight with many people saying that MOSFET was his concept. Unfortunately, Bell Lab did not file a patent on the name of Shockley. Otherwise probably this would not had happen. Shockley of course had brighter ideas then most people of his time.

So, nothing that he could not think because of very bad interface property then between semiconductor and the gate insulator MOSFET could not be realized till 1960 and the word I always say even Shockley could not make. In spite of all the intelligence he thinks he had.

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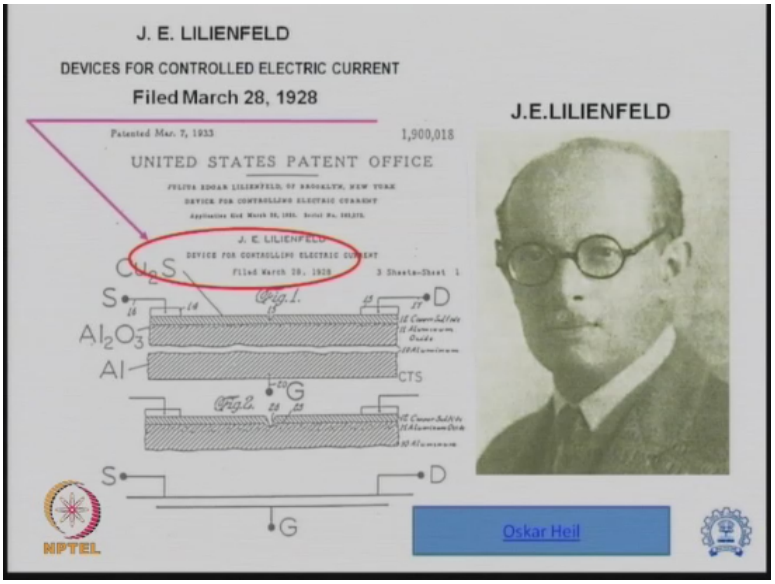

The first MOSFET as a concept was given by an air force officer of Royal Airforce of England, Britain. He actually filed his first patent the name is Lilienfeld. He has a US patent on a MOS surfaces and MOS devices. The MOS transistor was suggested by him he had an aluminum oxide as insulator, aluminum as a back contact, so is aluminum the top contact. And he did actually suggest that this may amplify as per as his theory goes.

But actually this idea was not so original because by the same time a German scientist Oskar Heil also was working on MOS and has actually has patented independent of Lilienfeld in 1934. He has another patent on MOSFET but that was a European patent. So, no one knew that Lilienfeld as a US patent. So, there was a fight between Heil and all sent the file could not last because no device could be made.

What I meant by interface properties can be seen from here.

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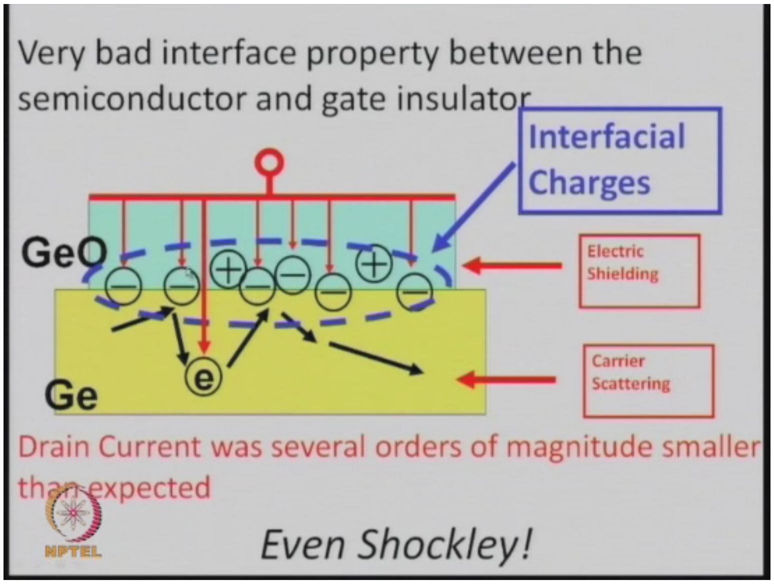

Between say germanium and germanium oxide if this is your insulator because there are two different materials they all silicon to germanium to germanium oxide bonds are not satisfied and therefore there are some charges left which are called dangling bonds charges, which are called interfacial charges. And the net effect was they were shielding the effect of voltage on the gate material and not every voltage could be then put into induced into the semiconductor.

And then there was another problem people could immediately think that if they carry outside to move they should move fast was there was lot of scattering but we called carrier, carrier scattering and also feel scattering which allowed very small amount of current to flow. So, it was found when the first MOSFET was made rain current which was measured by then was several order smaller then what theory was expecting.

And as I keep saying this was even Shockley could not explain then though later time when suggested that the surface traits has become inter phase states. The states were actually explained by Shockley and therefore they were also called Shockley states. By 1960 the first MOSFET actually was made at Bell Labs and the two people Kahng and Atalla.

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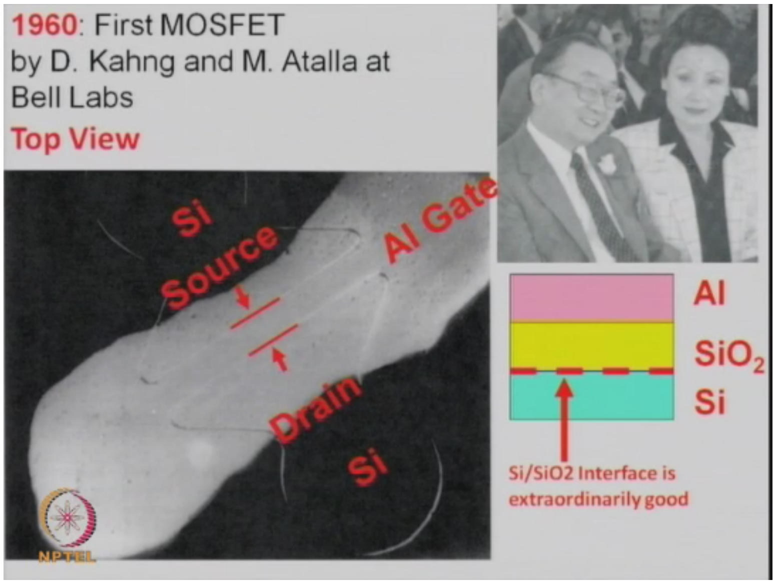

This lady is not Atalla by the way. She is Mrs. Kahng. They actually made the first MOS transistor and they made it out of silicon instead of germanium and they have SiO2 has the interphase as an insulator and the interphase between the Si and SiO2 was far superior then germanium, germanium oxide. There was very little shielding between insulator and gate and because of that the first MOS transistor worked.

