Microfluidics
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Lecture - 21
Microfabrication Techniques

Okay so we have been talking about electrokinetics. We finished our discussion on electrokinetics. Now let us look at microfabrication techniques. So in microfabrication techniques we try to understand the different techniques available to fabricate microfluidic devices. We would start our discussion on talking about silicon based fabrication because that is where you know the microfabrication originated from the semiconductor microfabrication.

And then we would also cover polymer and other substrates okay. So before we start our discussion on fabrication techniques let us look at some of the materials that are available for microfabrication.

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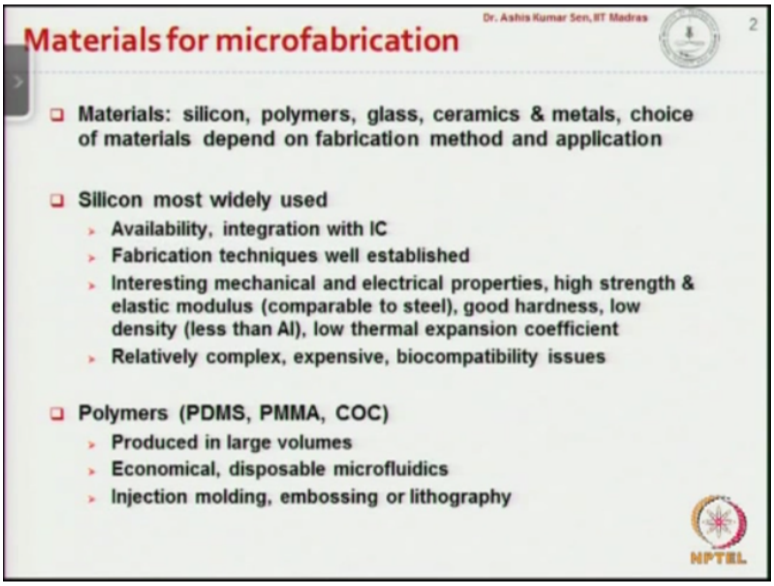

So you know the materials that are available for microfabrication are silicon, polymers, glass, ceramics and metals okay and the choice of selection of a metal would depend on the application that we are interested in and the fabrication techniques that we want to follow okay. So if you look at silicon as the material silicon is most widely used because it is widely available and it has the capability to get integrated with IC okay integrated circuits.

And the fabrication process for silicon is also very well established because that is the material that was used in semiconductor fabrication. Silicon has got interesting mechanical properties. It has got very high strength that is comparable to the steel and also the elastic modulus. Silicon has also got good hardness and low density. So density of silicon is typically less than that of aluminium.

And silicon also has got low thermal expansion coefficient which makes it suitable particularly for sensor application okay. However, silicon is relatively complex and is expensive to produce and it may have some biocompatibility issues okay. On the other hand, polymers.

You know in polymers we are using substrate like PDMS, PMMA and COC. PDMS is polydimethylsilane and PMMA is polymethyl methacrylate and COC is cyclic olefin copolymer okay. So polymers are produced in large volumes and they are economical, the price of the polymers is less as compared to the silicon and that is the reason why polymers can be used to fabricate disposable microfluidic devices.

Disposable microfluidic devices are particularly you know applied to diagnostic applications where we you know take a chip, bring a sample from a specific individual and test it and then dispose the chip okay so that is called disposable applications of microfluidic chips. The different fabrication techniques that are available to make polymer based microfluidic device are injection molding and embossing and lithography okay.

In injection molding, we will have to make a replica of the structure, negative of the structure that we are going to make and pressurize molten polymer material into that mold cavity and then we can you know cool it down and remove the polymer from the mold okay that is the injection molding process. In hot embossing, we have to make a master of the microfluidic structure that we are going to fabricate.

And from the master we can mold the specific polymer that we are interested in to create the microfluidic structure okay and in lithography similar to photolithography in silicon we can use some photoresist to pattern different structures, create channels on the surface of the polymer okay.

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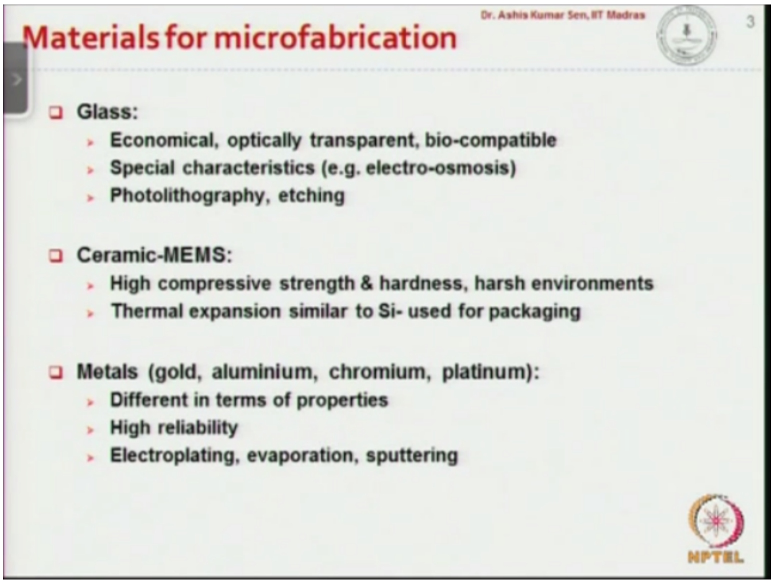

The next material is glass. Glass is also economical and it is optically transparent okay and one of the major advantages of glass is it is biocompatible okay so you know when especially in microfluidic applications we are dealing with you know biological cells, biological objects so in substrate like silicon and polymer, these substrates are not very much compatible with biological objects okay while glass is very much biocompatible okay.

There are some special characteristics like electro-osmosis so special characteristics like electro-osmosis, which we have discussed is very well exhibited by substrate like glass okay, which has a negative zeta potential. The fabrication techniques that we used to you know manufacture microfluidic devices in glass can be photolithography and etching okay. So similar to silicon we can have photoresist patterned onto the glass substrate and create microfluidic channels.

We can also do etching of the glass, which would require hydrofluoric acid HF etching in glass to create bulk you know channels inside glass substrate. Then, there are ceramic-MEMS where you know there are ceramic materials that can be used to create microfluidic structures. The advantage of ceramic is that they have got very high compressive strength and hardness.

So those were 2 important advantages of ceramic and for which they can be used in harsh environment okay. For example, we talk about a microreactor okay where the chemicals that we deal with are corrosive in nature okay. The other substrate may fail to work in this case whereas ceramic which is very much resistant to the chemicals can be used in this applications okay.

