Integrated Circuits, MOSFETs, OP-Amps and their Applications

Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 02
Introduction to fabrication of IC: Substrates

So, this is our second lecture and in the previous lecture what we looked at, we looked at the integrated circuit and then we have also seen the types of integrated circuit, that means, we have seen the linear integrated circuit, we have seen monolithic integrated circuit, then we saw thin film technology, then we saw thick film method of fabricating integrated circuit, finally, we were able to see the hybrid.

So, the point is once we know that this is how the integrated circuit looks like and we have also seen that there is a small chip within the package device, which is the within the integrated circuit, what this chip is? This chip is nothing but silicon, we have discussed it. So, the point is what is this silicon and what kind of other materials we can use?

We have also seen that, what is a substrate? We talked about it, that any material or any base on which we are going to deposit different materials is a substrate. So, the base is a substrate, it can be silicon, it can be oxidized silicon, it can be glass, it can be plastic, it can be flexible material, so there is PDMS, it can be anything on which you are fabricating the device.

In the case of integrated circuit, when you talk about integrated circuit what we see is, the substrate generally is silicon. Now, when you talk about silicon, how silicon looks like and what are the different size in silicon wafer, what are the orientations of silicon wafer and how silicon wafer is actually made. So, these are done a lot of patience like this. So, today in this particular class we will try to see, what are the kind of substrates and I will show it to you an oxidized silicon wafer, I will show it to you a plastic substrate or rather a device on plastic substrate, I will show it to you a glass wafer, so that you will have an idea of how the substrate looks like.

So, having said that the today's topic is to understand the substrate and the focus will be on silicon, all right. So, if we go back to the screen you will see, that we are understanding today what are the substrates and we will focus more on silicon.

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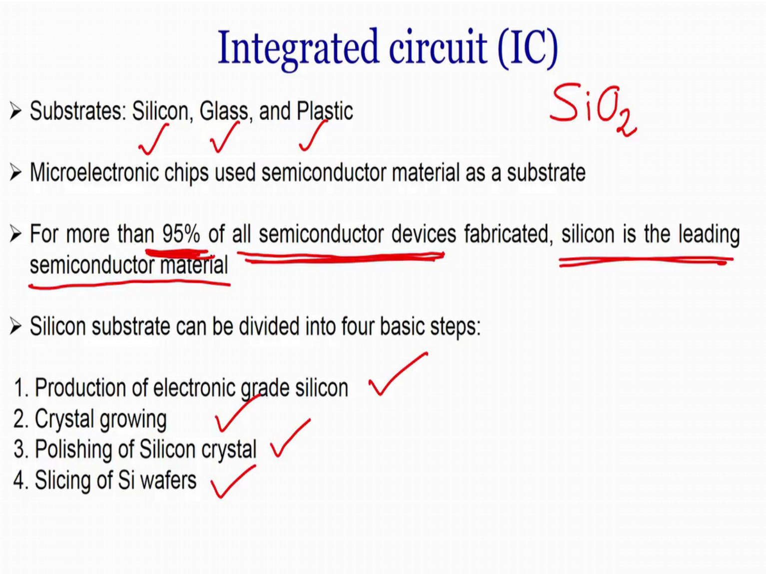

So, let me see the first slide and if first slide shows that generally we come across 3 kind of substrates, generally silicon, glass and plastic. Now, when I say what is glass? Glass is your silicon dioxide, SiO 2. So, do not get really confused, if I say how about, can I use a substrate which is silicon dioxide, yes because it is a glass.

So, now we will be looking at silicon in general because most of the micro chips or microelectronic chips uses semi conductor material as a substrate and the most commonly used or widely used semiconductor material is silicon. So, what is next step, microelectronic chips uses semiconductor material as substrate for more than 95 percent, look at this more than 95 percent of all semiconductor materials or devices of all semiconductor devices fabricated, silicon is the leading semiconductor material.

So, what we found is that more than 95 percent of semiconductor devices uses silicon, then it is very important for us to understand how the silicon is actually manufactured? But to understand the depth in depth the manufacturing process of silicon, it will require hours together to understand because a lot of techniques you have to understand in depth, float zone techniques, Czochralski technique, how the seed crystal is there, how you are pulling off the seed crystal. So, that can be in fact, part of my another series or course, which will be focusing on micro fabrication and sensors and micro fluidic chips and how you can use it for different applications.

So, for this particular course, we will see or will touch the base quickly and see how the silicon is manufactured. So, if you come back to the screen, what you see is, silicon substrate can be divided into 4 basic steps. The first step is production of electronic grade silicon, then second step is crystal growing, you have to grow the crystal, third step is polishing of silicon crystal and 4th step is slicing of silicon wafers. So, basically there are 4 steps that you have to understand, if you want to understand how silicon is manufactured.

First step is production of electronic grade silicon, second is we have to grow the crystal, third is we have to polish the silicon and 4th is slicing of silicon wafers. So, how these things are done?

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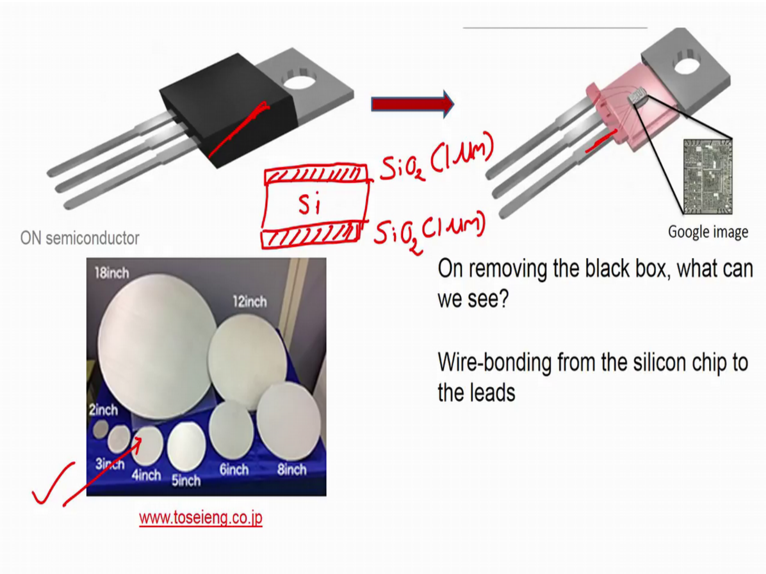

Now, if you take the integrated circuit like I said, if you take the integrated circuit and you open the integrated circuit, what you will find, is what is shown in the slide that when you take the in integrated circuit and if I remove the black box, what I can see? If I remove this black box, this black box what will I see? So, what can I see here is that there is a chip and there are multiple wires that are connected from the chip to the lead using wire bonding, this process of connecting from here to here, here to here is using wire bonding.