A figure could be shown here. This was the source area. This was the drain area and in between this was the gate and that was covered by aluminium. So, this was a first MOSFET which appeared in 1960.

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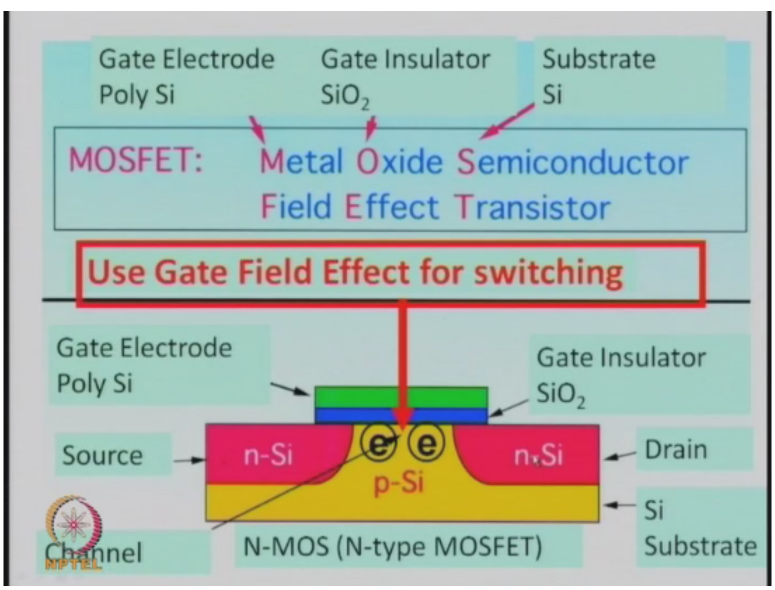

Then we changed from metal gate to poly silicon gate to reduce the capacitances we still kept on having SiO2 and silicon substrate for almost till 2000 or even today many Intel circuits or IBM circuits still have SiO2 as the insulator. They have changed, modified SiO2 with something else but silicon dioxide is still going strong. But in 2010 probably or 2005 onwards, we have shifted out of SiO2 and new (()) (25:35) are coming.

So, typically using a gate field effect one can see from here the gate could then control the carriers below by the induction Gauss's law and then connect between source and drain and large current could flow. This was the first MOS transistor way it was made successfully.

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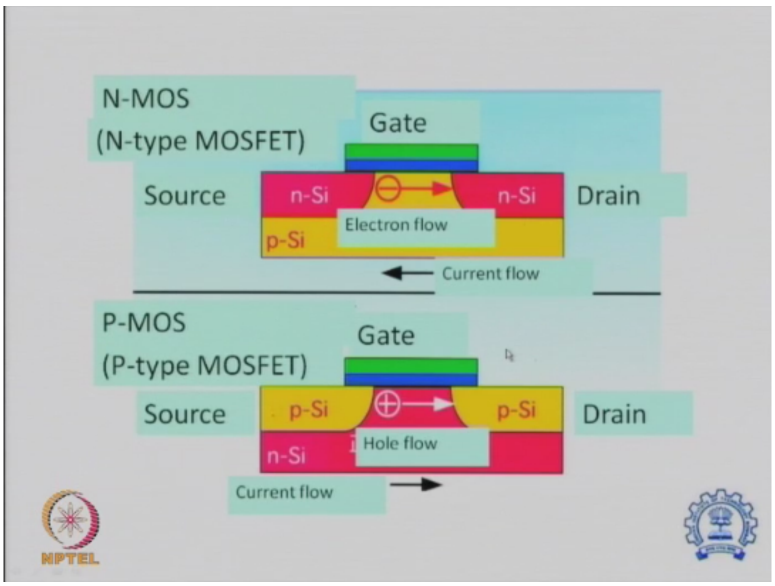

Two types of MOSFET were made one due to anti MOSFET in which the electron motion was possible because if you apply positive voltage and the gate the negative charges are reduced and between N silicon source and N silicon drain, electron channel could be created. We start with the p substrate therefore it is called inversion layer electrons could move under the electric field and laterally and if they constitute a current.

So, we say anti because the carriers were electrons. Where as in case of p channel we started with n substrate we have a negative voltage and the gate to actually create inversion layer of holes between p silicon source to p silicon drain. The holes can move and therefore hole motion was also possible and we therefore declared p type MOSFET. You will be wondering that I am talking about advance VLSI course and why this?

Because the first course which I gave was a web course in which all this was not actually provided. So, I thought if you are reading VLSI design one and VLSI design two in continuation let us at least come back and show what things happened over the years.

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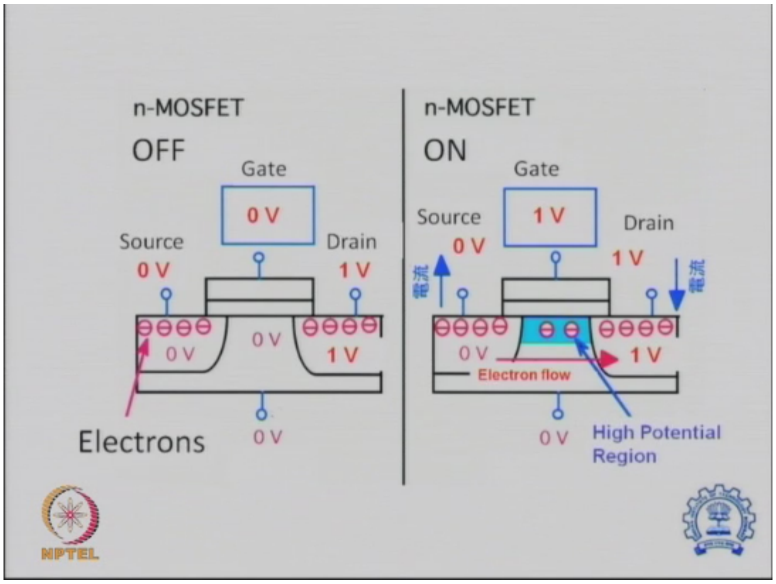

This is something same since we are looking for a MOSFET as a switch we found out it is much easier to actually say how it is off and on. So, we said okay. If you apply zero volt on the gate let us say you are N-Channel MOSFET is going so you require positive VG to create an inversion. So you apply less than that particular voltage we call threshold voltage, right now we put zero voltage which is less then positive VT then there is no channel between source and drain.