For example, creating you know humidity sensors for heating ventilation, air conditioning applications, ceramic is used ceramics based you know pressure sensors, temperature sensors, humidity sensors are used for HVAC applications because they have good resistance against harsh environments okay and the thermal expansion of the ceramic materials is similar to silicon okay.

So many times the ceramic materials are used for packaging of silicon structures okay so the devices that are actually fabricated using silicon substrate are packaged using ceramic materials okay. Metals are also used to create micro devices you know one is that they can actually be used to create the microfluidic device itself for example in microreactor application we can use metals to create microreactors.

And they can also be used to create electrode structure for making electrical contacts in microfluidic device where you can pattern materials and interface that with the fluidics okay. So there are different metals that are used gold, aluminium, chromium and platinum are most widely used. You know all these different materials differ in terms of their properties. The metals have you know very good reliability.

And the fabrication methods that you use to create metal structures in micro devices are electroplating, evaporation, and sputtering.

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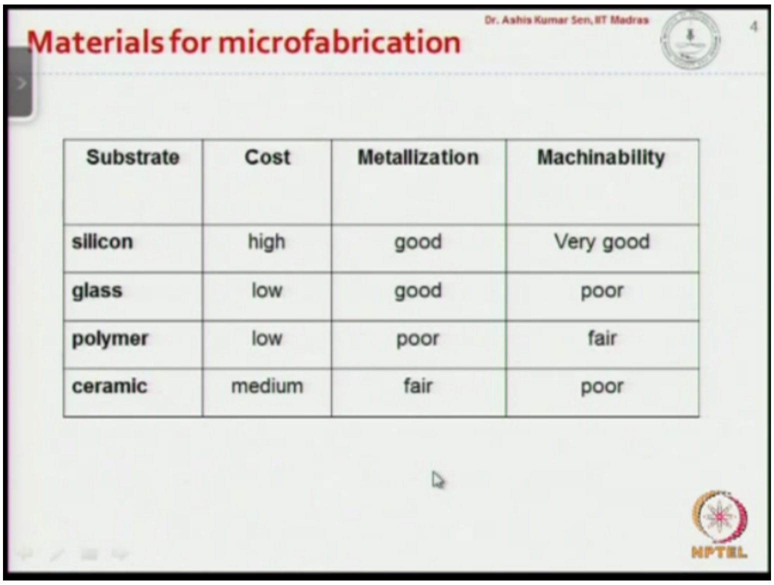

Substrate	Cost	Metallization	Machinability
silicon	high	good	Very good
glass	low	good	poor
polymer	low	poor	fair
ceramic	medium	fair	poor

So here we contrast you know different substrates based on the cost, the metallization capability and machinability. Silicon has got relatively high cost, but the metallization is good, we can very well put another metal on the silicon substrate and the machinability is also very good okay because the fabrication method is well understood, so the machinability of silicon is very good.

Glass has got low cost, but we can easily metallize on glass, we can easily put an electrode on glass, but the machinability of the glass is poor. We need you know hydrofluoric acid based etching to create microchannels in glass, which requires an expensive setup okay. So the machinability also the etching process itself is very slow okay. So the machinability of the glass is very poor.

Polymers on the other hand, they have low cost and the metallization is poor okay. It is very difficult to put a layer of metal on a polymer like you know PMMA or PDMS or COC very difficult to put a metalized layer on the surface of the polymer and the machinability is fair. We can use established fabrication processes like hot embossing, molding to machine polymers.

Ceramics have got medium cost, but the metallization is fair. They can fairly be a machined using the established fabrication process. They can easily be metalized using the established fabrication processes so easy to put a metal layer on the ceramic surface, but the machinability is also poor like glass okay.

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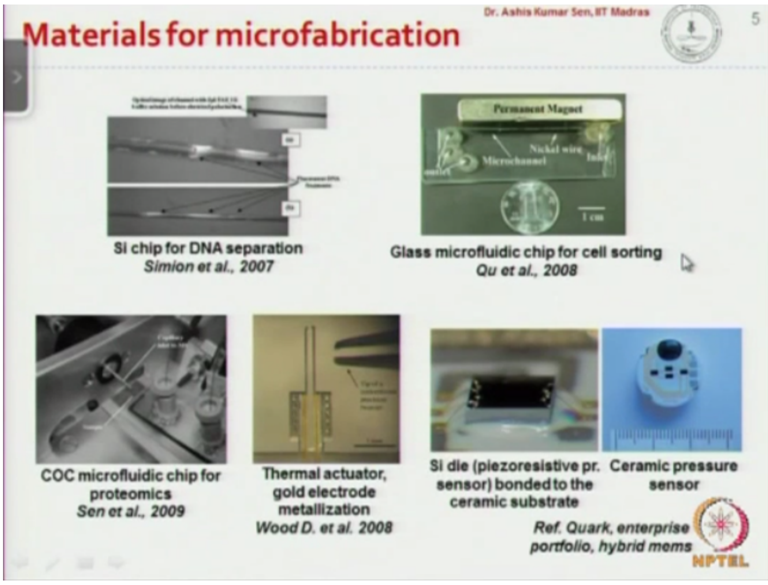

Here are some of the examples of you know different metals that are used to fabricate microfluidic device. Here is an example where a silicon chip is used to separate DNA and the second example where a glass microfluidic chip has been used to sort cells you know inside microfluidic channels. There is an example of cyclic olefin copolymer, which is a polymer that has been used to analyze proteins.

And here is an example of where metals have been put in in microdevices. This is a thermal actuator where we use gold as the metal in the device and here we see a ceramic substrate which has been used to (()) (12:39) piezoresistive pressure sensor, also ceramic has been used to create pressure sensors.