Now, if I magnify this image, I will see that there are billions of transistors on the same chip, billions of transistors it was a circuit, that we can design and it can be Analog VLSI circuits, it can be digitized VLSI circuits and you can design the circuits using cadence and you can send it to the foundry to manufacture the devices and transistors and circuits for you. So, the point is, when I open this black box or the packaged I find there is a chip within it, which is connected to the leads using the wire bonding.

So, wire bonding from the silicon chips to the leads I find. Now, if I talk about silicon wafers, what are the size of silicon wafers? Is it 2 in size, is it 3 in size, is it 4 inch in size, what is the current wafer size the industry is using, is it 12 inch, is it 18 inch. Now, I think we have discussed somewhere that the size of the silicon wafer matters because increasing the size you can fabricate more number of transistors onto the same area and thus you can reduce the cost because now you are throughput will increase or the number of chips on the silicon will increase, increasing the size will increase the number of transistors, will increase the number of circuits and thus your cost will come down.

So, instead of using 1 inch or 2 inch wafer, if I go for 18 inch wafer, then it is good from the industry point of view, from the research point of view if I want to fabricate 1 or 2 transistor or 1 or 2 devices or 1 or 2 sensors, I do not need to use 18 inch wafers, I do not want to use 12 inch wafers, it is really costly, wafer is costly.

So, if you see in a research laboratories around many places, you will see generally they use wafer which is 4 inch, some laboratories also use 2 inch wafer, 4 inch, some uses 6 inch, rarely some uses 8 or 12 inch depending on the funding you can also get bigger wafer, you have to have the equipment to accommodate such a big wafer and there are lot of other issues.

Anyway, the point is if you see the screen you will be able to see that the wafers can be from 2 inch to 3 inch to 4 inch to 8 inch to 12 inch to 18 inch. So, as you keep on increasing the diameter, this is diameter, then you will be able to see that we can have more number of component within the same diameter compared to 2 inch or compared to 4 inch. Correct, that is the advantage of using the wafers with a larger diameter.

So, let us see if I have this silicon wafer, let us consider this wafer which is 4 inch and I draw, I am drawing a cross section. So, this is silicon if I grow silicon dioxide on this wafer, then how this 4 inch wafer will look like, that is the point. What I am going to show you all is this 4 inch silicon wafer, this one. So, let me show arrow like this it is easier, this 1, but this 4 inch silicon wafer has 1 micron silicon dioxide, 1 micrometer of silicon dioxide grown on this silicon wafer, so if I have a 1 micron silicon dioxide grown on the silicon wafer, how my wafer will look like, so let us see.

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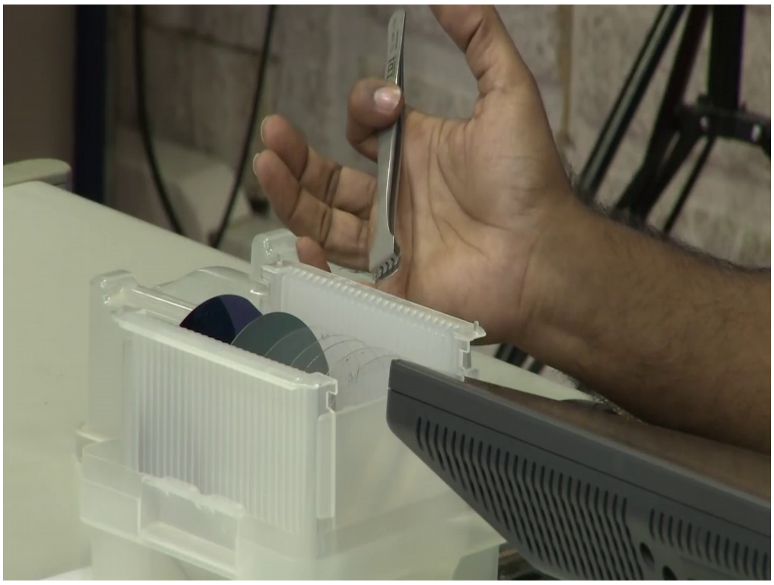

Now, if you see on the desk, my desk, I have this wafer box; wafer holder in which I have this oxidized silicon and I am going to show it to you. So, again please make sure that, when you are opening the box like this you are already contaminating your wafer because the environment in which I am talking right now, is not clean. Now, when I say clean do not take it as a dirty. When I say clean it is terms of clean room environment, which can be class 10, class 100, class 1000, class 10000, class 100000 and then we have the laboratory environment.

So, when you go towards the class 10 or class 1 this is extremely clean, when you come down class 100 little bit less clean, 1000 little bit less, 10000, 100000 and then laboratory environment, this is a lab environment. So, that is why I said it is not clean, but this environment can contaminate my wafer, but since this is the wafers for you guys to understand I took it out of my stock and I brought it here, so even it gets contaminates it is ok. Second thing is, you have to wear gloves when you are operating any kind of equipment, within the clean room also you have to wear the gown and everything, but even we are on handling the wafer you have to use gloves. Again, this is just to show you that is why I am not wearing gloves, but I am just holding a tweezer, this is called tweezer, this is used to hold the wafer and I will hold it right now.

So, it is more or less similar to the thing that we use to hold the utensils at home, if you are seen your mom or sister or maybe you guys are working right. So, you maybe cooking something, you are holding the equipment; the holding this utensil, that to hold the utensil the tool that is used looks similar to this, but now this nothing but a tweezer. So, if you see here there are some wrenches and here there is a holding things. So, it is very easy to look at the tweezer, yes this is better.