So, there is no channel between source and drain. So, therefore there is no current between source and drain. So, we say off state. No drain current. Of course there is a leakage current but that is a very small and we still declared it as an off state. On the contrary if we apply gate voltage which is larger than threshold on the gate an inversion channel can be created of electrons, source drain if I apply voltage across.

This is like Ohm's law. This is a register you are applying two contacts, drift current can flow and we call that as on state or one for the transistor. So, on and off zero and one could be created out of MOS switching and therefore it became the most important candidate for switching circuits or logic circuit.

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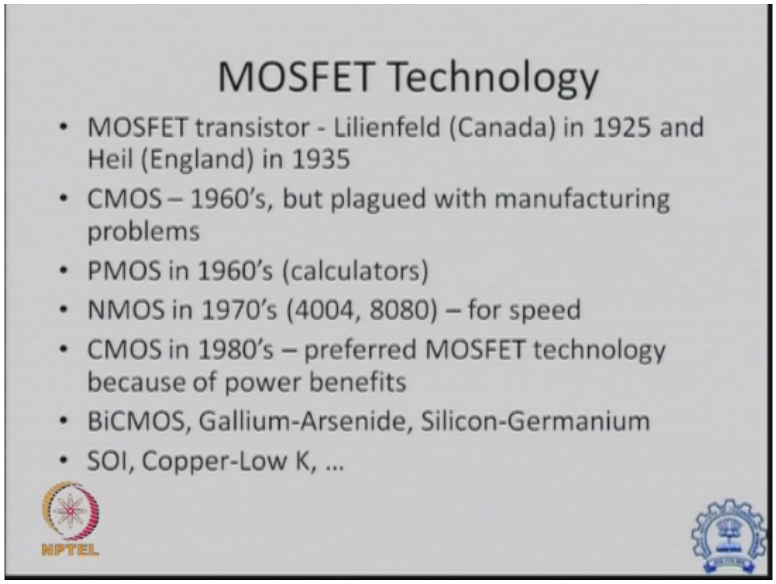

Over the years I again now summarize quickly the years through which we went through in technology. First, MOSFET transistor Lilienfeld and Heil in 1935 and 1925. CMOS 1960 but plagued with manufacturing problems. Please remember the first CMOS was attempted as early as 1960. It was not only P MOS it was actually they tried both and N MOS and P MOS together, N MOS could never be turned on because it was always on.

So, we just could not create a CMOS circuit out of it. It was depletion mode was always created. P MOS was then we continued to work with P MOS devices still late 1970 most calculators available then was P MOS based circuits 1960 to 1970 then N MOS technology was improved and then we shifted from P MOS to N MOS because N channel has larger mobility because of electrons.

So, more current at lower voltages and therefore N MOS replaced the P MOS individual case for improvement of speed. First Intel processor 4004 and 8080 were made in N MOS early 1975. In 1980 when both P MOS, N MOS technologies were controlled the first combine device was made. Complimentary MOS which has both P-channel, N-channel together and this has much more advantage.

Because it actually shows much lower power consumption or much lower power dissipation compared to either N MOS which is the more power consuming device then P MOS but both were power were power consuming device compared to when the CMOS is used. Then we went from COMS to another technology like BiCMOS. We always though that bipolar circuit were very fast compared to COMS for many years.

The obvious reason was there was huge current in a bipolar transistor and a capacitor can be charged much faster. Therefore, speed of a bipolar circuit is always larger at least till some years. But it was found that the power is also very large to create that high speeds and our ultimate aim for all MOSFET improvements were larger speeds at low power. So, people thought if we merge bipolar technology with CMOS we may get advantages of both.

Unfortunately, it did not happen as way. It actually got disadvantages both in a larger number then the advantages and except for very specific circuits some inputs circuits some input circuits were TTL input are to be given BiCMOS did not actually captured the imagination of most of the designers or most of the system designers. We also shifted to high mobility material like Gallium-Arsenide.

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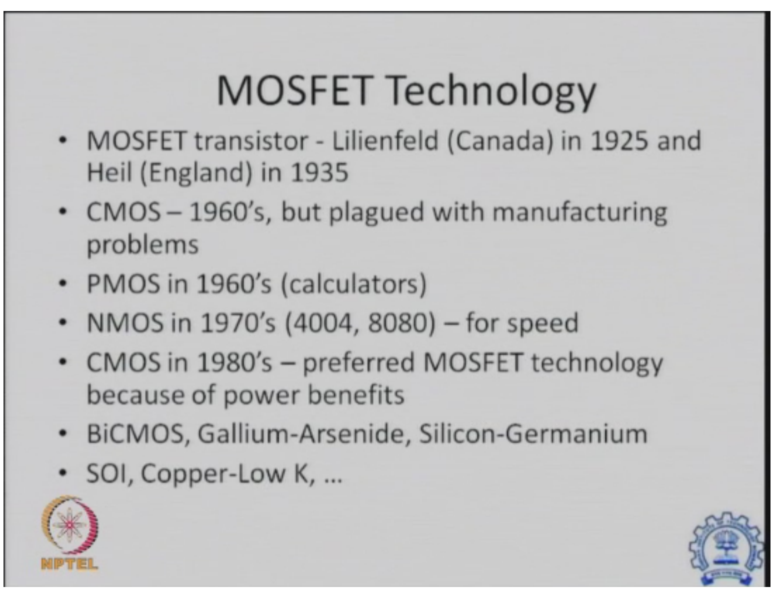

We thought that silicon has limited electron mobility compared to any other material then we say okay let for higher mobility materials we went through Gallium-Arsenide, Silicon-Germanium and even host of silicon nitrite is being tried, silicon carbide has been tried. Unfortunately, none of them have as good an interface with insulator as silicon. Therefore, silicon continues to remain the benchmark material for all integrated circuit technology.

Though I will show you at the end may if time permitting. Beyond Moore is silicon going to stay? Possibly. We also worked on SOI silicon on insulators. We are also working on interconnect, different interconnects like copper - Low-K. These are the new inventions in last 10 years. Aluminium was replaced by copper it is a very interesting technology thinking that if copper is known good, better conductor both electricity wise as well as by thermally.