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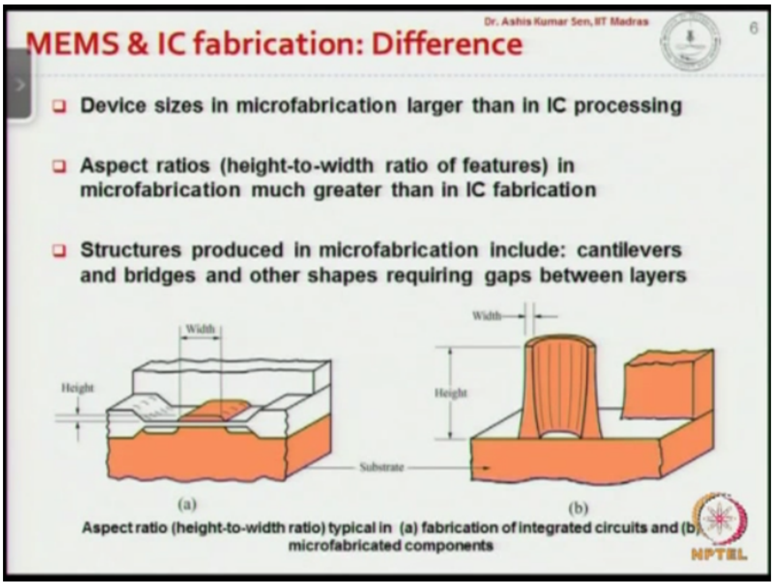

Now let us look at what is the difference between MEMS and the IC fabrication, where the MEMS originated from. Typically, if you look at here you know the semiconductor devices have got you know much relatively smaller size as compared to what we normally encounter in microdevices okay. So the device size in microfabrication is much larger than what we encounter in the integrated circuit okay.

And the other thing is that aspect ratio of the different structures that we encounter in microdevices for example height to width ratio is much higher as compared to what we encounter in case of the semiconductor fabrication. So the aspect ratio in case of microdevices is much greater than that of in IC fabrication and in microdevices many times we have to you know fabricate layers with gaps between them.

For example, you have to create a cantilever based sensors or a microchannel itself we would always have a gap between different layers okay. So that is the uniqueness in microfabrication, which we may not encounter in IC fabrication.

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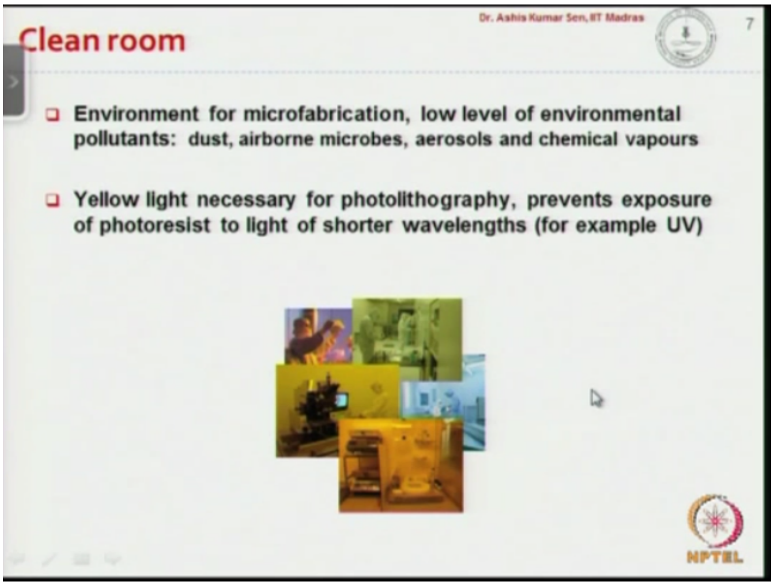

So next we talk about clean rooms. Clean rooms are the environments where we fabricate these microdevices okay. So clean room is nothing but the environment for microfabrication okay. So the clean room is the environment for microfabrication where the label of environmental pollutants is very low. You know when we talk about environmental pollutants we talk about dust, airborne microbes, aerosols and chemical vapours.

So these pollutants are very low in a suitable environment that we call as clean room okay and typically in a clean room, the lighting looks yellow this is because we remove the shorter wavelengths namely the UV light waves from the electromagnetic spectrum okay. So the UV shorter wavelengths for example UV is taken out from the light so which makes the light look yellow inside the clean room.

When that is required because inside clean room we use the UV light to selectively expose and had in the photoresist okay so in order for the photoresist to get in expose to the UV light while doing spinning or you know before we expose we use yellow light okay.

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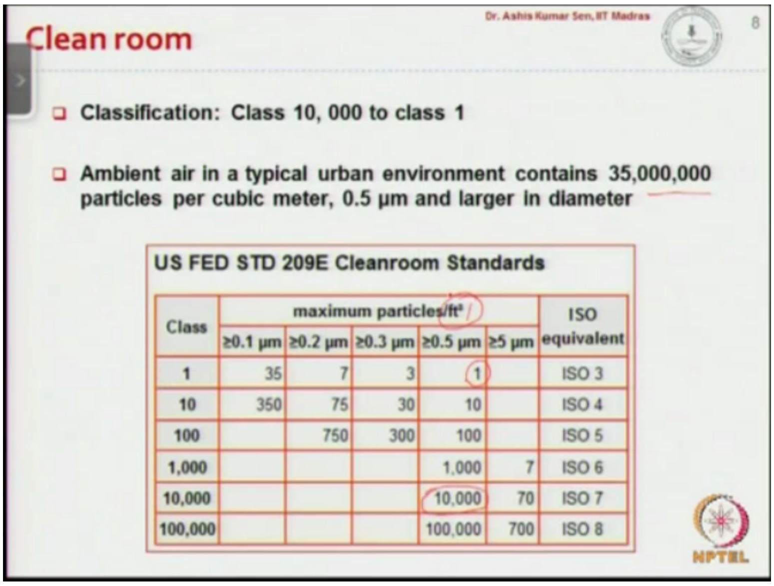

So clean rooms are classified from you know class 10,000 to class 1 depending on how good we are at you know taking out the airborne particles or contaminants from the environment. So a typical you know urban environment will contain about 35 million particles per cubic meter and here in the table we see the clean room standards you know class 100,000 to class 1.

A class 10,000 would contain 10,000 particles that are >0.5 micron okay per cubic feet of the air and a class 1 would contain only 1 particle that are >0.5 micron per cubic feet of air. So that is the label of cleanliness when you talk about clean rooms okay.

