Solid State Devices
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Lecture -2
Evolution and Uniqueness of Semiconductor Technology

In the previous lecture which was an introduction we have seen some of the devices and we have seen why the semiconductor devices are important, and how they help us build better systems in electrical engineering. We also saw the various topics we are going to cover in this course. In today's lecture we will discuss the uniqueness and evolution of semiconductor technology.

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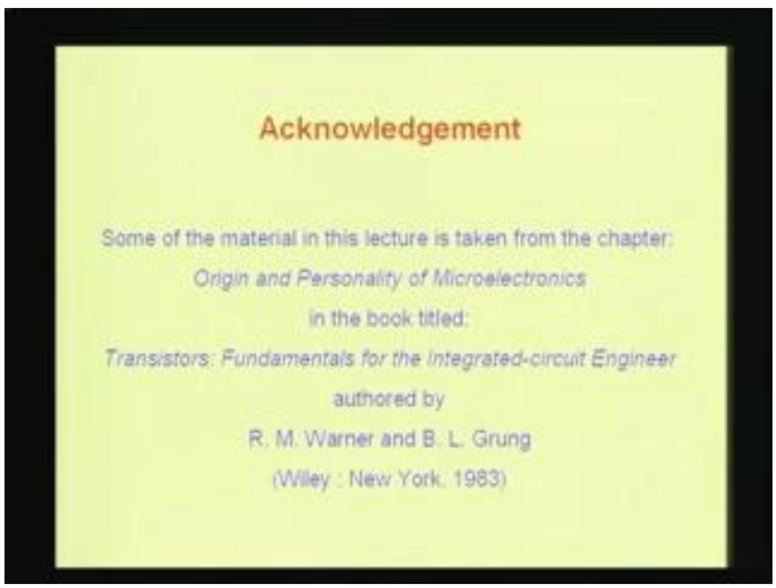

Some of the material in this lecture has been taken from the chapter: Origin and Personality of Microelectronics in the book titled "Transistors: Fundamentals for the Integrate Circuit Engineer." This book has been authored by R.M. Warner and B.L. Grung, it is a very nice book. And if you get a chance to look at this book please go through it.

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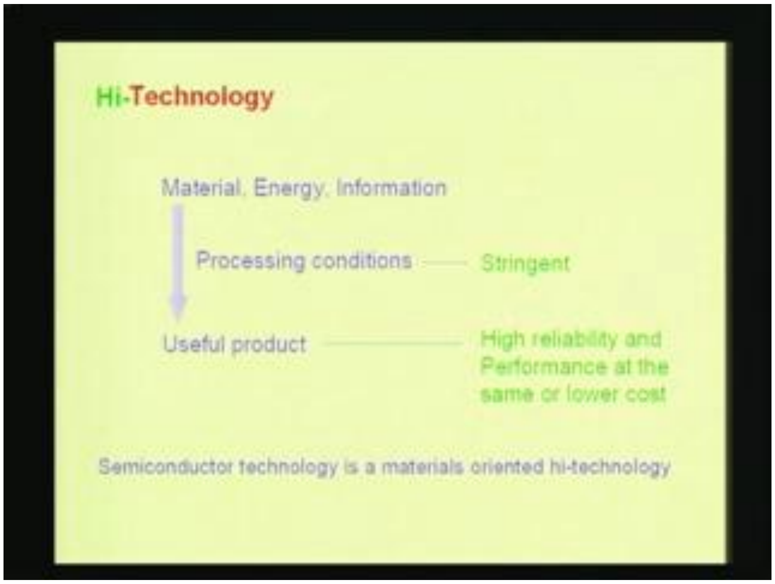

Let us begin by trying to understand what technology is, and then we will see what semiconductor technology. Technology means processing of material, energy, or information so as to develop a useful product. This is the general definition of technology. So you could either process material, energy in some form, or even information. That is why now-a-days we have, what is called, information technology.

So when does technology become high?
It is when the processing conditions are very stringent and when the product that you get has a very high reliability and performance and a low cost. You either get the same performance and reliability but at lower cost or at the same cost you get much higher reliability and performance, then the technology is called high technology. Semiconductor technology is materials oriented high technology. That is, it involves processing of material and you get products which have high reliability and much higher performance. For example, take the invention of transistors, how it has changed the reliability and performance of systems. Before the transistor was invented the device that was being used for amplification was a vacuum tube triode, it was made in vacuum tube. Now the size of the vacuum tube is large, if any of you have seen vacuum tube you would know, and then compare the size of the vacuum tube and a transistor. The size is large then the vacuum tube is fragile because it has a glass casing. It is said that when they built the first computer using vacuum tubes, the area occupied by the computer was about 900 ft square, and they had a number of engineers to maintain this whole system because it would fail very often.

Another important problem was how to dissipate the heat generated whereas you compare a computer that we use today - a note book computer or now-a-days you even have palmtop computers, see the power dissipated, the size and the speed. You are getting much higher performance and reliability, the computers are very reliable. So this is what the semiconductor technology has given you. The semiconductor technology has given you products which are highly reliable and which have a much better performance. Now it is important to know that this advantage is achieved only because the material is processed under very stringent conditions and that is the price you are paying.

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Let us understand that in a little more detail. What the processing conditions in semiconductor technology? What is shown here is a clean room where semiconductors are processed. You cannot make semiconductor devices in open air. So the first stringent condition is that you need a single crystal material.

Most of the semiconductor devices are made in single crystal material; this is a very stringent condition because a single crystal material means that the arrangement of atoms should be very regular throughout the size of the crystal. A lot of energy and cost you are expanding and getting a single crystal material.

The next stringent condition is an ultra clean environment like what you see in the diagram here, the person who is processing is wearing a mask and some kind of attire which prevents any dirt from him getting into the environment. This is not only for protecting him against chemicals but for protecting the environment against pollution by the person. When the size of the transistor is a very small, of the order of microns or even submicron; it means that even a very small dust particle can kill a few transistors on the chip. How do you measure the cleanliness of environment? When people talk about "the class of the environment" for example, a class 10 clean room - this means that there are no more than 10 particles of size more than fractions of a micron like 0.3 micron in per cubic feet.