Why at all we started with aluminium? Why not copper? Unfortunately, copper for many years even now is called poison to silicon device because it actually creates the levels the levels in the band gap of silicon which actually reduces the life time. So, copper was never allowed probably if you come even to a lab like ours in 1985 which we made in IIT, Bombay we had no copper tubing anywhere inside the lab.

Because we were told that any mass or bipolar circuit will not work if you have a copper tubing of gas also coming. So, no question of directly on silicon however there was a (()) (32:45) came from the efforts of Texas Instruments, IBM. I think everyone claimed. I do not know who should be given credit they actually replaced copper and to protect copper from silicon they had some kind of cladding around which was titanium nitrite.

And using this they could then makes an interconnect of copper which has a higher conductivity therefore lower resistance and therefore higher speeds. We also wanted to put more than one layer of metal interconnects. So, between the two metal interconnect lines we put low dielectric constant materials, insulators like many of them HFC and many others were tried. Glass of course is the only one available earlier we will try to see whether low K materials can be used.

Air of course is the best but you cannot put two metal line separated by air so when asked to find some material which can give physical support. 1970-1971 the first generation of LSI appeared.

This is Intel 1103 DRAM.

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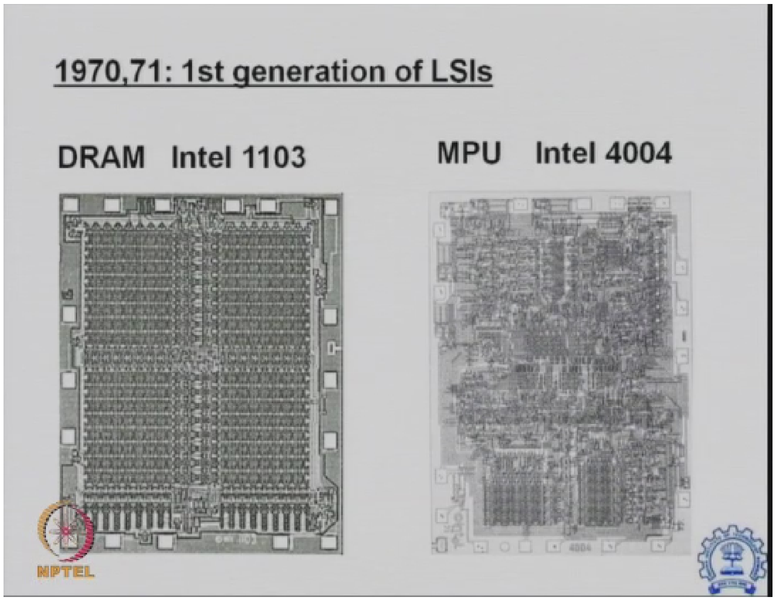

You can see what kind of structure it has? How it looks? The first microprocessor as I said earlier is Intel 4004 and just for our Indian students I may say India's only semiconductor manufacturing company which was semiconductor complex at Chandigarh somehow purchased the know how to manufacture 4004 god knows why? I do not want to say more than that.

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	Name of Integrated Circuits	Number of Transistors
1960s	IC (Integrated Circuits)	~ 10
1970s	LSI (Large Scale Integrated Circuit)	~1,000
1980s	VLSI (Very Large Scale IC)	~10,000
1990s	ULSI (Ultra Large Scale IC)	~1,000,000
2000s	?LSI (? Large Scale IC)	~1000,000,000

So, repeat performance what I said so far 1960 integrated circuit came. So, people started thinking how to do we name improvement in number of transistor or technology? So they say okay if one when we have appeared it has only 10 transistor maximum. So, we call integrated circuits IC. Then we say if you have more than 1000 transistors. We say it is largescale integration. In between there is this small scale, medium scale integration.

Then we say 1980, when we say we are larger than 10,000 transistors. We started talking of very large scale integrated circuits. By 1990, this became some kind of 1 million transistors. Then we say ultra large scale but if it is one then more than a billion now as they are coming up probably we may call it I do not know what a giant large scale or whatever it is, giant scale. But it so happen, the designers did not like these technologies names.

So, they kept on calling anything beyond VLSI, as VLSI and therefore it stuck. So even if now you have a billion transistor on chip it will call a VLSI chip whereas technology people will not like it to call VLSI because for them VSLI means around 10,000 transistor alone. So, what is integration I just come back again you say okay there are multiple devices on one substrate and this question as I say is always asked how large is very large?

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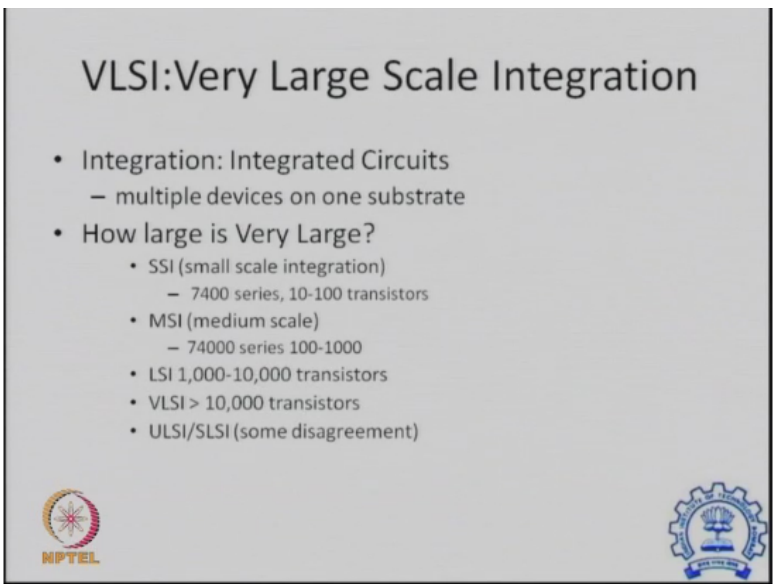

So, we say okay small scale integration chips I would give numbers. TTL has 74,000 series or 7400 series which typically as 10 to 100 transistors. Then you have 74000 series from TTL which has around 100 transistors plus and we say okay this is a medium scale and when we actually moved away from bipolars and we went for large scale thousand to 10,00 transistors.