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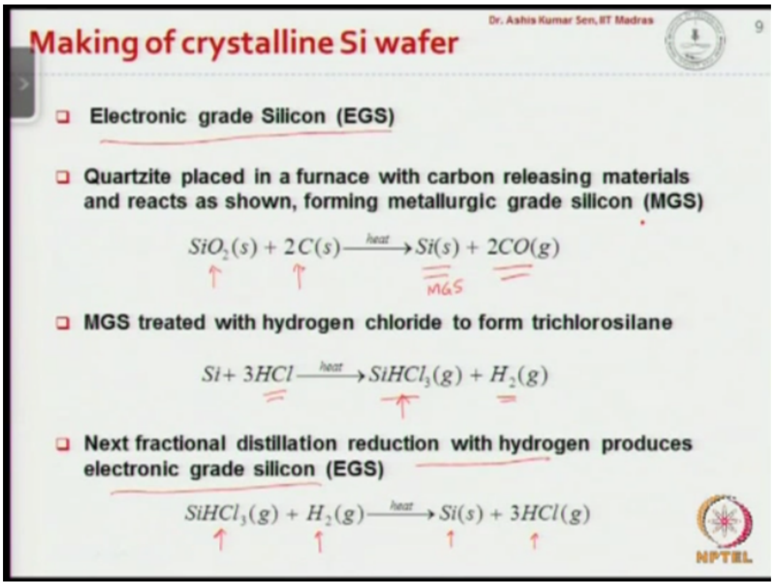

So now let us talk about how we make silicon wafers. So this is the procedure that is used to create electronic grade silicon. First we take a quartzite and place it in a furnace with a carbon releasing material and the reaction happens in presence of heat to produce what is called the metallurgic grade silicon MGS and carbon monoxide. Then this metallurgic grade silicon reacts with hydrogen chloride to produce trichlorosilane and hydrogen.

And then the distillation of this you know the trichlorosilane and when it is reduced with hydrogen it would produce the electronic grade silicon okay. So when trichlorosilane is reduced with hydrogen it would produce silicon and hydrogen chloride okay. So this is the procedure that is used to make electronic grade silicon

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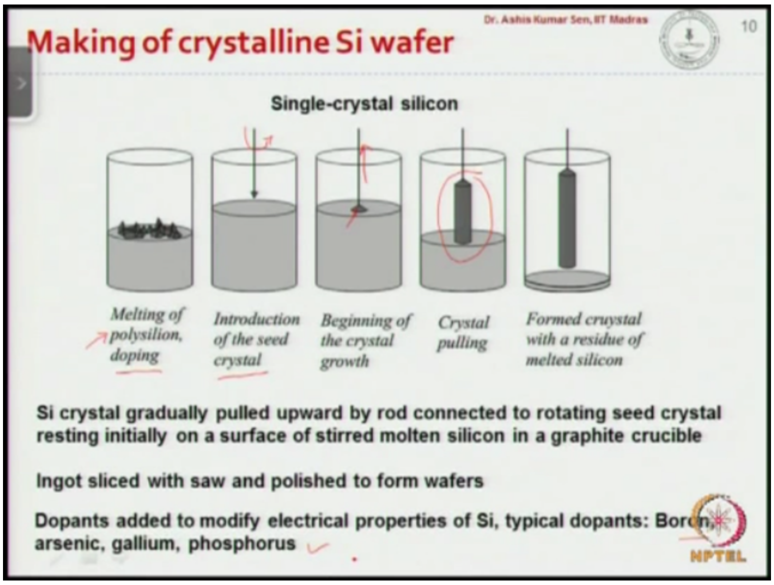

And here is the process that is used to create the single-crystal silicon so we take polysilicon and melt it in a graphite crucible and then we introduce what is called a seed layer so the seed layer will have the crystal structure of which we are going to create this silicon ingot. So this seed crystal will touch the surface of the molten polysilicon and this seed layer will be rotating okay and then this is gradually pulled upwards okay.

When it is gradually pulled upwards, the molten polysilicon will you know bound to the seed crystal and tend to grow on the seed crystal and then finally when it is pulled up we get an ingot sort of configuration and this ingot is cooled and it is sliced and polished to form the wafers okay and you may notice that here we are talking about doping okay. In fabricating silicon wafers, we use dopants to modify the electrical characteristics of silicon.

So use different kinds of dopants like boron, arsenic and gallium, phosphorus depending on how we want to control the electrical properties of silicon.

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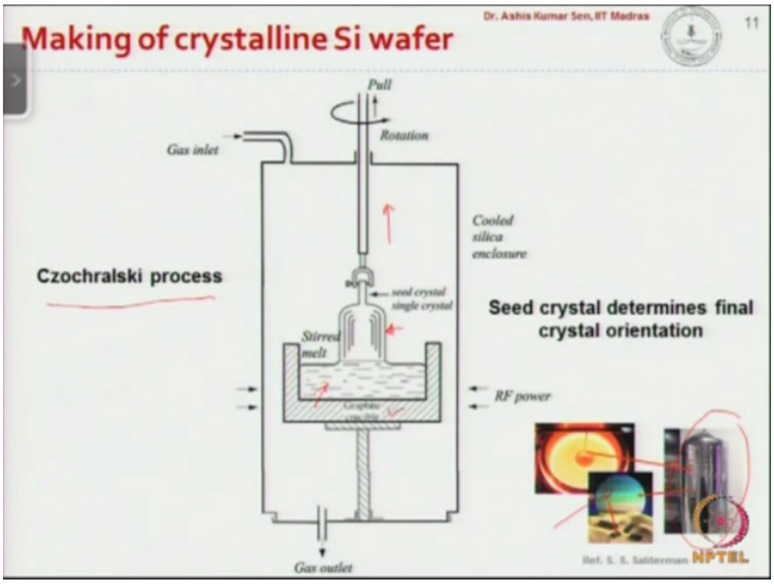

So here is the process which is used to fabricate the single-crystal silicon what we discussed in the previous slide, it is called Czochralski process. So essentially we have you know the molten metal present here okay. So this is the molten polysilicon that we talked about in a graphite crucible and here we would have the seed crystal, which will be rotating and it is gradually pulled upward.

So we would have this molten polysilicon growing on the seed crystal forming sort of an ingot okay and this ingot will be cooled which will be looking something like what we see here and that will be sliced using a wafer saw to create this silicon wafers okay.