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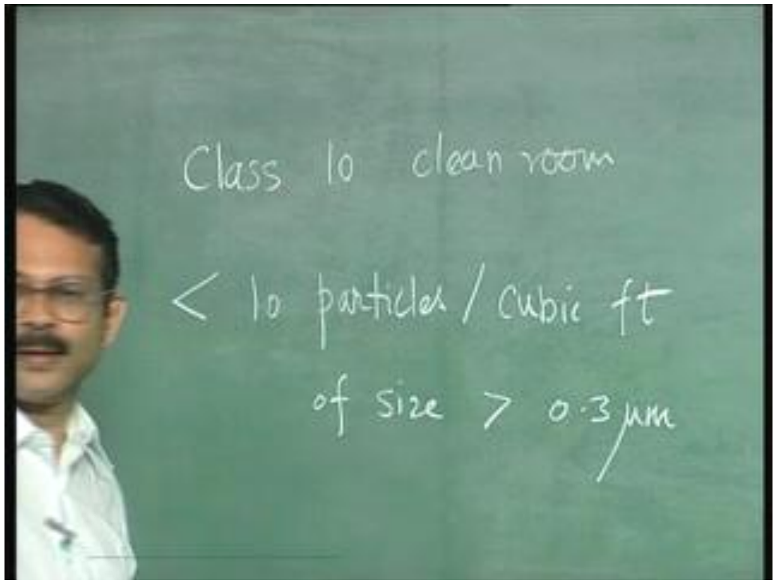

A class 10 clean room means that the number of dust particles of a size more than 0.3 microns is no more than 10/ft cube. Let us get some idea of what is involved in creating such a clean room which is required for semiconductor processing; in open air the class is more than a million. Because it can be as bad as that, a lot of cost and energies is involved in reducing this particle count to class 10. Another stringent condition: the water you need for processing materials should not have ions, it should be pure. The water used in semiconductor processing is called 'De ionized' water (D I).

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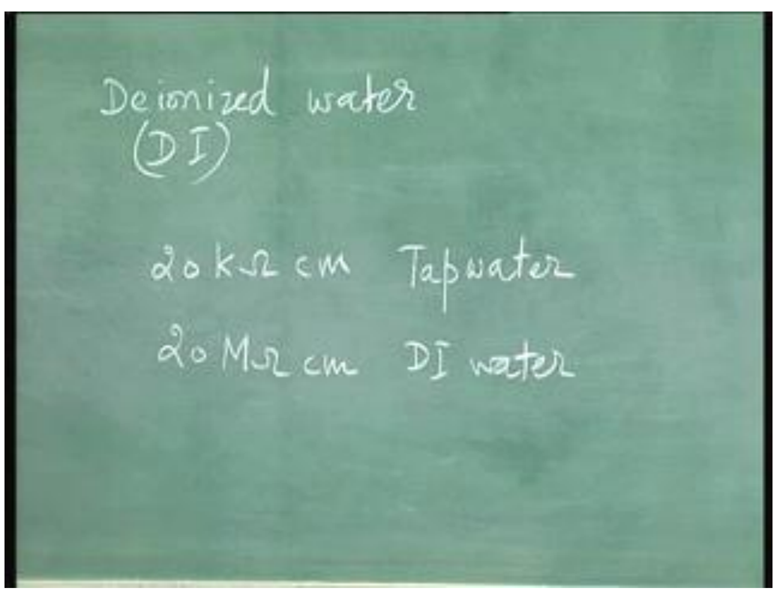

To measure the cleanliness of water you use the resistivity of water. The resistivity of tap water is about 20 kilo ohms cm tap water, whereas the resistivity of water that is used for semiconductor processing has to be as high as maybe 20 mega ohms. So you have to remove the ions from the water so that you get the clean water then you have ultra clean chemicals.

So, if you look at the bottles that are used, bottles containing chemicals, when you are doing experiments in Chemistry, if you have taken care to see the labels on the chemicals there are several grades of chemicals, starting from the lowest grade like laboratory grade then you have analytical grade, then semiconductor grade and even in semiconductor grade now you have what is called the MOS grade Metal Oxide Semiconductor grade. This is because to make MOS transistors cleanliness has to be even higher, so they have introduced what is called MOS grade chemicals. So gases also have to be similarly ultra pure. These conditions are rather stringent.

In fact the amount of capital investment that you must do because of these reasons into a functioning semiconductor manufacturing unit is enormously high. Even a simple semiconductor unit making discrete devices, making the investment could be something close to 500 crore rupees! It is said that, if you want to compare different Nations in terms of the wealth they have, all that you need to do is count the number of semiconductor factories these countries have. So number of semiconductor factories is the index of the wealth of a country. This is the reason why even though the products are very useful and of very high performance, unless you have large amount of capital invested in this you cannot make these products. So you can call this as one of the limitations of technology. In spite of the high capital investment, the cost of the product becoming lower is because the production volume is very high.

You are able to generate new applications with products which are high performance, which are very light and so your production volume is becoming very high and that is how the capital investment, the cost that you are putting in it gets divided, and that is why the computers and pocket calculators and so on are becoming so affordable.

One big unit trying to make large number of products is how this particular technology works. It has its advantages and disadvantages. The disadvantage is, only a very rich country or very rich man can set up such a unit and then he or she may be able to control, that is the disadvantage of this. There are many aspects of technology that one needs to understand. I have focused a few of them here which are related to the semiconductor technology.

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Another thing is the sophisticated equipment which is also responsible for the high cost of the semiconductor unit. Most of the equipment we use for this manufacture in India is imported. You can also see the cleaner benches in this diagram - the environment which is maintaining higher level of cleanliness in the place that you are processing. The room itself is clean but the particular environment in which you are processing the silicon pieces and so on; subjecting it to various chemicals is even cleaner.

So, for example, what you see here is called the cleaner benches. In fact this person is processing in a cleaner bench. High cleanliness is maintained by maintaining a slightly positive pressure in the region where the processing takes place. So the air is sucked in from outside through some filters and then it is formed into this region and then the air flows out. By this way the positive pressure is maintained, constantly air is coming out of that region and that is how you can prevent the dust particles from entering into the region. That is how the cleaner bench is made. Let us discuss some other things related to this technology.

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Products of semiconductor technology: Unlike in many other technologies, the use of the products becomes progressively easy with advancement of technology. It is a very unique feature of semiconductor technology.