We actually started going large scale and above 10,000 as I said we all started calling VLSI. So, even if now you have million transistors or billion transistors everything we say is very large scale.

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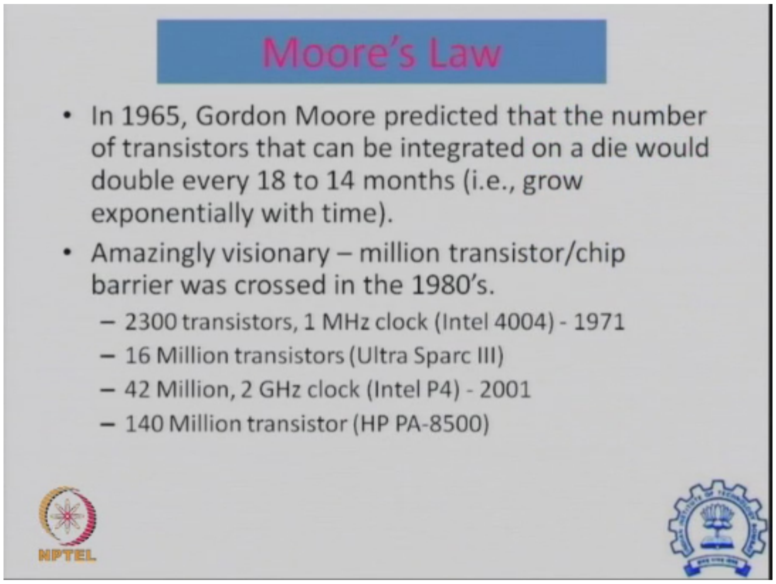

If I do a course in VLSI design and I do not utter a word or utter a name Gordon Moore, probably I will be fooling myself. He is our so called demigod for VLSI integrated circuits. Gordon Moore was one of those who joined, who left Shockley company then he joined along with Noyce and others at Fairchild and then started Intel with them. He was a very visionary person when the technology was being grown at Intel and earlier at Fairchild.

He figured out the way technology is improving on the day because of the improvement I can see that components doubling. So, first he thought it may double every 14 to 18 months. But later on he said it may double every year he says it would double the component or large scale you can say it will start doubling. Or essentially you can equivalently say exponentially with time the number of components will double on check.

It was certainly I must say this was amazing visionary pronouncements and you can see 1980 itself according to what Moore thought you should have million transistors on the chip and we did crossed that barrier in 1980. So, as if there is a joke going on in both technology group and design group that all of them are working to see that Moore is correct as if. So, we work strive very hard both technologically as well as design way so that the Moore’s law still is agreed to by almost everyone.

Even if we do not reach what Moore thought then we say okay, deviations from Moors law. But we kept on talking of Moors law all through our careers and may be you will also keep talking in your whole career till you work in the area of integrated circuits. Just to give some numbers of transistors. The first Intel 4004 was 2300 transistors which was working on one megahertz clock. UltraSPARC from Sun which has 16 million transistors.

Two GHz Intel P4 which appeared in 2001 has 42 million transistors and in 2003 HPs first PA 8500 appeared which has one 40 million transistors. Currently, many of the processor quad one, Athlon or other from AMD all have more than 400 million transistor on chip.

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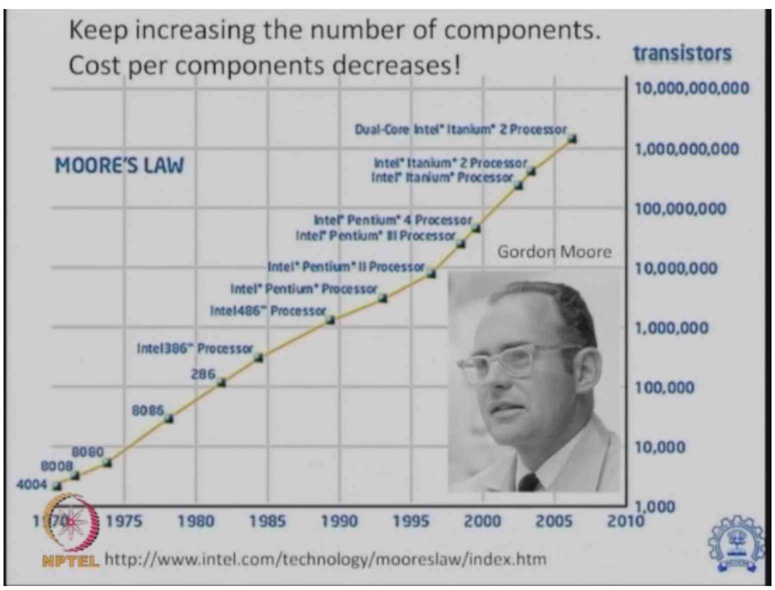

So here is the Moore’s. So what essentially Moore’s law has? As I already said on your right, right of the scale is the number of transistors. This is a billion numbers as I show. Sorry, this billion, this is ten billion. So, you can see the face of Gordon Moore. I am happy to share you that I have met him in one of the conference in US. Of course met fleetingly, I do not know think he knows me or I know him.

But it is a great thing to know who is this so called Gordon Moore. So from 1970, till 2010 all the processors if you see are actually as per the number of transistors count as Gordon Moore suggested and they kept on following the years. Of course it is not hundred percent straight line linear everywhere a little bit slope change here. But again it has started rising in the similar old fashion and therefore one can say Moore's law is back in full force.

For example, Dual-Core Intel, Itanium 2 processor which was announced in 2008 it has more than a billion transistors. So, Moore's law essentially was telling that the components density or transistor density will double every year was followed till very, very late.