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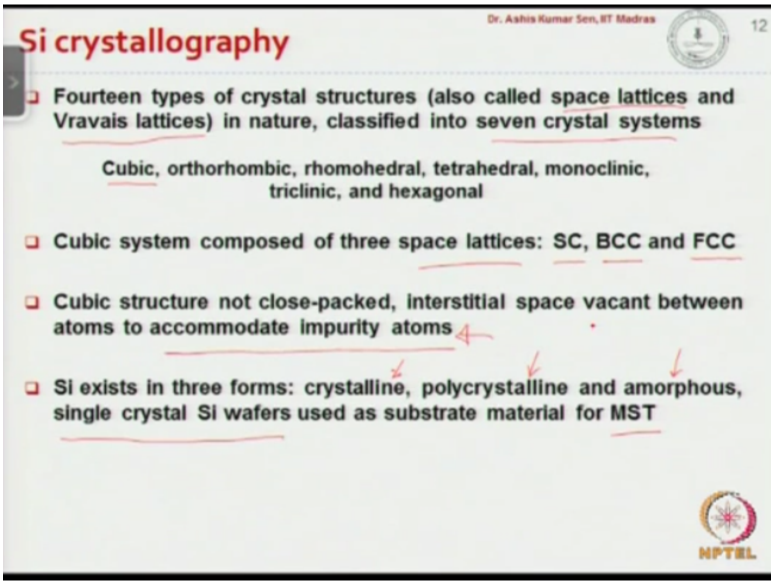

So you know if you look at silicon crystallography, there are about you know in nature we have about 14 types of crystal structures that are available and these crystal structures are known as space lattices or vravais lattices and they are classified into 7 different crystal systems. Cubic, orthorhombic, rhomohedral, tetrahedral, monoclinic, triclinic and hexagonal. So among these the cubic system is of interest to silicon okay.

And this cubic system would have composed of 3 space lattices, 1 is simple cubic SC, BCC is body centered cubic and the third one is face centered cubic and these cubic structures are not very well packed. There is always space between the atoms and that is to accommodate any impurity atoms okay. So you know the cubic structure is not very well packed, can always accommodate the impurity atoms.

And the silicon exists in 3 different forms, 1 is the crystalline, which has got a definite you know crystal structures or polycrystalline or amorphous okay and it is the single crystal silicon wafers that is used to create you know microdevices okay. So single crystal silicon wafers are used are substrate material for microdevice fabrication.

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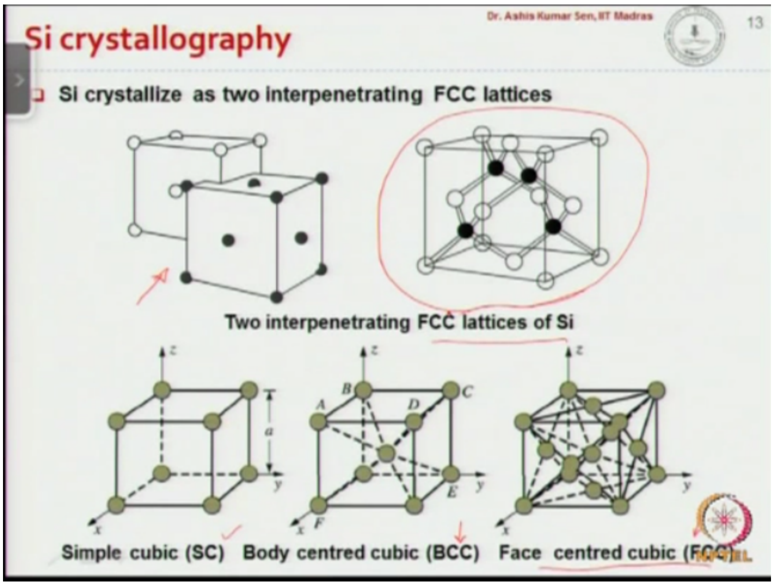

So you know if you look at the crystal of silicon, it is basically formed by 2 interpenetrating FCC lattices and here you see the 3 different lattice structures we talked about. This is the simple cubic lattice structure where we have the atoms present at the different corners of a cube and in body centered cubic we would have atoms present at the corners of a cube and additionally we have an atom at the center of the cube.

And in face centered, we would have the atoms at the corners as well as at each of the faces of the cube okay and will also have 1 at the center. Now the lattice structure of the silicon is viewed as if 2 you know interpenetrating FCC lattices. So 2 FCC lattices as penetrated into each other as you can see here okay. So in doing so this is the crystallography structures that we get for silicon okay.

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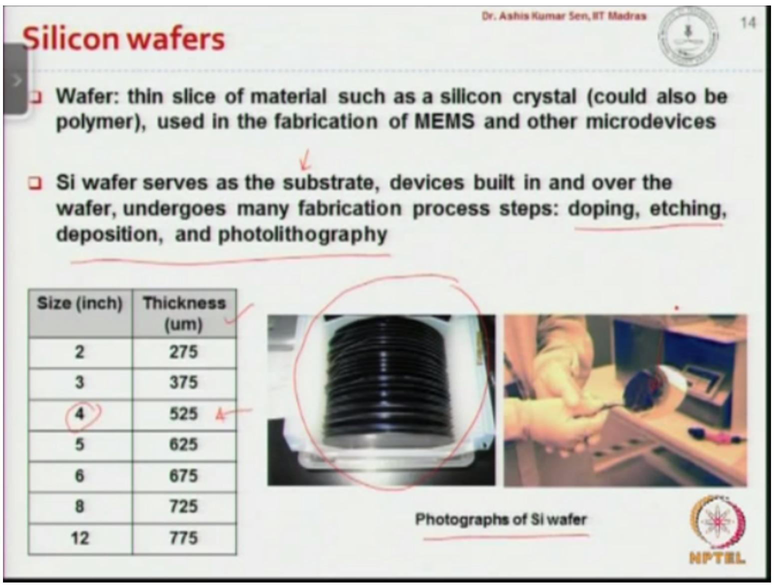

So let us talk about the silicon wafers by wafer we mean thin slice of material. So the silicon wafers are thin slices of materials of silicon crystal and we can also use you know wafers for other materials like polymers, glass and ceramics. So they are basically thin slices of materials of specific size that we use to create microdevice okay. So you know the silicon wafer serves as the substrate okay.

So the silicon wafer servers as the substrate and we build structure either over the substrate or onto the substrate depending on the fabrication process. So for example if you are onto create some electrode structures you have to create the structure on the silicon substrate. If you want to create a channel by using bulk micromachining, you will have to create the structure inside the substrate okay.

So there are different fabrication steps that the wafer goes through, for example doping, etching, deposition and photolithography. So we will look at each of these steps in detail. Talking about the size of the silicon wafers, the size may range from 2 inch to 12 inch and for each size of the wafer there is the thickness associated for example a 4-inch wafer will have a thickness of 525 microns.

So it is about 0.5 to 5 millimeter so on the right you see some photographs of silicon wafer. Here you see how the wafers has stacked in a box is known as cassette silicon cassette and here on the right hand side you see a single silicon wafer held okay.