To give an idea, supposing you take automobile technology in which there are the products which will reflect the advancement in technology. Let us start with the cycle, not really an automobile but the simplest thing that gives you the mobility. To start with, the cycle, and go to scooter, then goes to a car, then you can go to may be an aircraft, and then probably you can talk about a spacecraft. So you see advancement in technology. The person who is operating this vehicle needs higher and higher levels of skill, almost everybody can ride a cycle but only a few can ride a scooter. For car again you need much better training and then you go to the aircraft and then you go to the spacecraft.

This is one example where, as technology advances you need higher and higher levels of skills to use the product. Whereas in the case of semiconductor technology what you find is, as technology advances it becomes more and more user friendly, so even an illiterate person can make use of this. The level of skill required is less. There is something very positive about this. Another unique feature of this technology is that the performance of new products can be predicted using relatively simple models because you are using the single crystal material.

The single crystal material is difficult to make but the performance of devices which are made in this material is easy to predict because you have regular arrangements of atoms, so modeling is easy. That is why you have so many simulators and so on which are used to predict new devices even before you make them. This is not something that is easy in other materials. For example, in glass and steel the performances cannot be predicted so easily because these are not single crystal materials.

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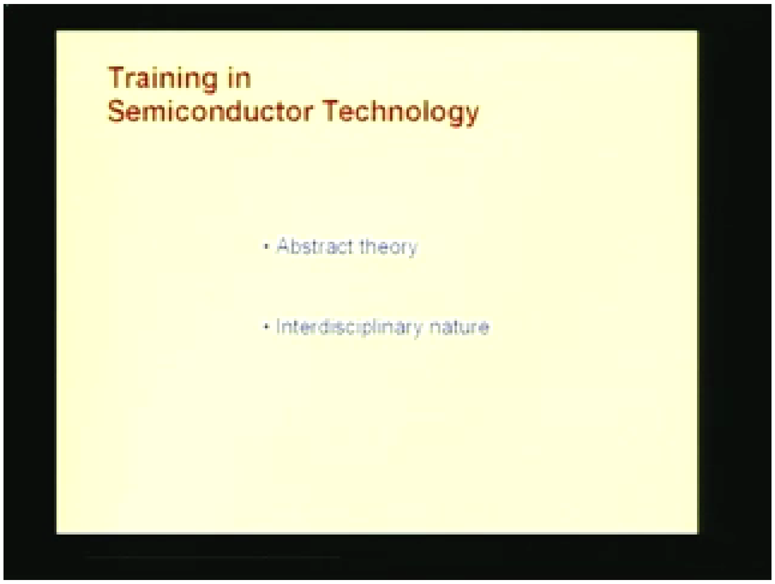

Let us come to the training required in semiconductor technology. The theory of semiconductors is abstract and also if you see the technology in its totality it is highly interdisciplinary. For this reason, you need a strong training in Mathematics as well as in Sciences to really be effective in this technology.

A person who is working with steel or glass the level of training required is much less than a person who is to be trained in semiconductor technology. A semiconductor industry or lab, for example, appoints people ranging from Mathematicians, Chemists, Physicists, material Scientists, electrical Engineers and chemical Engineers; so they need people of all skills to really make the technology work. That is why we have students undergoing a theory course before they are taken to the practical class.

Those who are working with steel and glass can start playing with the material and with a large amount number of trial and error they can come to some understanding of the material. But that is not the way one enters the semiconductor technology. One does not start playing with silicon and then you find you are interested. So let us understand this more and then let us take a course. That is not the way it works. You have a course on devices and so on and technology and then you start practicing.

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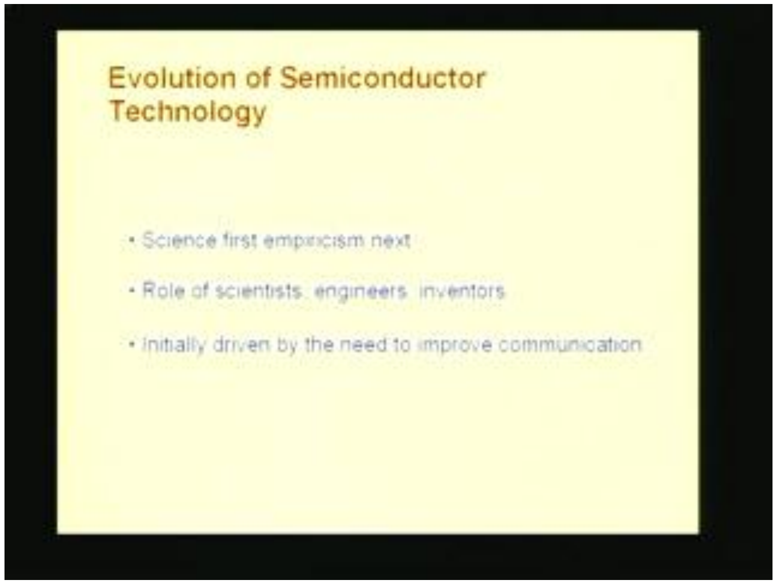

So let us look at the evolution of this technology. As I said a high level of training is required. This is because, in this technology, the Science came first and the empiricism came later. Some of these features we will see when we see the sequence of events which I am going to just talk about in a short while. Again taking the example of other materials like glass and steel where people have been working with these materials for hundreds or may be thousands of years. They did not have an understanding of the atomic structure or molecular structure of steel or the structure of the glass before they started working with these materials. But by doing lot of trial and error experiments they have perfected the art of making better and better steel and glass and so on. The understanding of the structure has come only recently in last 200 years or something like that. Of course that must have also helped them to build better material there is no doubt. But a lot of progress has taken place even before the Science of the materials was understood. But that is not true of semiconductors.

In semiconductors first came the Science, that is, lot of experiments were done and they found that semiconductor materials have different set of properties than metals and insulators, then they tried to understand the structure and so on. And after they understood the structure then they realized that may be you can do large number of things with this particular material. And that is how this area has acquired importance. So this is what is meant by Science first, empiricism next. Trial and error experiments come later after understanding the Science. The only other example in this category is nuclear Science or nuclear technology and even there the Science came first and then empiricism or the practice of this.