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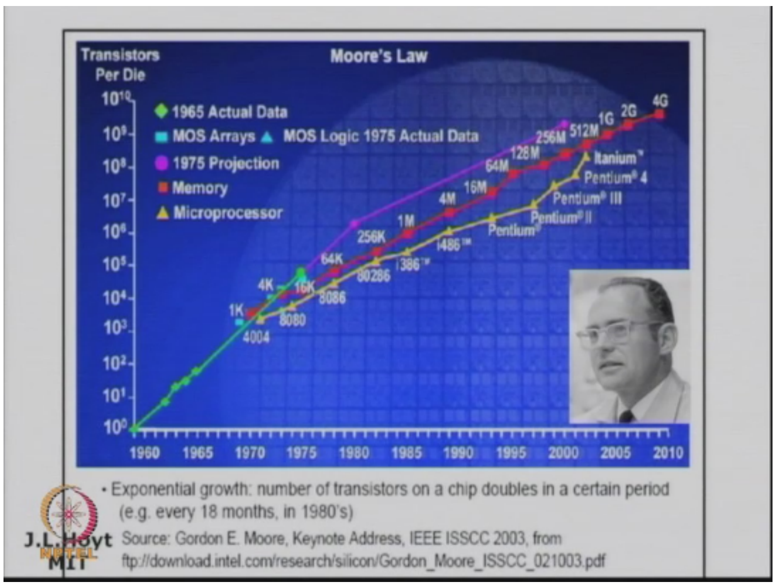

This is something two components shown on the same based. One is memories the other is microprocessors. Why people choose this? Because in an integrated circuit or VLSI if someone ask you the marker. What decides the technology node or what decides the progress? The two devices we always discuss or two such different parameters we look for. One is the improvement in speed and other performance of a microprocessor.

The second is memory, how many bits memory can you create in a smaller number and what is the excess time. So, these are two though they are more made out of MOS transistors but their operation is different from each other. One is purely based on logic, the other is based mostly on the charge or discharge of a capacitor and because of that the progress of a MOS technology was always gauged based on the memory as well as microprocessor.

So the Moore’s law if you apply on these two components microprocessor and this you can seek not exactly one to one correspondence but yes by 2010 4 GB DRAM is available in the market which means the Moore’s law is still getting followed. Whereas we already reached Itanium, Pentium 4 Quads so we are already crossing the numbers of transistors which was projected as early as 1970 and we are still going strong with it.

Now question is always asked how long this will last? Well, at the end of this first lecture of mine probably you may have some idea about where it will end if at all. Because if at all is a word I keep using because there is a strategical theory that there is no zero probability. So, one cannot say nothing will happen. I mean there is a probability it may reduce but may still happen one does not know.

Moore figured out that by 2000 that his double every year law is not being followed so he projected that it is called Moore’s second law. He says okay, double every 2 years. First, he said 18 months then break it 24 months. And now he says okay every 3 years. So, all that he is now changing the slop. But there is still a law which is been seen as Moore’s law and people are trying to meet what Moore’s says.

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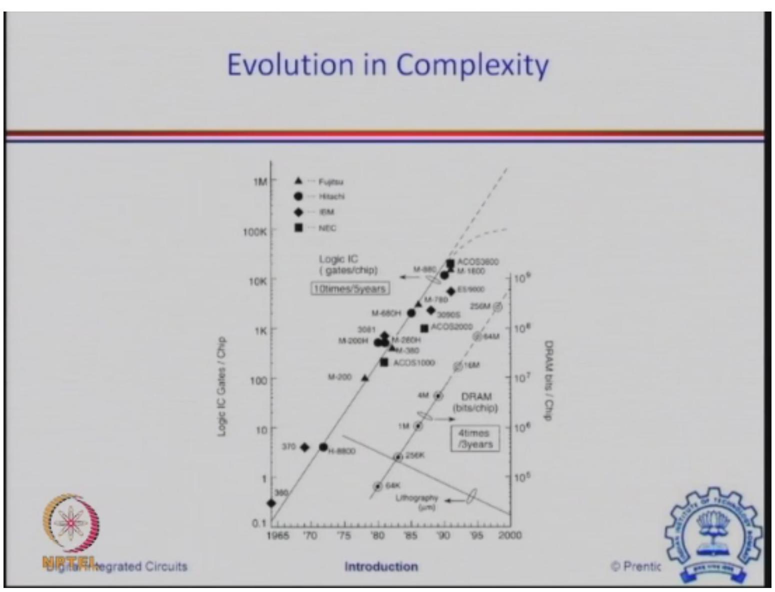

So this is called same this is a graph between the years as well as the logic number of per chip or logic or gates per chip and you can see it is slightly separated. The same graph Moore's law I have shown separately. This is for memories and this is for processors. You know this line is essentially why this graph has been shown in the integrated circuit manufacturing one of the major worry right now is what we call how to print the small dimension?

If you reduce the dimension you have to print something on silicon before of that dimension. Nanometers say thirty nanometers, twenty nanometers, 10 nanometers. So, when you print something you need process called lithography. Transferring image from one to the other now this is a limiting point right now. We are still using Photolithography which is called 193 nanometer process.

And may be in 2010 onwards or 2012 onwards we may go forward, we call extended UV process which is still not been available to any manufacturer Intel is working, IBM is working, TI is working. But that is not on the manufacturing though it has successfully been tried. So, the limitation now people are saying is not because of the DRAM thinking or this. It may come essentially because of the lithographic process may not allow you to go much smaller.

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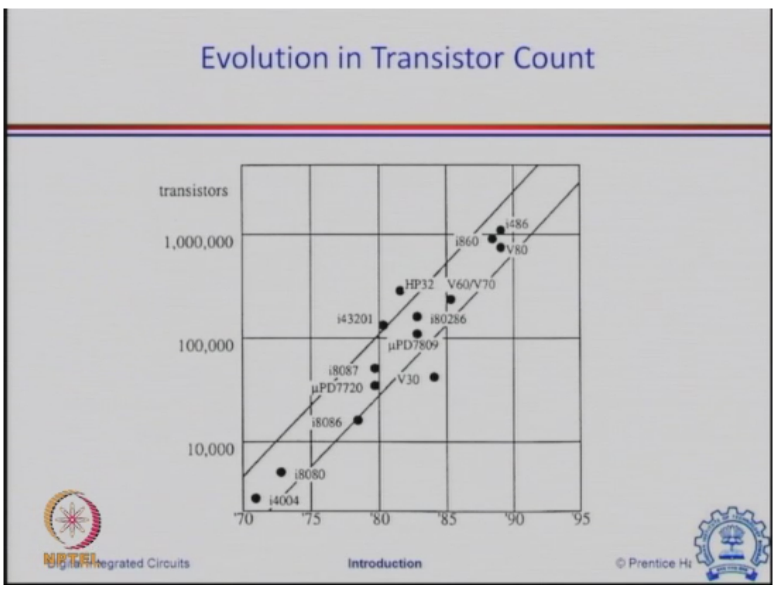

But all said and done if there is a problem there is a solution and therefore I do not see why it will not occur. This is same figure again.