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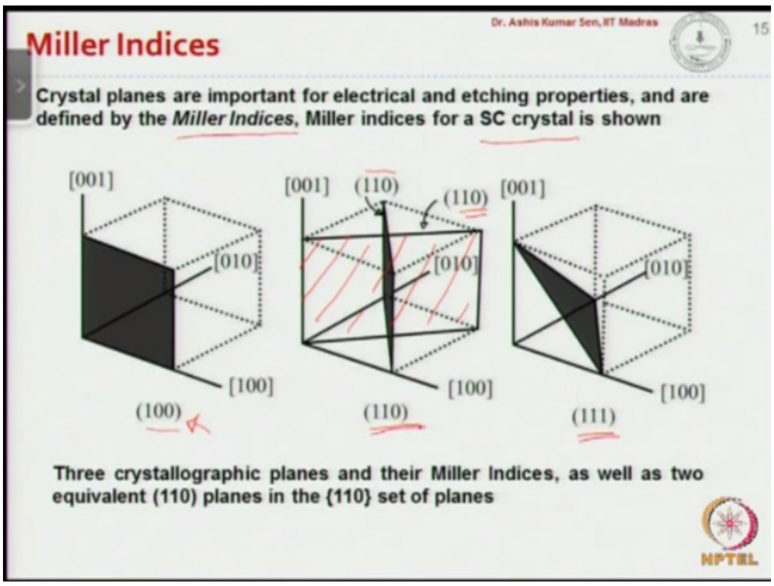

So the crystal plane is very important in you know when you talk about silicon wafer the crystal plane is very important for the electrical and etching properties okay. So the electrical and etching property of the wafer would depend on the specific crystal plane and the crystal plane is defined by what is called Miller indices okay. So the crystal planes are defined by Miller indices.

And here we see the Miller indices for a simple cubic crystal okay. We talked about simple cubic crystal and here we see the Miller indices for a simple cube structure. So this is the 100 plane okay and this is the 110 plane in fact here we have 2 110 plane. This is 1 110 and we have one more 110 plane here okay so this plane is also 110 and here we have the 111 plane. So different crystallography planes denoted by the Miller indices okay.

And here we have 2 different planes so 1 crystal may have many different specific planes for example here in this case we are talking about 2 110 planes in a simple cubic crystal.

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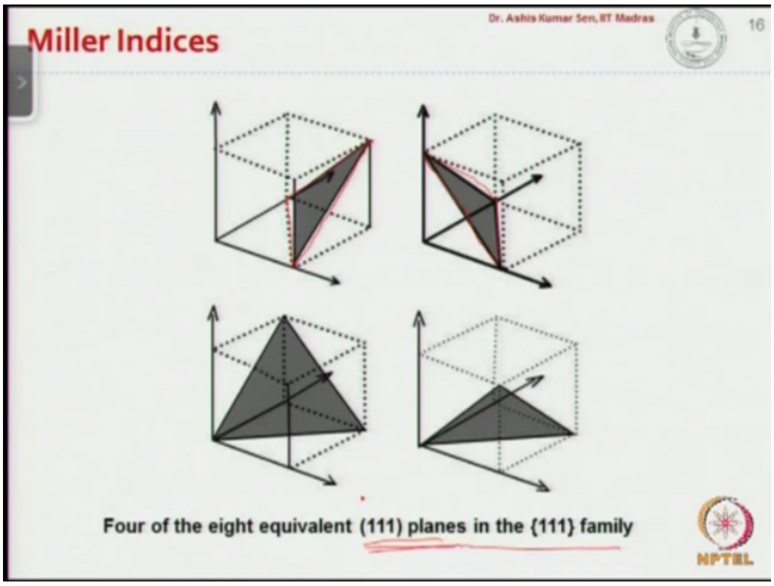

Here we see you know 4 of the 8 equivalent 111 planes, so typically there are you know 8 different 111 planes that are possible in the 111 family of planes and here are you know 4 of those shown so it is basically the plane connecting these 2 here and then connecting the third vertices here okay and similarly we can have these opposite diagonals connected and then connected to these vertices there.

So if you create planes in this manner, we would get 8 different planes, 8 different 111 planes and 4 of such planes have shown here.

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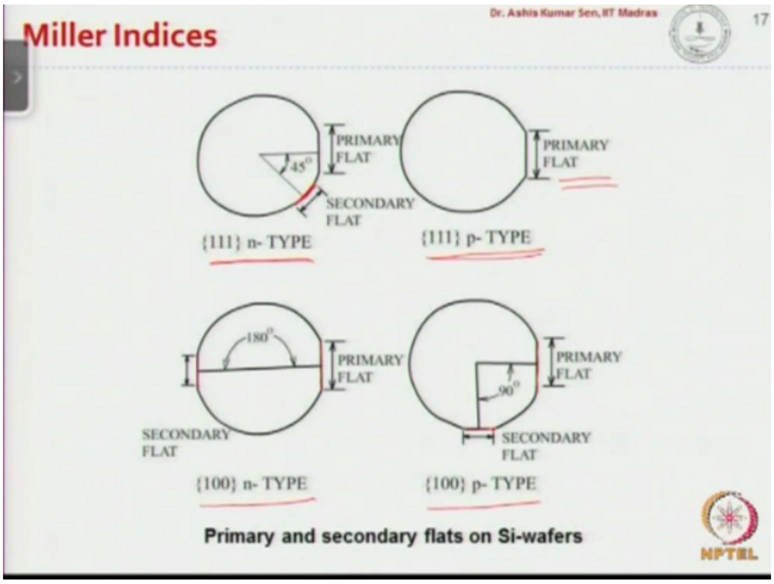

Now just by looking at a wafer, we should be able to tell what is the type of the wafer that we are talking about. Now we have here 111 n-type wafer. The n-type wafer would have a primary flat so this is 1 flat and there would be a secondary flat here okay this is another flat and the 2 flats located 45 degree to each other. So you can tell if we look at the top surface of the wafer and if we say that there are 2 different planes, which are located 45 degree to each other we can say that is a 111 n-type wafer.

Similarly, we can have 111 p-type wafer. So n and p are coming from the doping, which we will talk about in the due course. So 111 n-type and 111 p-type how do you difference it? 111 p-type will have only 1 primary flat okay. So 111 p-type will have only 1 primary flat whereas the 111 n-type will have 2 different flats at 45 degrees. Then we have 100 n-type. In 100 n-type, we would have 2 flats okay.

One primary, one secondary flat located 180 degree relative to each other okay and in 100 p-type we would also have 2 flats but they are located 90 degree to each other. So that is how just by looking at the top surface of the wafer we should be able to say what is the type of the wafer that we are talking about okay.