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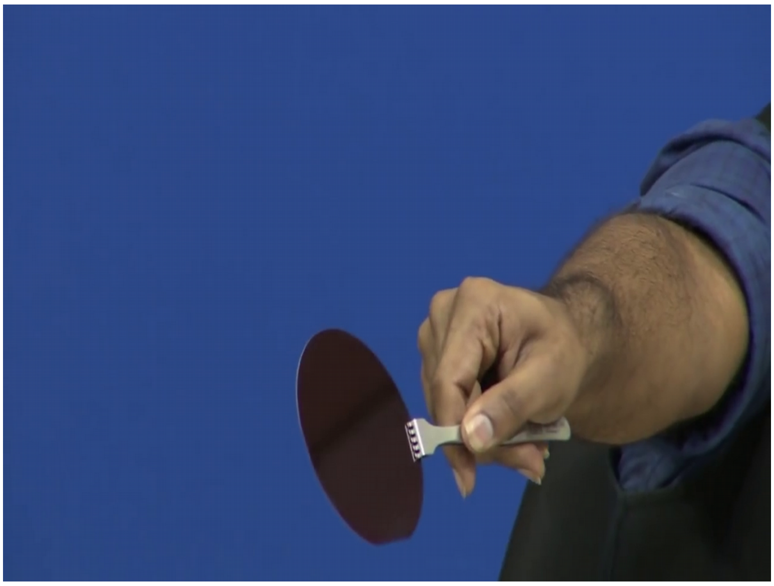

Now, with this tweezer I am going to hold the wafer. So, what I am doing is, I am holding a wafer and I will show it to you, what you see is, yes it is a 4 inch wafer in my hand and you see in the backside this is single side polished wafer, that means, one side is polished this is the polished side, this is the unpolished side, this is the unpolished side, this is the polished side and on that I have grown 1 micron silicon, 1 micron of silicon dioxide, you can see greenish colour.

This is 1 micron silicon dioxide, carefully look at the wafer it has 2 flats, 1 flat is here, second flat is here, there are 2 flats 1 is here. So, if you see, let me show it to you here and if you see this is not completely circle, it is not circle, 1 flat is here and second flat is here, correct. So, there are 2 flats this is called primary flat and this is called secondary flat. This is primary flat, this is secondary flat, so all of you can see very clearly primary flat, secondary flat, oxidized silicon wafer, single sided or single side polished oxidized silicon wafer. This is how it looks like.

So, and it is very easy to grow oxide, we will see quickly in our lectures how can we grow the oxide. So, I will put it back just to show it to you in my hand it is a 4 inched oxidized silicon wafer, I am not talking about the orientation right now. Orientation we will see that little bit later stage, there are different orientation of silicon wafer or crystals it is 100110, we will see there is a p type, n type and how, why these flats are there? Why there is a primary flat? Why there is a secondary flat? We will see in following classes. So, I will put this wafer back into the box.

Now, let us see the next slide.

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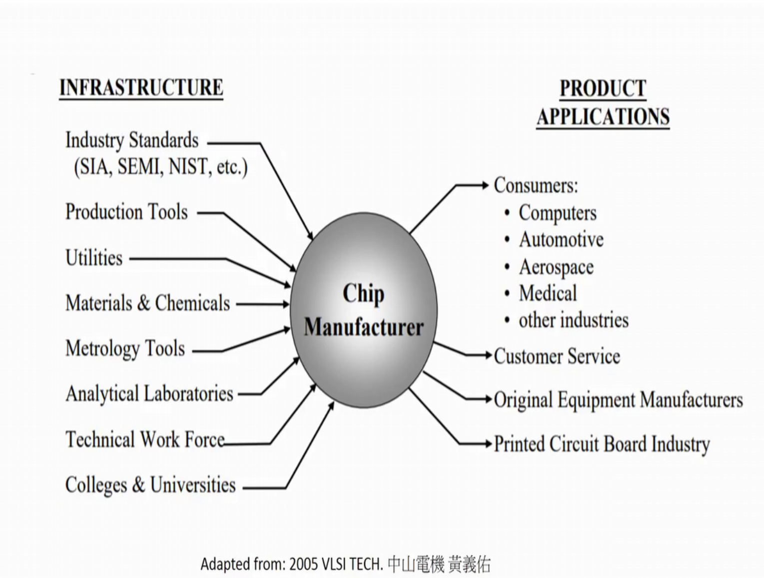

So what we see, we see that the chip manufacturer if you see where it the silicon can be used and what kind of infrastructure it requires to manufacture to operate this chip or what kind of product application has this chip has what kind of product applications. So, if you see it what is product application from consumer side, there are several list of product applications.

We will start from computers, how you think that the chip is used within the computers, think about it. What about automotive? What about aerospace? What about medical?

What about other industries? So, chip manufacturer or chip are used for several application, the consumer applications are computers, automotive, aerospace, medical.

We will take few examples of medical and all this silicon chip on which you see the transistors and indicator circuits in our computers, motherboards everything is made on silicon chip. If it is a Intel processor, this how the processor is actually fabricated? How it is manufactured? It is manufactured using the silicon substrate. Next is your customer service, can be used chip manufacturer or any equipment manufacturers, printed circuit board industry, it is linked with college and universities, lot of people buy the chip, lot of people use or work with chip manufacturer.

So, it can help for technical work force, it can help for metrology tools, it can be used for materials and chemicals, it can be used in a utilities production tools, it can be used for industry standards, SEMI, NIST, SIA etcetera. So, this chip manufacturing is a broad area or chip manufacturer is associated with lot of things not only infrastructure, but also product applications. So, you have to understand that the silicon has a huge market and when you say about chip manufacturing, that means, you are designing the circuit, when you have to design the circuit, when you have to fabricate the circuit you require lot of things to come into play to finally, manufacture a single chip. So, let us not go into really detail because this just to give you a glimpse.