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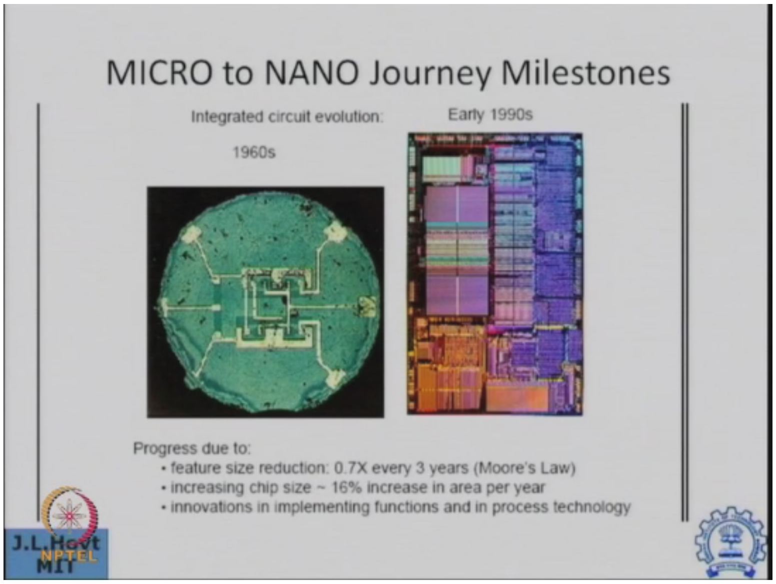

So, what I am trying to show you on this our journey over the years have become micro to nano. We started with dimensions which was say 100 microns in 1970. I have worked on a chip, a transistor which has a 100-micron channel length in 1976. Of course by few years we have went to 10 microns but we start our first MOS transistor TIFR was just 100-micron length and we made it and it worked.

The importance it worked then we of course went to 10 microns in the next MOS. So, in 1960 we started with 100 of microns and by 1990 end of 1990 or even early 2000. We are talking of million transistors on chip. So, this is what we call really mile stones. We went from IC to VLSI to nano now. So, what essentially nutshell moves it? When you say double, essentially he says that when the size of feature, smallest feature on the chip reduces.

So he says okay every technology improvement will be improving it by point seven times. It will reduce the number by last point 7 times and which now he says every 3 years. The new modern law is 6.7 x. So, for example if you are working on 90 nanometer technology earlier so 0.7 of that is 63 then we say next technology will be 65 nanometers. If I multiply it by 0.765 it will be around 40 odd numbers. So, it is called 45 nanometer nodes.

If I multiply by 0.75 nanometers it will become 32 nanometer nodes. If I multiply it by 0.7 to 32 it will become 22 nanometers and that is how nodes were actually described. And you can see behind all this was Moore, multiply it by 0.7. Now, this as you increase the chip size now 60 percent every year and you reduce the size of the transistor 0.7 into 0.7 that is half of it. Obviously, that number of transistor will increase because you are increasing the size and you are reducing the size of the transistor.

So, obviously number of transistor will keep on increasing every year when the new chip will be appearing. Now, the question came till 1970's or early 1980's the designers use to say I want to put such a large system it will require a 10 million transistor or 8 million transistor but your technology can not give so many transistor on chip. By 2000 or 1995, a reverse has happened there are number of transistors available it can be as high as 800 million or a billion transistors. But there are no systems which can actually implement all of them in 1 chip.

So, now the designers have more problem then the technology because designers do not know what to actually I should put they started putting 4 processors on chip. So they are oh, oh I have now quad it. But actually one processor is anyway what you are using on the same chip you put four so four times. But even then there are numbers of transistors available is much larger than most designers can even think.

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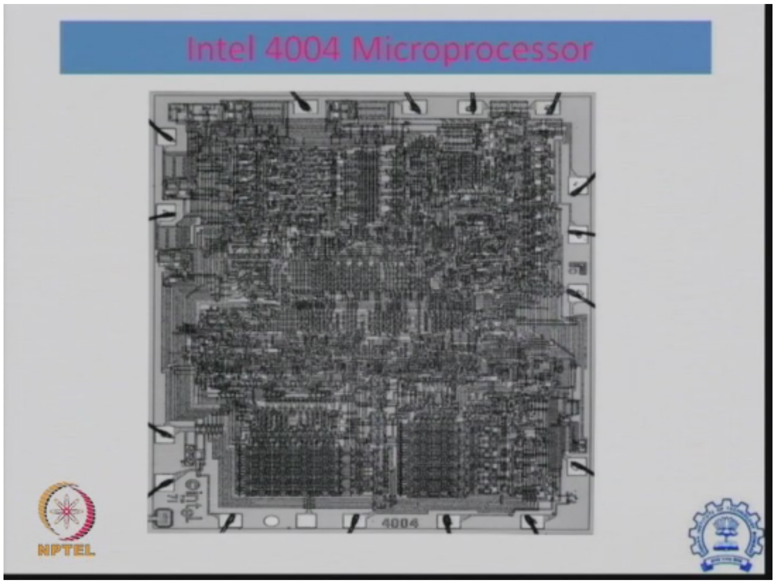

This is a good micrograph of Intel 4004 if you see how complex it looks. If you see these are the pads. You can see from here there are around 14 pads on a 4004 Microprocessor by the way it works. I have worked on 4004.

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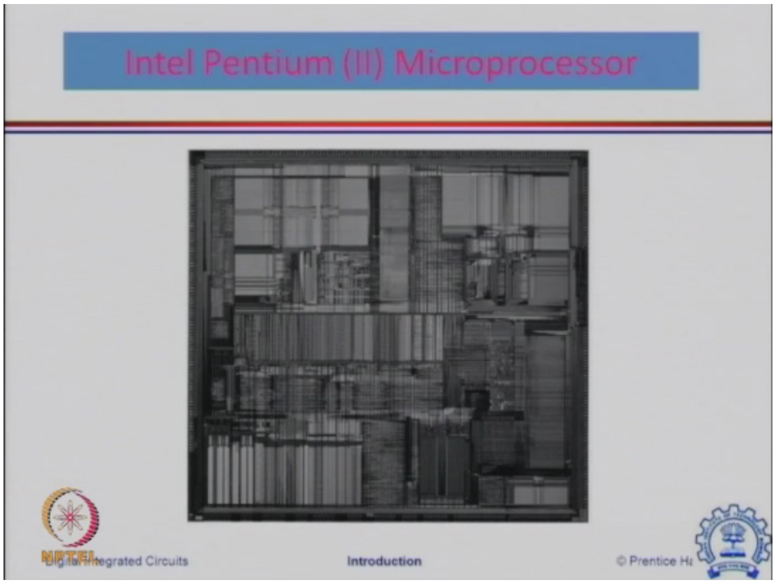