The second important point is that in the growth of this technology, Scientists, Engineers and Inventers all these three types of people have contributed extensively. Often we use these terms interchangeably scientists, engineers and inventers. But it is not true if you try to look at people who have been working and you understand what Science is, what

Engineering is and what invention is. The type of people, their capabilities, their way of working is quite different. So a person who is a good Engineer may not be a Scientist. Similarly, an inventor may not be a good Scientist or they can be a Scientist who is not an Inventor. So these three types of people have contributed extensively to this technology. We will see a little bit on Science, Engineering and Invention because it has a relationship to this topic that we are discussing.

Another important thing that you need to understand about evolution is that the interest in the technology was driven initially by the need to improve communications. How to improve communication, how to make communication faster, and more effective was the goal. So in beginning it was found that this technology will help you to improve communication and that is how the interest developed. But after the technology developed, now, the communication is being driven by all the developments that you have in this technology. It is the other way around now, the communication field is being driven by the solid state field.

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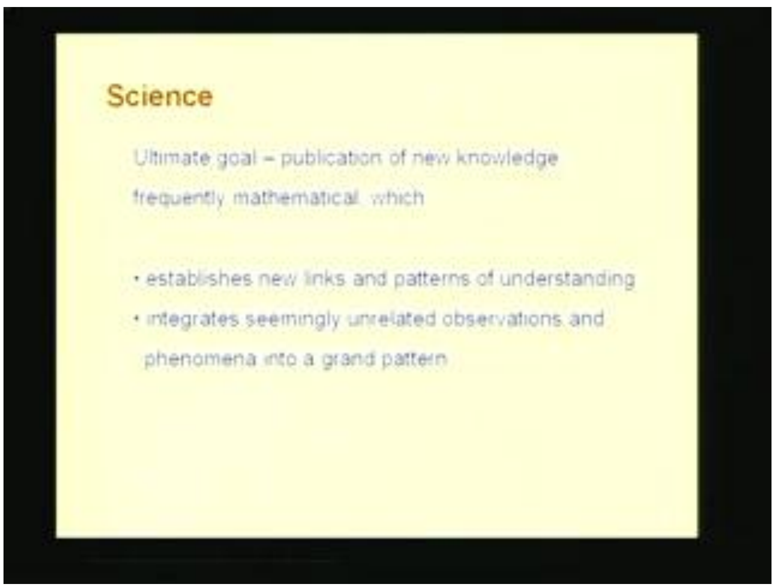

So let us understand the difference between Science, Engineering and Invention. In Science the ultimate goal is publication of new knowledge frequently mathematical. The ultimate goal of Scientist is to publish a book, a paper or something which establishes new links and patterns of understanding and integrates seemingly unrelated observations and phenomena into a grand pattern. That is the job of the Scientist. So definitely a Scientist is highly intellectual. But the important thing is whatever he or she does need not result in a useful product. It is some sort of a publication which details this knowledge.

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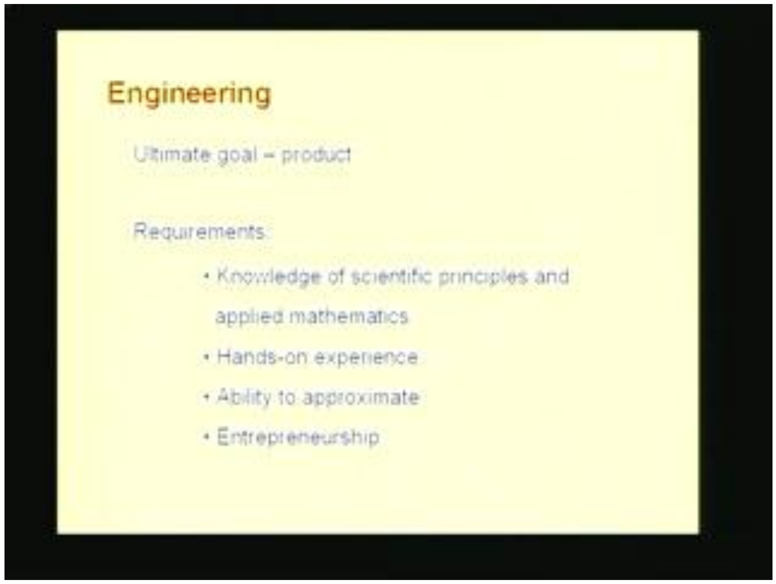

In Engineering the ultimate goal is the product. The requirements for Engineering are knowledge of scientific principles and Applied Mathematics, hands on experience - this is very important. So if someone says that he or she is working in the area of semiconductor technology and an Engineer or a technologist, then it is not sufficient to just take a few courses and understand the fabrication steps for a semiconductor device and how a device works and so on. He or she must have hands on experience, must have used the material, processed it and so on, then the ability to approximate. This is another important property that an Engineer must have. So an Engineer must be able to work with very simple formula; derive simple formula for design purposes. And then finally one aspect of engineering that is related to economics and so on unlike Science you cannot deal Engineering by Economics that much.

Entrepreneurship: that is, you must have a person who sets up a unit that translates all these practical knowledge and so on into a useful product. So in fact the level of Engineering in any country also depends on what is the extent of entrepreneurship in the society. How many people are trying to set up units which will make products. They might fail but the question is how many trials have been made. So it is found that those countries which are advanced engineering there the number of people who try to setup units, who try to be entrepreneurs is very high. If you compare for example, United States and India, in United States you will find the number of entrepreneurs is very large. May be one in four only succeeded but the number of those trying is very high. So this is also an important requirement for Engineering.

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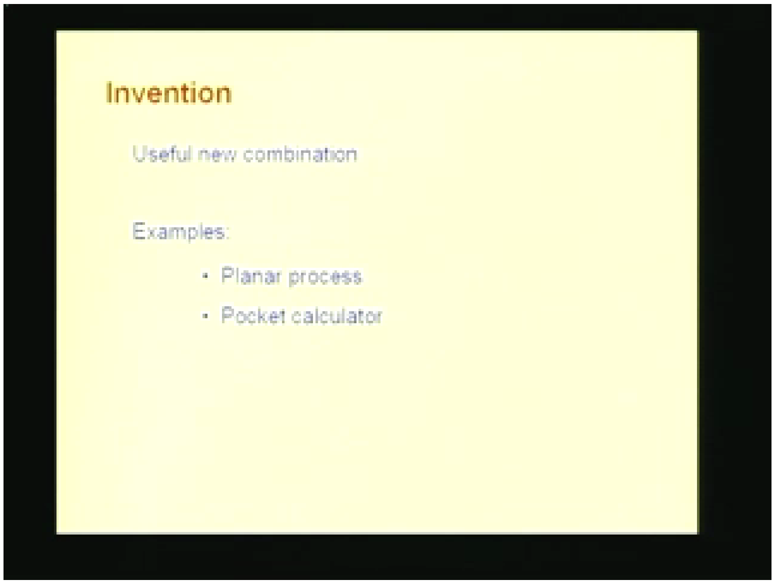

Let us look at the invention. What is invention? It is a useful new combination. Let us consider examples in the context of semiconductor technology. So I have given here two examples, one is called the Planar process and the other is the Pocket Calculator. Planar process is the process invention and pocket calculator is the product invention. Let us discuss this in little more detail.