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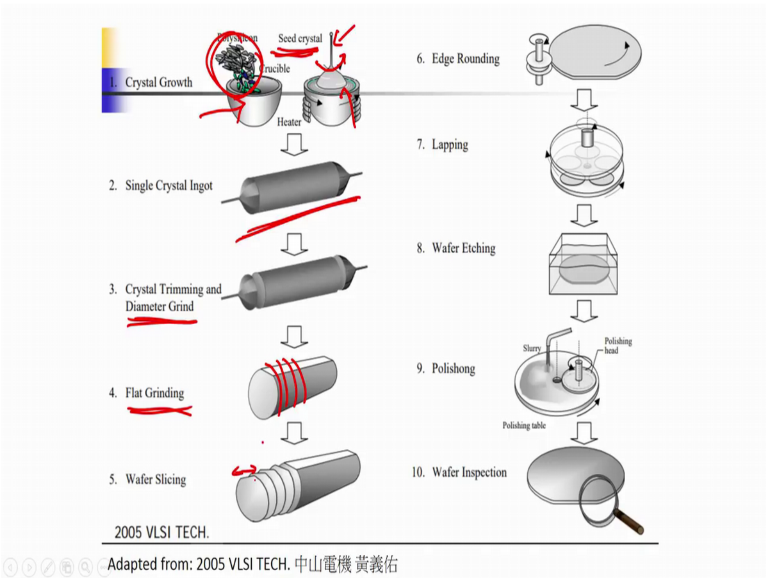

Let us see, the next slide and which is very important slide because here we will quickly see how to form the wafer or manufacture the wafer from polysilicon, from scratch till the end. So, the first point is crystal growth, how we will grow the silicon? How we will grow the boule? This called boule, b o u l e. So or ingot it is called ingot. So, first you add polysilicon to the crucible, this crucible is at extremely high temperature, this crucible is at extremely high temperature you add your polysilicon into the crucible and it will melt, then you use single crystal or seed crystal and you pull this up in a uniform fashion, you see there is a uniformly it is rotated when you rotate it slowly because the temperature of the seed crystal is lower than the temperature of the molten silicon there will be formation of the single crystal.

Finally, you will be able to get the ingot as you see in slide number 2, again we are not going into deep of each manufacturing process, we have to just understand quickly what are the steps? So, I am not going into depth. So, if you see second number this is a single crystal ingot you get it. Once you get this one, then you have to use the crystal trimming and diameter grind, you have to do crystal trimming and diameter grind, then you have to do flat grinding, one of the flat you see, one of the flat is grinded.

So, this will help us to get the primary flat, you see primary flat because now if you have 1 of the primary flat grinded, if I keep on slicking it, like this, this, this, this, I will have the primary flat, you see primary flat is here, primary flat correct.

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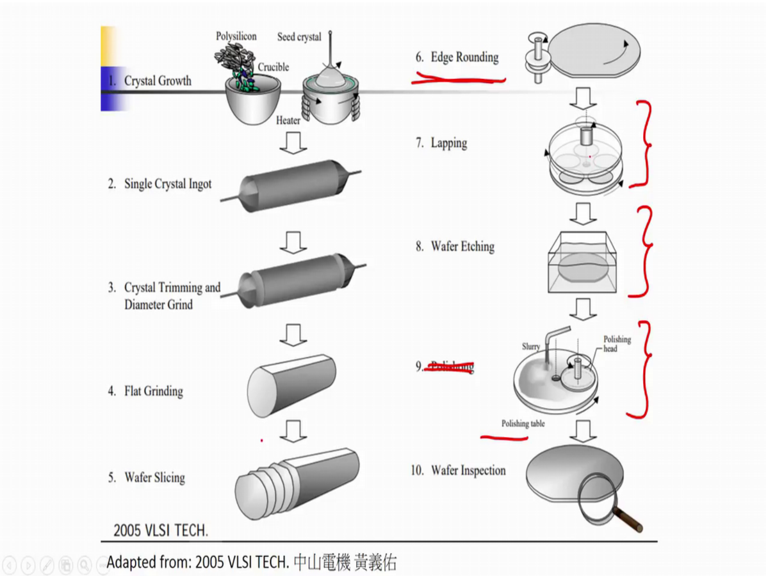

So, point is that once I have my polysilicon I have my seed crystal, I can grow a ingot, from ingot I can trim the crystal, I can do flat grinding, I can do wafer slicing after wafer slicing I have to do edge rounding, the edge is very round, only primary flat and secondary flat there were there. In some wafers you will see there is only one flat, which is primary flat.

Once you do this edge rounding, you have to do lapping. Lapping followed by etching, followed by polishing, this is wrong polishing p o l i s h i n g polishing. So, the process is once I slice the wafer, I will take this wafer and I will do the edge rounding. Once, the edge rounding is done, I will perform the lapping, once the lapping is done I will perform the etching, once the etching is done I will perform the polishing, once the polishing is done I have to inspect the wafer. So, when I say I that is not me, it is a foundry. This is the basic process or quick process to understand how the silicon wafer is fabricated because we are using silicon as a substrate. So, we should know how silicon is fabricated all right or how the silicon is manufactured.

So, we are talking about the process that is used in foundry we are just talking or we are just looking the glimpse of it, not we are just touching the surface and an or quickly touching the base and coming back we are not going really in depth and spending lot of time on this because that is not the idea of this particular course. So, if you see quickly in 10 different steps, we can we can have silicon wafer which you have just seen before few minutes right how it looks like.

Once you have silicon wafer, you can either polish one, one side, depending on whether you have polished on one side or both side you can have single polished wafer or you can have double sided polished wafers, easy. Let us go to the next slide then.

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This is how it looks like, these are all silicon ingots, this is silicon ingot, silicon ingot. Now, you see here the ingots and wires, so diamond coated wire is there, which is used to slide this wafer, wafers are sliced. You see here, a wafer this ingot is there and it is used to slice it. So, how the slicing is done? Slicing is done using the wires which are diamond coated wire and you can see this whole process here, excellent. This I had taken from Micro Chemicals.eu. Just as an example to show you that, how this is done. I thanks to these guys that they have helped us to understand how it is done.

We have diamond coated wires, diamond coated wires are used to cut the silicon wafers. Now, once you have this, what we can do? We have to use, this is a we have to a lap it and then we have to polish it, we have to etch it and then we have to first lap it and then we have to etch it, then we have to polish it and finally, we can inspect it.

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So, lapping what is or how lapping is done? Lapping is done in this particular fashion, you can see the silicon wafers which are rough, they are loaded onto this holder and that too machine is there, it moves in this particular direction, the substrate the holder substrate will move in this particular direction, will start lapping this particular silicon wafer. So, this is just to again quickly give you an understanding of the lapping process, really not important in terms of understanding how the integrated circuits are fabricated this is just to understand that how silicon is manufactured.