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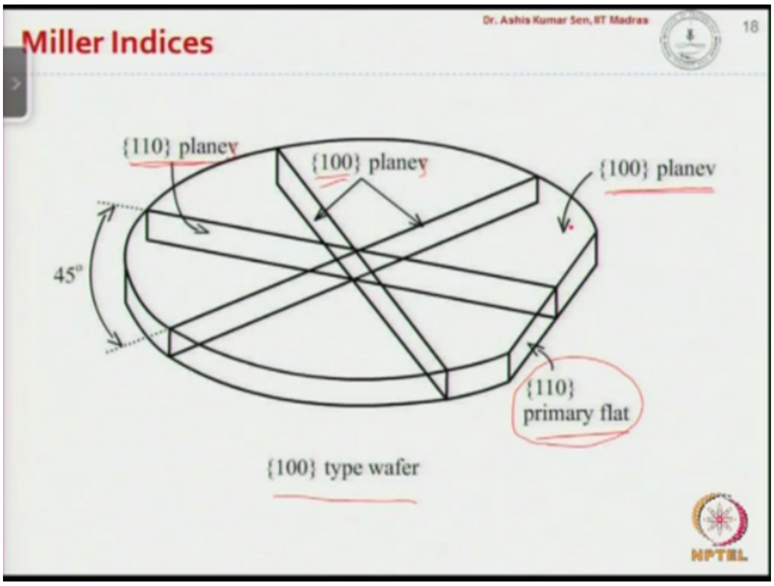

Now here we just take a 100 wafer and here we define different planes. In a 100 wafer, the primary flat is shown here. This is the 110 you know plane, this flat is 110 plane and then you know perpendicular to this plane we would have another 110 plane okay and at an angle 45 degree to 110 plane, we would have 2 100 planes okay so these are planes. So perpendicular at an angle 45 degree to 110 planes we will have 2 100 planes.

So these 2 planes are at 45 degree to 100 planes and then we would have another one on the surface of the wafer, which is of course the 100 plane, which is perpendicular to this flat okay this flat plane. So that is the reason why it is called 100 wafer because the top surface is 100 plane.

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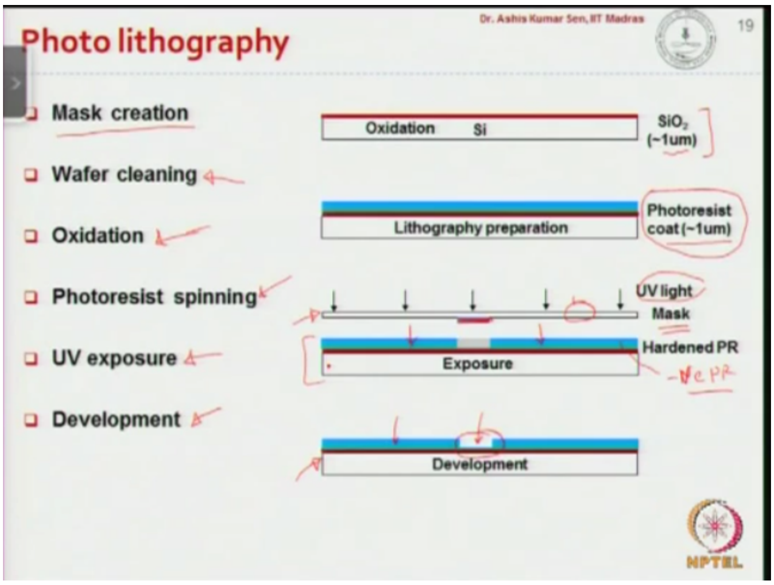

So with that let us move on and talk about the basics of photolithography okay. So photolithography is a process that is used to you know fabricate microdevices using the characteristics of light okay. So in this case we use light waves like UV light to selectively cure part of the structure while etching the others to create a specific pattern okay and the pattern comes from the mask that we will be talking about.

So according to the structure of the pattern, we would create a mask and expose the light through the mask to create the pattern of the structure. So the first step is the creation of the mask, which as I said would depend on the structure that we want to fabricate and you know for example if you want to create a channel like structure as you can see here depending on the photoresist that you are going to use you may have a mask, which would look like this.

So these areas may be opaque to light okay so if you know what the etch structure that we are going to obtain accordingly we can design our mask. Then the first step it starts with is wafer cleaning where we try to you know clean the wafer, make sure that it is free from dirt, dust any organic deposits and it is perfectly clean so that the photoresist adheres perfectly well to the surface okay.

So we start with wafer cleaning in fact before we go to spinning photoresist we do oxidation where you grow a layer of oxide on the silicon wafer and oxidation is done many times to you know electrically insulate different metallic layers on the surface of the wafer from silicon okay.

Silicon is semiconducting so if you want to create an electrode pattern for example on the surface of the wafer, we would use a silicon dioxide layer so that these electrodes are not short circuited okay and in some cases we use silicon dioxide as a adhesion layer between the substrate and the photoresist. So photoresist will stick much better to the silicon dioxide layer as compared to the bare silicon okay.

So that is why we need to oxidize the wafer and we will talk about how oxidation is done and once we oxidize the wafer, the next step is to do the photoresist spinning okay. So this is where we grow a layer of oxide on the silicon wafer. So typically less than 1 micron and then we coat a layer of photoresist okay, which is sensitive to light okay. So depending on the depth of the structure, we would control the thickness of the photoresist.

And after the spinning of the photoresist then we will go for exposure of UV light okay and we do expose the UV light through a mask depending on the pattern that we are going to create. So let us say here in this case, this is a negative photoresist okay, it is a negative photoresist so if it is a negative photoresist, all the exposed areas so these areas of the mask are transparent to UV lights.

So these areas of the photoresist get exposed to UV light, they cross linked with each other, they become hard and they do not you know develop when we go through the development process. So here we expose through the mask and then we go for development. So in development depending on the exposure process considering that is negative, the exposed areas will retain when they go through the development process.

And on exposed areas will clean away when we put this wafer in a developer solution okay.