What is the Planar process? In fact the person who worked with this Planar process who used it for making ices has got a Noble prize recently. Who is the person who got the prize? In fact this is the only example where an Engineer has been given a Noble prize for the invention because the integrated circuit has revolutionized the entire Electrical Engineering. And in fact you can say the whole life that is the number of different kinds of systems that has been built and the amount of new Science that has been generated, integrated circuit is a vast area of study but he was given a Noble prize. That is why let us look at this planar process.

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You can make a diode as follows which was the initial process that was used in olden days, when I say olden days it means the beginning of the evolution of semiconductor technology. That is, may be 50 years ago. So this is a structure of PN junction made by what is called the MESA process. That is, the structure looks like a MESA pyramid. So here, how is this device made? Well you have a wafer or a piece of silicon, N type silicon, whole of which at the surface is converted into P type. The size in those days could be of 2 inch diameter; it is a circular wafer, a circular piece.

The thickness of this is of the order of 200 microns. To give you a feel for this thickness - the human hair is about 50 microns diameter, so this is about four times the thickness of the human hair. This thickness depends on this diameter because you must be able to handle the silicon piece mechanically. So for 2 inch diameter wafer it is about 200. Convert the whole of the surface into P type but your individual diode is very small. So you have to separate this particular wafer into individual diodes. So how do you do that? Now that is where what you do is you etch out locally, the materials. And then you dice or break the wafer at these points. Now each of these devices is what is shown here that are separated.

When you separate this particular wafer into devices, what will happen is the surface will be exposed to the atmosphere, and impurities can get in there which will spoil the characteristics of this diode. So what is done is, you have what is called as a passivation layer. So it is some material which you put here so that the surface junction is protected from environment, this is the MESA process. What we want to talk about is the Planar process. After understanding the MESA process, now we will appreciate the innovation involved in the Planar process. These particular diodes were quite leaky, that is the leakage current was high.

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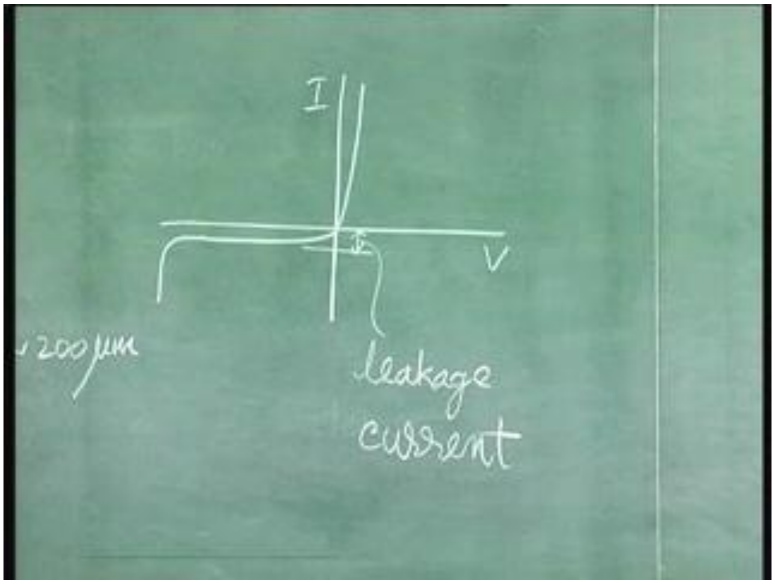

Here are the diode characteristics, this is current versus voltage. So in reverse characteristics this represents the leakage current. That leakage current was high for these devices. Now let us look at the structure of the diode which is made by the Planar process.

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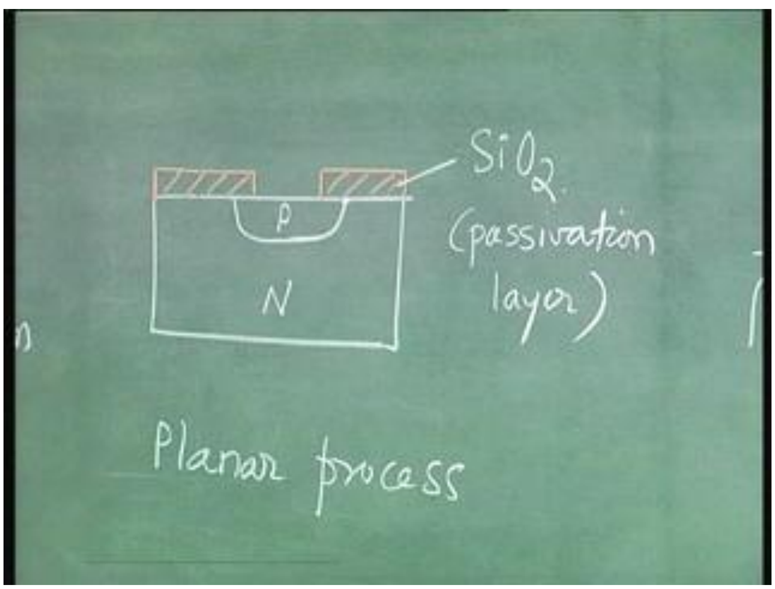

So, first I will draw the individual diode structure and then we will discuss how this individual diode is separated from a complete wafer. This is a structure of a Planar process, the device made by a Planar process. So here what is happening is this is the so called passivation layer made of silicon dioxide. And what you find here is the junction is on a plane surface and that is why it is called a planar process. The PN junction is exposed to the atmosphere and wherever it is exposed that is on a plane surface, that is why it is called a Planar process.