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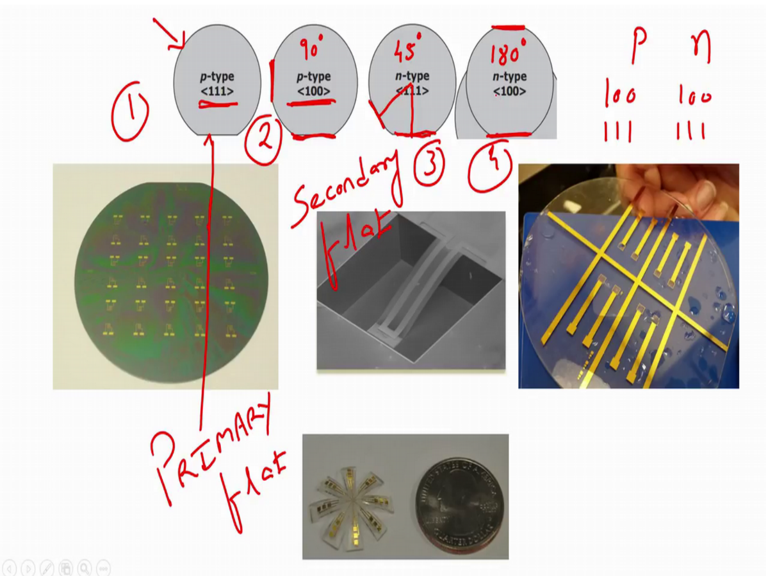

Now, let us see this one. So, what we have seen? We have seen a silicon wafer, which had 2 flats, remember there are 2 flats. Now, there are 2 types of silicon wafer first when the silicon wafer is not doped is undoped, there is no impurity inside the silicon wafer, that silicon wafer we call as an intrinsic; intrinsic silicon. Now, if I dope the silicon wafer, if I add the impurities inside the silicon wafer and the impurities are n type impurities, if the impurities are the n type impurities then my silicon wafer becomes n type. For example, it becomes extrinsic and it is also n type. So, n type impurities you already know example is phosphor, excess electron where is 1 excess electron.

If I dope the silicon with p type then there will be excess whole and that is why it is a p type silicon. So, one is n type, one is p type another one wafer we can sometimes if we are not really interested in understanding the circuits and MOSFETs we take the wafer just as a base and that is the intrinsic semi conductor not doped.

So, here when you see the screen what you are able to see? You are able to see a flat, one thing you see this wafers, if I say 1, 2, 3, 4 what I see? I see a p type I see a n type. So, basically 2 types, one is p second is n, p type n type. Then, what I see? I see 100 and I see 111, these are the crystal orientation. So, how we can now understand whether this p type 100 or n type 100 or p type 111 or n type 111, how you will know?

So, that is why, there are 2 flats, in some wafers there is 1 flat in 1 wafer and the flats are at different angle. So, let us see, p type 111 there is only 1 flat here, you see only 1 flat primary P R I M A R Y, see primary flat is here also, there is primary flat here ok, primary flat here very good, primary here ok. So, every wafer has primary flat, but not every wafer has secondary flat. So, in p type 111, there is no secondary flat. Can you find a flat in this circle? There is no flat in this particular circle. Now, if you go for p type 100, then we also have a secondary flat along with primary flat. So, let us see, where is secondary flat all right, let us see.

So, if you have a secondary flat, if see on the screen you have a secondary flat at 90 degree to the primary flat. So, if I just delete this, you can easily see this secondary flat, which is this 1, this is called secondary s e c o n d a r y secondary; secondary flat f l a t flat, primary flat f l a t, this is my secondary flat. So, let me write, let me draw with red pen here, this is my secondary flat, this is my primary flat, good.

Now, we know to how to distinguish p type 111 and p type 100. So, what if there is a n type 111. In n type 111 what we see is, there is a secondary flat which is here. Which is at 45 degree, so you see here it is 90 degree secondary flat with respect to primary flat, here there is 45 degree secondary flat with respect to primary flat, here if you see primary flat and here you see secondary flat this is at 180 degree, that means, that if I have the wafer in which primary flat is at 90 degree, I have p type 100, if I have a wafer, sorry if I have a wafer in which secondary flat is at 90 degree I have 100 p type. If I have a wafer in which there is no secondary flat I have p type 111, if I have a wafer in which the secondary flat is at 45 degree I have n type 111, if I have a wafer in which the secondary flat is at 180 degree then I have n type 100.

So, the primary and secondary flats are given to easily distinguish between n type and p type and to distinguish between the orientation of the wafers whether it is 100 or whether it is 111, whether it is n type or whether it is p type. So, now, if I once again show you the wafer then can you identify whether it is n type or p type 100 or 111 let us see, you see. So, if you see clearly, if you can still little bit zoom yeah, there is a primary flat here and secondary flat here at 90 degree.

So, you see yes, this is better. So, you have primary flat here and you have secondary flat here, this is 90 degree, 90 degree with respect to primary flat. So, 90 degree with respect to primary flat is what is my p type 100, so now, let us see 90 degree with respect to primary flat, if you go back on the screen, we can see that 90 degree with respect to primary flat is my p type 100 beautiful, beautiful. So, that means that it is very easy to identify the type of the wafer and the orientation; crystal orientation of the wafer depending on or where the primary flat is and where the secondary flat is with respect to primary flat or whether secondary flat is there or not.

So, once again quickly if we see, the first one shows no secondary flat, second one shows secondary flat at 90 degree which is p type 100, third one shows secondary flat at 45 degree which is n type 111, 4th one shows secondary flat at 180 degree which is n type 100, these are the silicon wafers with different orientation; crystal orientation and with different type, n type or p type good.

So, now what to do? Now, we have to see how the other substrate looks like, we are focusing on silicon, but that does not mean that we should not know the other substrates and how they look like at least. If we do not use it, that is different, at least how they look like? So, instead of silicon, if I want to use glass or if I want to show you what is glass then how glass will look like, you all have seen glass you hold the glass right, glass water you have seen, do not say that oh I do not know, oh how glass will look like do not get like this right, we have all seen the glass.

Glass wafer you may not have seen and why this wafer is thin, it is thin, chips thin, we eat potato chips or not we eat wafers; potato wafers they are thin, thin slice. This you see, this 500 micron thickness, 500 micron thick diameter is 4 inch, thickness 5100 micron, diameter 4 inch keep on increasing diameter thickness also increases.