This is the current Pentium, then it started in ends of 1980s Pentium II now it looks much more component density then what earlier 4004 had. Of course please remember this everyone ask us in IIT at least why we are still teaching 1980, 1985? In my opinion 1980, 1985 microprocessor is one of the basic microprocessor architecture. And any new architecture unless you change from what that architecture has it will follow same 1980, 1985 architecture in modified form and keep using it unless you go from (()) (49:09)

I do not know how changes can be made. Otherwise, there is a standard procedure of actually executing data and as long as that happens 1980, 1985 remains our work horse. However, to improve the speed, to improve the functionality of the microprocessor improvements were made and one of the major improvements now coming is availability of large amount of cash on chip and we will show you this later. So, this is Pentium II.

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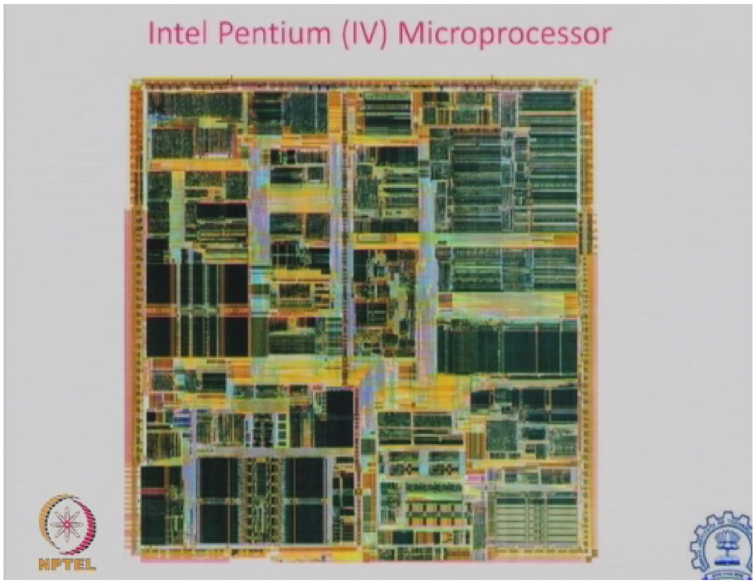

This is what all you are working right now on your desktops, Pentium IV microprocessors 2 gigahertz and now of course 3. 4 gigahertz and soon it will be 4.8 gigahertz. You can see from here any structure which looks blackish because they are identical. These are actually cash and now one believes that there will be a huge cash area on the microprocessor rather than the controller part or the chip register part or ALU part.

The major decision of doing things will rest on how much cash we have and how fast we can take data out of cash and put to processor and back to cash. So, this kind of newer way of doing faster analysis will come and that is the only improvement one expects in coming years.

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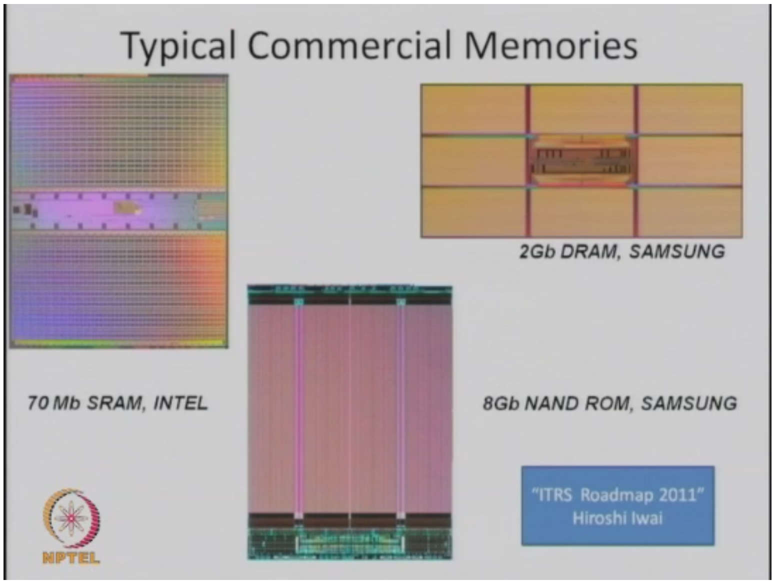

Last slide for day, these are typical commercial memories we have a 70 Mb Intel SRAM which is on the left. This half of here and half down then this is Samsung 2 Gb DRAM of course I have a photograph of 4 Gb but I think this was better so I put a 2 Gb photograph. You can see this is 2 Gb DRAM. So, if I can put 2 Gb, 2 Gb, 2 Gb you can see there is 918 Gb Dream and then even if I do 2 then I can actually improve the speed because I can share the work and then we will call DDRAMs.

It is essentially same. It is a fast DRAM, word quant but essentially said DDRAM and because of that the speed improves. So, the idea is now to parallel so many DRAM and may create sooner or later 64 Gb DRAM itself. The another memory which is very, very dominantly used by most logic systems are electronic system uses what we call as a NAND ROM. ROM does not require power on for retaining a data.

Whereas DRAM, SRAM do require power. So, this was another area where much of the research went through and 8 Gb NAND ROM is what is now marketed and people believe that sooner –of course there speed is not as close to SRAM. But closer to DRAM so maybe they will first replace, DRAM may replace SRAM and DRAM will be replaced by NAND ROM sooner SRAM may not remain or SRAM will never be called SRAM but will be called RAM alone.

So, coming back to this slide again at the end of the day I must tell you that whatever can be manufactured is only can be done. The manufacturers only look for profits after all they have invested money and any system to be manufactured they first should actually found out that this system is going to be in what larger product. What is the window of that product in which it is going to be marketed?

And what is the performance that system requires from your IC chip and if you cannot reduce within that window time probably your whole product will not be of any consequence. Therefore, whatever people keep saying in design it is a very good design. I always say there is nothing called very good design any design which can go into a system and gives money to the manufacturer is the best design.

Thank you very much for the day. We will come back next time and continue with this remaining part and also give you the more details about the course and my other colleagues. Thank you for the day.