All the devices are made on a single plane. However, here you can see that it is not a planar device because the structure itself is like a MESA. So the advantage of this is, now the PN junction is automatically passivated. It turns out that the silicon dioxide interface can be made of a very high quality and the leakage current of this device is therefore much lower. That is not the only advantage of Planar process or rather even the main advantage. The main advantage is, now it makes very easy for a person to integrate various devices on a single surface, that is the main property of the Planar process. You can make different devices in a single plane.

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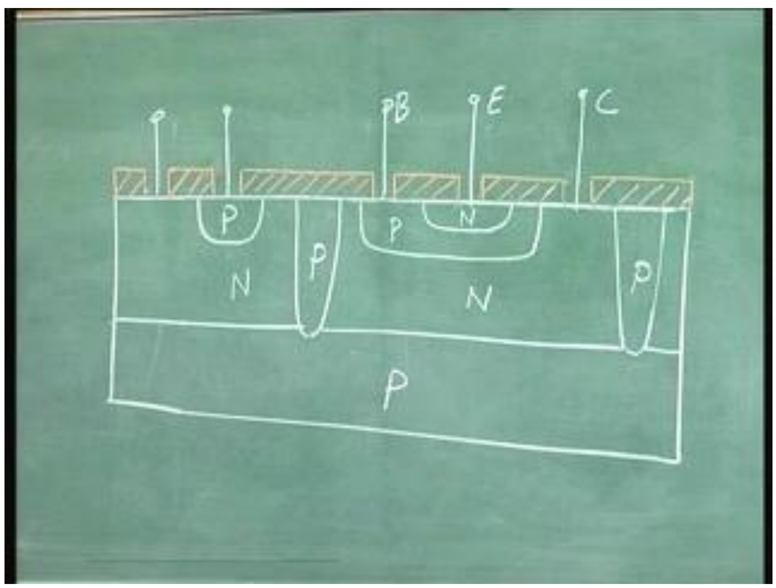

So I can have a diode like this and then I can have a transistor, so this is an example where I am showing a diode and a transistor in the same silicon wafer. This is the so called emitter contact, this is the so called base contact and this is the so called collector contact and they are all in the same plane.

Look at this MESA process, here this is the top contact and this is the bottom contact. Whereas for PN planar diode both the contacts can be on the top, this is P contact, this is N contact. That is what is happening for the transistor also, all the contacts namely the emitter, base and collector are on the top on the same plane. So you can integrate this very easily. I can run a metal line, suppose I want to connect this region to a diode for some reason, I can just run a metal line here and connect, so there is interconnection of various devices on a single plane, that is uniqueness of this and it is this arrangement that enables you to build millions of transistors or devices on a single silicon wafer because you can go on shrinking the sizes and you can increase the density of the surface. Incidentally these two regions are called isolation regions which should be P type so that the PN junction along this area isolates this transistor from other devices and prevents unwanted interconnections between them. So PN diode, for example, made by Planar process will have much lower leakage current than a PN diode made by MESA process.

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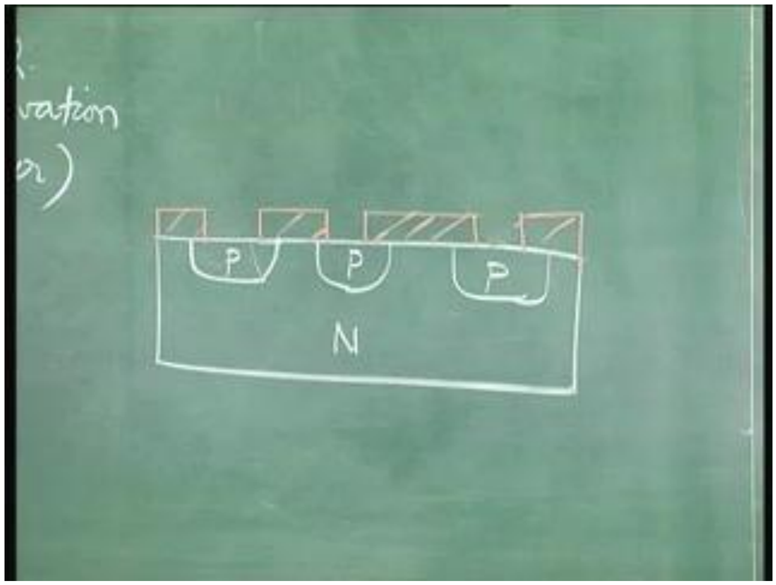

Also MESA process will not enable you to integrate various devices. So here how is this diode made? The sequence of steps is as follows. You take the same wafer N type wafer, but the first step in a Planar process is to grow the silicon dioxide layer which is the so called passivation layer, then you etch windows, that is areas where you want the P region, you remove the silicon dioxide. And then in these regions you create P regions by a process called diffusion, that is, introduce impurities through this particular window so as to create the P regions. Now automatically what happens is since the impurity is diffused inside they also diffuse sideways and the junction goes and sits under the passivation layer, automatically it is under the passivation layer.

So as I have said the silicon dioxide interface can be made of a very high quality. It is possible to make a very high quality interface using simple means and therefore it enables you to get very low leakage current and very good passivation. The surface is protected against the environment. So now this was a process invention which made possible putting larger and larger number of devices in smaller and smaller area, the Planar process. Now you have some such inventions it gives you a jump, it opens up many possibilities.

Now the next question arose, you have the capability of integrating large number of devices in a small area, but what do you do with this capability, what product you make, because this is also very important, what is the product that will be very useful out of this particular capability? So, in fact one of the first products that were thought of was the pocket calculator. So someone said we can use this technology and make a small device which will calculate and everybody can have this device in their pocket. When the suggestion was made people made fun and said it is not going to be very useful at all.

Now-a-days almost everybody needs a calculator. The product invention of a pocket calculator is a very important invention. It looks like a very simple idea. All inventions which have a wide capability possess a property that they are very simple in consumption. Pocket calculator is a product invention which showed how you can exploit this planar process capability and make a useful product.

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Now let us see how Scientists, Engineers and Inventors have contributed to the growth of semiconductor technology. Here what I have done is I have listed a number of important events in a chronological order. The events are listed for the field area of communication. Side by side we can see the developments in science of solid state. One can trace it back to 1820, the development that initiated the communications field was magnetism from electricity and vice versa, Orested and Faraday; the idea of electromagnetic induction and so on. So here you have the suffix indicated against the names of the persons associated with this event. S stands for Scientist, I stands for an Inventor and E stands for an Engineer.