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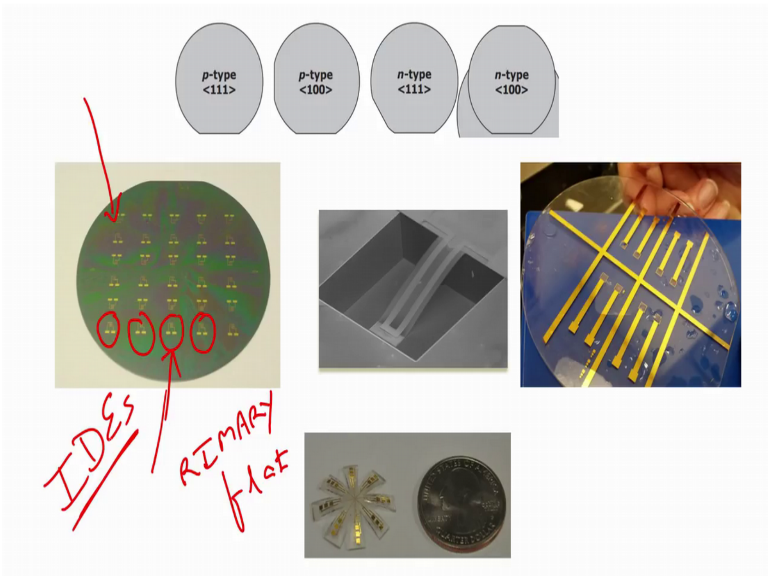

So, if you come back on the screen what I will show you is, this is 1 wafer, which is oxidized silicon wafer with some devices fabricated on this oxidized silicon wafer. What are these devices? We will see in the following lectures. So, that you understand and that the again understand this course is not on understanding how to fabricate sensors, this course is to understand.

How you can fabricate a MOSFETs or an integrated circuit and then use this as their applications whether when we understand Op-Amps, how we can use Op-Amps for different applications, but before we understand Op-Amps we should understand what is within Op-Amp and for understanding within Op-Amp not in terms of what are the circuits within Op-Amp, but how the circuits are fabricated. In fact, when you talk about circuits just about talk about 1 single transistor, which is your MOSFETs. If you understand, how you can fabricate the MOSFETs, the rest of these things becomes easy, it becomes comparatively easy.

So, the idea is to help you to understand how you can fabricate a MOSFETs, but to understand how you can fabricate the MOSFETs, I will go slowly, so that you do not get, you know lost in understanding the process flow. So, that is why when you see the screen what I have, I will show you in the following lectures is how you can fabricate a simple device which is nothing but an inter digitated electrodes IDEs. This is oxidized silicon substrate and we will see IDEs. Then, if I just clear the screen, so that it becomes easy for me to write.

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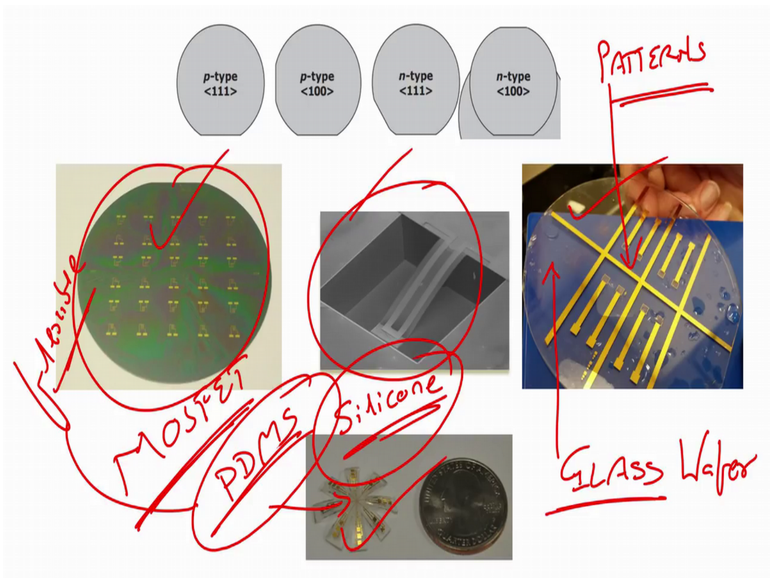

If you see this particular figure, this is a piezo resistive micro cantilever, you can see this is piezo resistor, very clearly you can see excellent, but what you can see it has not been released from the silicon substrate this is attached to it, it is not released this part is released this part is not released that is why you see a bending right you see a bending.

So, you see a bending like this you see. So, if I draw it once again see you will see a bending which is like this it is attached it is attached all right, but anyway the point is this is also silicon this is also silicon all right. Let us go to the next slide no not next slide the next figure this is glass this is glass GLASS this is glass substrate I am planning to take one more course on how to fabricate different kind of patterns on glass, on silicon, on different materials.

So, right now you do not worry about it I will explain you in this particular course this particular thing I will explain to you piezo resistive cantilever and then I explain you MOSFETS fabrication all right. So, dot worry the point is this is glass and these are some patterns on the glass these are some, these are some patterns, PATTERNS, PATTERNS on the glass right. This is glass wafer GLASS wafer. Finally, what you see here is PDMS this is also called silicon s i l i c o n e, this is soft, this is flexible, silicon PDMS it is flexible.

So, the point that I am making here is that you can use oxidized silicon, you can use silicon, you can use glass, you can use flexible substrate all this are substrates, all this is nothing but your substrates got it. So, all this are, your substrate with the most important 1 is your silicon and then we see, how the glass substrate looks like? We have seen the silicon substrate, we have seen the oxidized silicon substrate. Now, let us see how the glass substrate looks like.

So, again do not get confused if there is some pattern in the glass, the point is you see how the glass wafer looks like, glass substrate looks like. I am talking about the wafer that means, I will show you a 4 inch glass wafer. So, again I am holding a glass, so can you see on the screen. It is very difficult, so I will put it little bit close to my jacket.

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So, you can now see, yes, yes you see again let me put it clearly. Now, if you see, you can see the glass wafer in my hand, here there is no orientation because there is no crystal everything is oxidized, SIO 2 silicon dioxide that is what glass is made up of, SIO 2 and you can see very clearly in my hand this glass is there yeah, yes. Somewhere here, I am trying to show it to you.

So, that you can see it clearly this is better. Now, you see a glass wafer I am holding again it has a primary flat, but it does not have secondary flat, it need not be secondary flat because there is no crystal orientation, there is no crystal here. In silicon there were crystals it was oriented, that is why 100 111 in glass no, but the glass wafer looks like this, you can see through, except the pattern that is there within the glass, you can see me through this glass, it is a transparent glass.