So one of the purposes of this particular phrenology is to show how a Scientist develops an idea and then comes an Inventor who exploits it and makes a useful product. That sometimes require the knowledge of some new observations, so again you have a Scientist who comes in and who explains some of the new observations, this results in more knowledge, then there is an inventor coming in who exploits this new knowledge that is developed. So you have the sequence going on, Scientist - inventor and so on.

So here, for example in communications you can see that after understanding ideas of magnetism from electricity, Morse was an inventor who came up and proposed the telegraph. How to use these ideas for communication? Communications with wires, then you have the theory of Electromagnetism being given by Maxwell. On the right hand side you can see the developments in solid states.

Here the two strands are separate and there is no connection between them, as of now, as in 1820. So you have a set of Scientists studying the solid state materials - thermoelectric property. So they were studying the thermoelectric property of various materials, they found some materials seem to be showing some unique features in this property; then came the intrinsic property and photovoltaic effect by Faraday and Becquerel, then photoconductivity.

After the studies of all these properties, there was an inventor who suggested that we can use these unique properties of material and till then it was not known or the word the "semiconductor" was not coined by 1870. But the Scientists understood that there was some material which behaved in a peculiar fashion; neither like metals nor like insulators. So Braun was an inventor who said that you can put a metal contact to this material and it will have rectifying property instead of having a resistive property, that is, the current for one polarity of voltage is very different from current for other polarity. And then he said we can use this kind of a device in communication for detection.

First device that was proposed by was an inventor Braun and thereafter again you have Scientists studying the properties of semiconductors in the solid state field.

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Telephone was an invention by Graham Bell for improving the communications. After that you had an experimental proof of electromagnetic waves by Hertz who was a Scientist. Maxwell gave the theory for electromagnetism, but the presence of electromagnetic waves practically was demonstrated by Hertz, so moment this was demonstrated, came an inventor that is Bose-Marconi, there is still some confusion as to who is the original inventor of wireless communication. The latest information is that Bose was probably ahead of Marconi in this. Then you had vacuum tube Diode and Triode, again an inventor came up and proposed the device for detection in wireless communication.

How do you detect the radio waves? We use this device for detection; on the right hand side here you see magneto resistance being studied in solid state and then the understanding of Quantum Mechanics by Max Plank and photoelectric effect by Einstein. It was in 1910 that the word semiconductor was coined. They found that this set of materials had so many unique properties that they wanted to give it a separate name which is not an insulator, not a metal and not a conductor. So the word semiconductor was coined in 1910. At around this time the communications field was still developing, you can see that positive feedback and sine wave oscillator, how do you generate the signals required for communication? This was the topic that was addressed by Armstrong. To proceed further, in the area of communications you have an engineer coming in here. Armstrong also as you can see was an engineer and an inventor.

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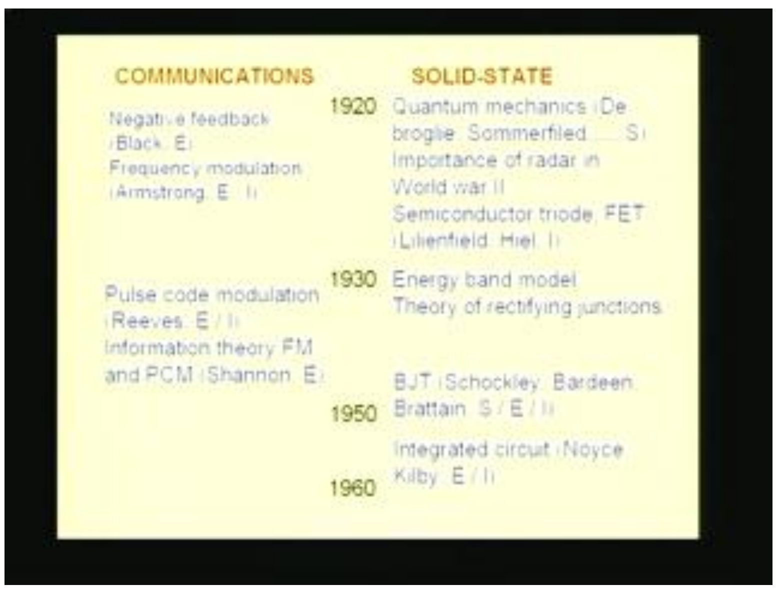

Similarly Herald Black proposed a negative feedback which was very useful in building good amplifiers, again for communication purposes. Then you had frequency modulation, Armstrong proposed, so you had lot of developments in the field of communications here. Now, after 1920 because of the importance of radar in World War II this is the important event which actually brought the communications and solid state fields together. There was certainly lot of interest in the solid state area because they found that using the vacuum tube which was used for detection in communications could not go to very high frequencies and that is where they found that the diode proposed by Braun which was simply being considered as a rectifying device was very useful as a detector.

Instead of a vacuum tube he used a solid state diode, it is much better it is very small in size, it has a small capacitance and therefore you can use it at higher frequencies. We started perfecting this device, beyond this the solid state and communications which where as separate areas joined together. And thereafter you have an inventor coming here in this area of solid state, the semiconductor triode. If a Braun's diode can replace a vacuum tube diode and give you much better performance, then people thought why not replace the vacuum tube triode, vacuum tube amplifier by a solid state amplifier.

So someone suggested how you can translate this idea of vacuum tubes into a solid state field. When we discuss the MOSFET we will discuss about this particular invention of the semiconductor triode a little more in detail, the field effect transistor. And thereafter the interest in the area of semiconductor grew exponentially and you can see a large number of models to explain the behavior of semiconductor devices, the first important model being the Energy Band model, then the Theory of Rectifying Junctions and so on. And in around 1950 that is in exactly in 1947 was the invention of the first solid state amplifier that is the discovery you can say the Bipolar Junction Transistor (BJT).

So although the first transistor that was proposed is the field effect transistor, the first device that was made is the Bipolar Junction Transistor because they were not able to make Field Effect Transistor and in trying to study why Field Effect Transistors were difficult to make, they accidentally discovered the Bipolar Junction Transistor. And thereafter you have the Planar Process being used for integrated circuit by Noyse and Kilby.