So, even the glass slide that you use in the biology lab or in a chemistry lab is also a substrate. It is a glass substrate, glass slide can be used as a substrate, this is glass wafer, wafer because if you see cross section it is extremely thin, it is 0.5 millimetre. 0.5 millimetres is 500 microns. What is thickness of our one hair? The thickness of my hair or approximately thickness of a human hair is about 82100 microns, 80 dash100 microns. This is 500 microns; this is the thickness 500 micron, the thickness of the silicon wafer 500 plus minus 50 microns. For 4 inch, this is 4 inch glass you got it.

So, now you have seen the glass substrate, you have seen silicon which is oxidized silicon substrate, cool. Now, if you have seen oxidized silicon substrate, if you have seen glass substrate, then why do not you see plastic. So, I brought you another substrate which is plastic and here I can hold the plastic, again this is just a demo. So, that is why I am holding it just to help you out and to see. This is the plastic; this is a plastic in my hand. So, this is a plastic wafer, plastic substrate in my hand, I am holding a plastic substrate in my hand you can see a plastic in my hand, all right this is a plastic.

Now, plastic means it can bend it is a flexible material. So, the point is plastic can be used as substrate, glass can be used as a substrate, oxidized silicon can be used as a substrate. So, when you talk about substrate it does not restrict to only silicon, but when we talk about semi conductor devices 95 percent of the semi conductor devices uses silicon.

That is why in that particular application, when you are talking about chip manufacturing, when you are talking about chip designing, when you are talking about MOSFETs, when you are talking about circuit designing, when you are talking about foundries, most of the foundries they use silicon. It is not only silicon, there are other materials as well, people have started using gallium nitrate, then they are using gallium GaAsP, gallium arsenide phosphide, G A P gallium phosphide.

So, lot of material has been explored people are also have used germanium wafers, they have used silicon wafers, but silicon is used because silicon dioxide this is started from the raw material is silicon dioxide and silicon dioxide we get it from sand and sand we get it from the clean sand 99.99999, 9 times 9 we can opt, we have to purify it to finally form the silicon wafer. So, from whatever silicon dioxide we get, that is sand we get from the land we have to purify it to 99.9 times 9 and some of the foundries they claim that they can purify it from 99.11 times 9, this much purification. That is required to fabricate or to formulate or to form, not formulate to form or to manufacture a silicon wafer.

So, point is we have lot of sand, silicon is used maximum. That is why we are focusing more on silicon and less on other substrates.

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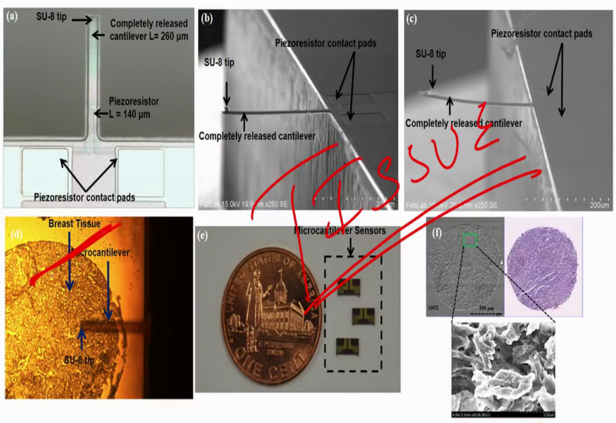

FIGURE: Photographs of (a) top-view of piezoresistive microcantilever, (b) cross-sectional SEM image of piezoresistive microcantilever with 200 nm of Si_3N_4 as stress compensating layer, (c) microcantilever without Si_3N_4 layer, (d) piezoresistive microcantilever indenting the breast tissue core, (e) microcantilever sensor chips, and (f) FE-SEM and H&E images of breast tissue cores.

So, we go to the next slide and what you see is that using this silicon substrate you can fabricate several devices including a piezoresistive micro cantilever, including what, a piezoresistive micro cantilever. So, let us say if I hold this, right in front of me or let us say from here and if this is stiff, I press it, it can bend. If this can bend, this is stiff, this can bend then this becomes cantilever. Another example, you stand on a if you have seen swimming, if you go for swimming or if you have seen in TV, how swimmer dives on the dive board that dive board.

So, if you see dive board is something like this, it is holding like this, the person has to go on the top, he jumps and then he dives into the pool, correct, this dive board is also a cantilever. So, it is very easy when you think about the actual applications in life with your and merge it with your academics, merge it with your study it becomes interesting and lively. Then we do not have to worry oh cantilever, what is cantilever? I do not know, no it is not like that. Cantilever is a very easy example, you can immediately give. Now, but when you talk about piezoresistive cantilevers (Refer Time: 48:53) is micro because the size is microns, that is why microns.

So, micro cantilever we got it. Cantilever is made up of what? Silicon all right. Now, how we can make it piezoresistive? What is piezoresistive? We all have studied piezoresistive. Piezoresistive is when you apply pressure, when you apply force there is a change in the resistance of the material is piezoresistive material. So, what is piezoelectric then? When we apply force, there is a change in the voltage output change is in the form of voltage. For example, there are piezoelectric crystals rho callosity is one of the crystal. So, we will see this piezoelectric crystals and how we can use oscillator using piezoelectric crystals later on. Right now, what we understand is piezoresistive micro cantilever.

So, how we can fabricate piezoresistive micro cantilever, again if you understand the process of this particular cantilever then you will be able to understand MOSFETs as well. So, once you understand the process of fabricating a device, then you can understand the process of fabricating lot of other devices including your transistors including your circuits. So, that is the idea.

Now, if you see here on the screen what you see? What you see is a is a piezoresistive cantilever and if you see here, this is the piezoresistors doped inside this diffusion, we have done diffusion. What we have done? We have diffused boron to make the polysilicon piezoresistive. Here, you can see a completely released piezoresistive micro cantilever with a SU-8 tip here. Here, you can see again a completely released cantilever, but there is a strain or stress in the material, there is a stress in the material because of which you can see bending of the cantilever. This is straight and this is bent, this bending is because of the stress created in the cantilever because of the use because we are not using a particular material during fabrication and I will tell you later on why? I wanted to check whether if I do not use a particular material what people are suggesting whether it is really causing a stress or not.