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So in fact Kilby got the Noble prize for his invention of integrated circuit and thereafter now we have the solid state area progressing and driving the communications. So you had series of devices being proposed MESFET, proposed by Mead then you had medium scale integration, the integration of devices into IC started, filters, then you had large scale integration being used for making a Random Access Memory and analog to digital converters, microprocessors and so on. Then in 1980s you had the High Electron Mobility Transistor (HEMT), and then in integrated circuits you had VLSI that is 64Kb Random Access Memory (RAM). In 1990s you had three dimensional integration that is, you integrate not only on a plane but also in the vertical dimension. Most recently we have had Nano electronics coming up wherein we make devices out of either Nano crystalline materials or we make devices which are of Nano dimensions but made in crystalline materials.

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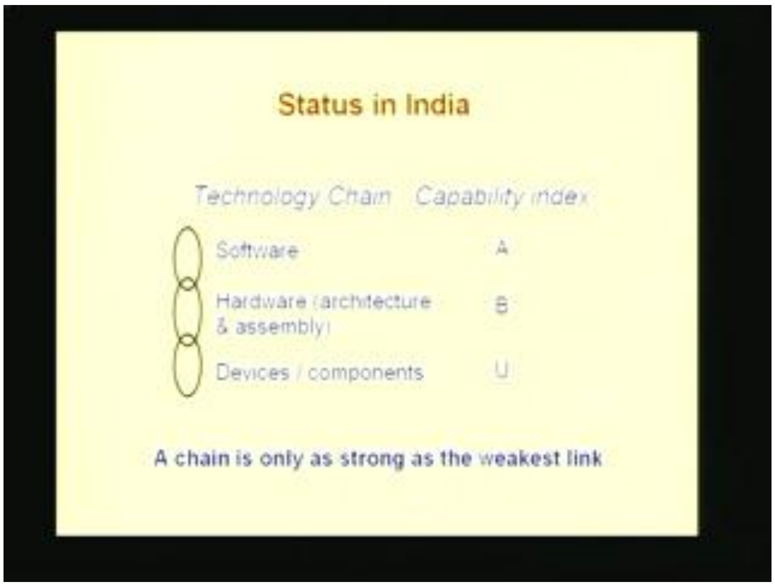

Now having seen the way the semiconductor technology has evolved and how Scientists, Engineers and Inventors have contributed to this evolution, let us briefly review the status of this technology in India. Broadly we could divide the technology into three levels: the software level, the hardware level which involves architecture and assembly, and finally the devices or components level which is heavily dependent on materials.

The capability index for this technology is indicated here, we are doing very well in software, so that is A, excellent or very good, we are exporting software, in the hardware level we are good, we can make super computers and we are sending satellites into space so this level involves integrating components and making systems.

However, at the devices or components level we need improvement, that is presently the level is not satisfactory as **U -** stands for unsatisfactory and we are improving but we need to improve more. The reason why we are weak at the devices or components level is because we are weak in the material oriented technology so we import the technology for making sewing needles which is based on the processing of steel material, so it is not surprising that we imported technologies for making semiconductor devices, semiconductor and steel both are materials. Now the chain is only as strong as the weakest link so the level of engineering or technology in India can become excellent only if we are strong in all the three levels and the chain is strong.

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Now let us see, as a part of the status in India what are the various industries, research laboratories and academic institutes which are participating in development of technology. So in industries we have Bharath Electronics limited Bangalore, Continental Devices India Limited CDIL New Delhi, we have semiconductor complex Chandigarth, then we have Indian Telephone Industries that is ITI Bangalore.

So the research laboratories are solid state Physics laboratory in New Delhi, the Central Electronic Engineering Research Institute CEERI in Pilani Rajasthan, then there are academic institutes which are participating in the development, which have small laboratories but which have strong teaching programs in this area, these are the Indian Institutes of Technology and the Indian Institute of Science, Bangalore. For all the purposes of developing the video lectures is to have more colleges in the country involved in teaching of this technology which is advancing rapidly.

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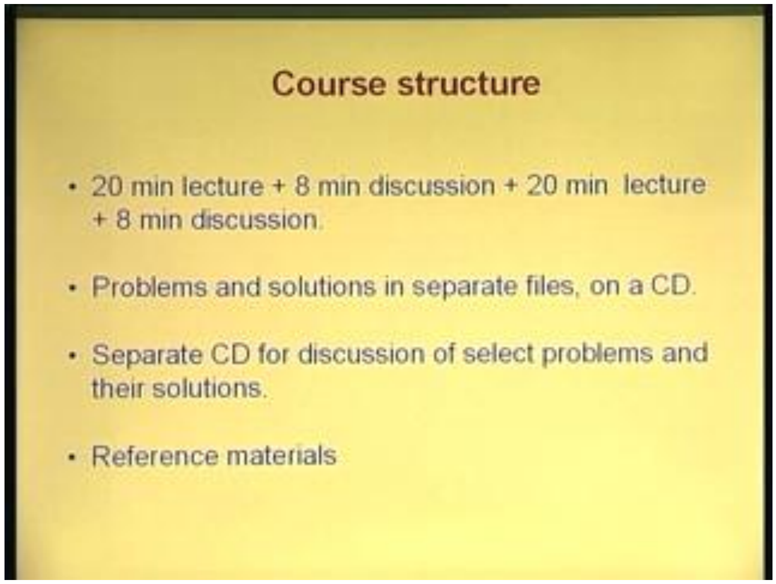

Now in the end of this lecture I would like to tell you in what ways the remaining lectures will be conducted. So, for the remaining lectures we will have 20 minutes of lecturing followed by about 8 minutes of discussion, and then we again have 20 minutes of lecturing followed by about 8 minutes of discussion. This is an approximate idea of the division of the time of 56 minutes into lectures and discussion which involve questions and answers.

Then problems and solutions are provided in a separate CD, some problems will be solved in class, but some will be given to you and you have to solve them yourself, these are provided in separate sheet. Then also have a separate CD for discussion of select problems and their solutions. And finally there are reference materials. Apart from listening to these video lectures you could refer to text books which are available.

There are many textbooks such as textbooks by M. S. Thyagi of IIT Kanpur, on Introduction to Semiconductor Material and Devices, and then Bends Treatment is a book on semiconductor electronic devices. Now apart from this I would also urge you to use the internet for understanding various concepts and I will demonstrate to you in the remaining lectures how internet can be used.