So, I tried of not using that material and I found that yes, you see if you do not use that material, then it will cause stress in the material and because of the stress your whole cantilever beam instead of straight, it will be bent. It will be bent like this, instead of straight it will bend like this right. So, that was the experiment that I did and this is from my own work which I am showing it to you right now and then we will see that how we can use this micro cantilever for several applications including understanding the stiffness of the tissue, including understanding stiffness; STIFFNESS, stiffness of the tissue. Tissue, TISSUE, which kind of tissue any tissue any tissue so, if I take the tissue from the breast, during the biopsy I can understand the elasticity of the breast tissue. that is why I am using here see breast tissue, if you see here breast tissue.

So, the point is that I can use silicon substrate for fabricating not only MOSFETs, but also to fabricate sensors and actuators using the micro fabrication process and the same process is used more or less for integrated circuits as well. That is what, we have to learn.

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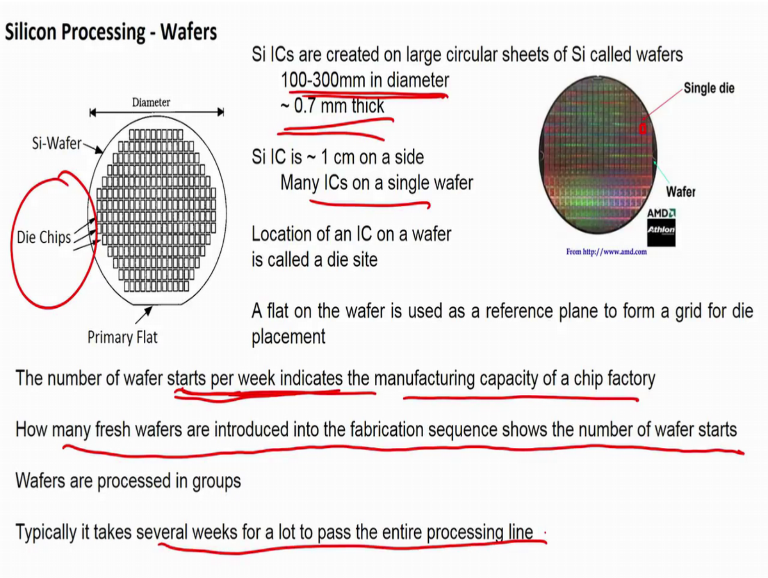

So, now, if you see silicon wafer processing wafers, when you see silicon ICs they are created on circular sheets of silicon wafers. We have already seen how wafers looks like, you can see the diameter of the wafer is measured like this. This is the silicon wafer with die chips, this is the primary flat here, then there are 100 to 300 millimetre in diameter, this is just a case when it was a old case, now we have wafer with much bigger diameter, we have wafer with much more thickness and then we can have many ICs on 1 single silicon wafer. I have taken this image from AMD dot com and you can see a single die, is nothing but a small piece of this chip here and that consists of your lot of transistors, lot of devices.

A flat on the wafer is used as a reference plane from the grid for the die, you see the flat on this wafer, a flat on this wafer is used. Suppose, this is a primary flat let us say this is the primary flat or actually yeah let us say this is a primary flat, this flat is used or if this is a primary flat this flat is used to understand or to help as a reference plane to form the grid for die placement. These are grids, there are so many dies and this is a single die and if you magnify this die, you will see other whole device all or many devices into 1.

So, number of wafers starts per week indicates the manufacturing capacity of the chip factory. How many wafers you are using, new wafers in a week? How many fresh wafers you are introduced into the fabrication sequence shows the number of wafers starts? How you know wafer start? First sentence was that the number of wafer starts per week indicates the manufacturing capacity of a chip factory, but how many, how you can understand what is wafer start.

To understand what is wafer start, we have another definition or they have another definition, which shows that how many wafers are introduced into the fabrication sequence. How many wafers; new wafers are introduced into the fabrication sequence that shows the wafer start and how many wafers starts per indicates manufacturing capacity of a chip factory, wafers are processed in groups and finally, typically takes several weeks for a lot to pass the entire processing line.

So, this is how the silicon is wafer is made and the ICs or single die or multiple dies within the silicon wafers are manufactured or fabricated and this is the last slide for this particular lecture. What we have seen today is very important, even though it is very basic, that what kind of substrates are there, how can we use this substrate and how this is manufactured, using we will see later on, but one example or 2 examples we have already seen, where we can make inter digitated electrodes or we can see piezoresistive micro cantilevers, we have also seen types of substrate.

You have seen silicon, oxidized silicon, silicon sizes, silicon orientation, primary flat, secondary flat. With respect to secondary flat if primary flat how we can identify n type or p type, 100 or 111, then we have seen glass and how glass wafer looks like, we have seen oxidized silicon wafer, what kind of oxidized silicon wafer we had, we have seen plastic substrate and the idea of today's lecture was to help you to, you know introduce you with these substrates and in particular with silicon. Why, because silicon is used in most of the semi conductor devices.

Now, in following lectures we will see how you can fabricate a single sensor, very simple, extremely simple basic. Why, I have to teach you that, so that when you learn that, you will be you will moving forward to understand how you can fabricate integrated circuit. Suddenly, if I start with a doping of n type and p type into n type silicon and p type silicon and there is a diffusion, diffusion of pre deposition and drive in and then you have to create a thin layer of silicon dioxide as a gate, gate oxide and you have to create a polysilicon you have to deposit double metal, how many processes 4 5 mask, but what are this mask? How the silicon wafer is? How the doping can be done? You have to understand this things and to understand to help to understand this particular steps, we will start with basic, that is how you can pattern a simple thing on an oxidized silicon substrate.

Once you understand 1, then we will move forward and we will see how you can fabricate a integrated circuit, that is the idea. That you should know at least how a MOSFETs is fabricated. At the end of this particular series you will be able to know, how you can fabricate a MOSFETs not actually in terms of experimentation, but at least in terms of process flow. So, with this I hope that this module is useful to you. You now know what is called substrate, you now know how the substrate looks like, you can now identify whether it is silicon or it is plastic or it is glass, how the wafers looks like, how a 4 inch wafer looks like.

So, I will try to show you more of this kind of devices. So, that you keep on understanding how the things looks like, the same time we will move forward with our lecture in which we have to understand how you can fabricate the integrated circuit and then you will understand the operational amplifier and it is uses. So, for now you guys take care and I will see you in the next class, which will be more on how to fabricate the integrated circuit, till then you take care, bye.