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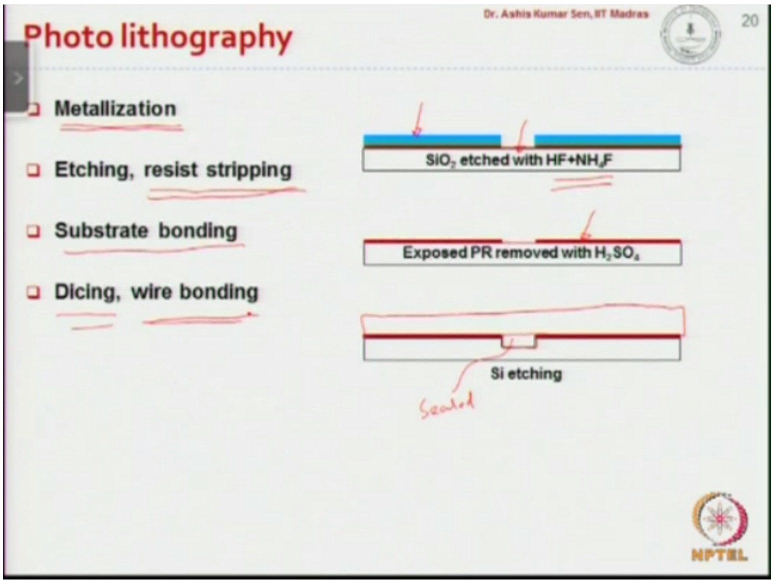

The next after we develop the photoresist layer then we may have to many times create electrode structures okay so we go for metallization so around those areas which are you know where the photoresist is removed we can create metal structure on the silicon dioxide okay and in some cases you know after the development step, we go for etching okay.

So in this case for example after the photoresist is developed, we are etching the silicon dioxide layer okay, so silicon dioxide is typically etched in hydrofluoric acid and combination of hydrofluoric and ammonium chloride. So after the silicon dioxide etching what we go for is resist stripping okay. So this photoresist is used as basically a mask layer in this case to etch silicon dioxide.

And once the silicon dioxide is etched, we remove the photoresist because it is not needed anymore okay. So the photoresist layer is stripped off and then here in this particular case, this silicon dioxide which is patterned because you have waste silicon dioxide around here is acting as a mask for etching the silicon okay. So silicon dioxide is etching acting as a mask to etch silicon.

So here silicon is you know etched using bulk micromachining okay. So once let us we have a create an open channel like this and then we want to use it for microfluidic application so you would have to bond this with another planar wafer. So you take another planar wafer on the top and bond it with this wafer so that we get a seal channel okay. So this is done by substrate bonding.

And then we go for dicing and wire bonding okay. So typically on a single silicon wafer, we create many such microdevices and once this microdevices are all identical but because to utilize the space available on the surface of the substrate we use many of these devices on a single wafer and then to separate this individual devices, we go for wafer dicing okay. So we dice the wafers.

And in some cases, we need to establish electrical contact between the external supply and the electrode on a specific device okay. For example, if you have a microfluidic device which also integrates an electrode you have to make electrical contact between a particular location of the electrode with an external point, you can do that using what is called wire bonding okay so you would use wire bonding to do that.

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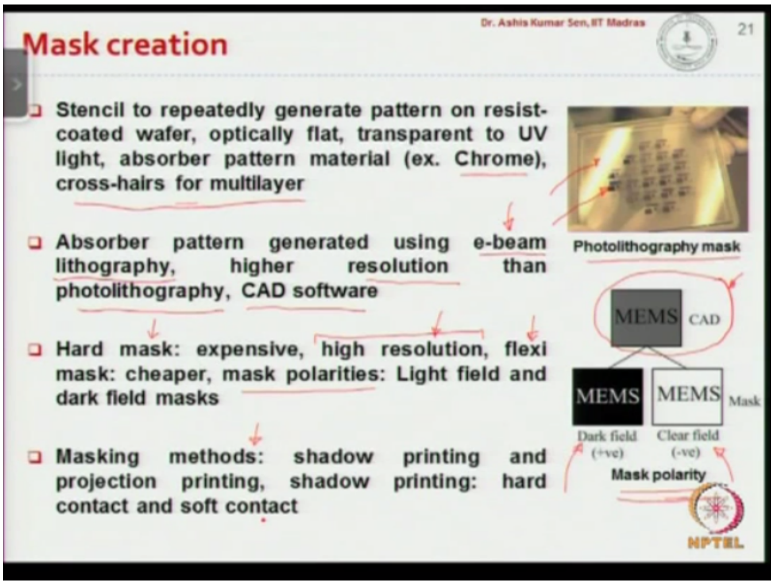

Now let us look at the first step of fabrication, which is called the mask creation. So typically a mask looks like this. This is a photolithography mask. It will have pattern depending on the structure that you are going to create, so the patterned areas all those black areas that you see here are the opaque to light, they do not allow light in those areas of the mask okay. So mask is nothing but it is a stencil to repeatedly create pattern on a resist coated wafers.

And these masks are optically flat because they have to be you know put together with the surface of the substrate which is flat and you know the material that we use to generate this mask is typically optically transparent. So they can be transparent to UV light and the dark areas that are opaque to light can be created using different materials. For example, chrome is one material that is typically used to create these opaque structures, patterns on the mask.

And when we design a mask, another important thing is to have the alignment marks what we call it as cross–hairs okay. So when we do multilayer photolithography for example we do patterning of a one layer and again we go for you know putting the photoresist and you know exposing the UV light. Then we would have to make sure that the second layer is registered properly with respect to the first layer.

So you would need to align the mask okay and for the mask alignment we need to have this alignment marks or the cross-hairs. So this is an important feature of the mask design. Now to create these opaque patterns or the observer patterns, we use what is called e-beam lithography okay.

So we use the mask for photolithography, but to create the structure or the pattern that is used in photolithography we used a more sophisticated technique called e-beam lithography, which has got higher resolution than the photolithography okay and this is ensured because we would have the design of the mask so using a CAD software it can be converted and we can ask the e-beam writer to write mask on a specific material.

Mask can be categorized as hard mask okay or soft mask. Hard mask is expensive okay because we use a material like quads or glass to create these hard mask and the resolution of the hard mask is typically you know much better as compared to the flexi mask okay and we use e-beam lithography to write this high resolution mask. Flexi mask on the other hand are cheaper.

They can be simply printed on a transparent sheet and the resolution is typically poorer as compared to the hard mask. Now let us talk about mask polarities. The mask polarities can be either light field or dark field. Here is one example of what you mean by mask polarity. Let say our CAD software is giving this sketch here, so we are going to write the word MEMS on some kind of pattern on silicon wafer.

So we create this CAD design where MEMS is written. If we ask you know we define the dark field mask okay if we tell the vendor who is printing the mask for example to create a dark field mask, so this is the mask that we will be getting okay. So the later patterned areas here in this case in the dark field case is transparent to light. On the other hand, if you ask for a clear field mask, this is what we get.

The patterned areas become opaque to light, so this is very important to understand when we design a mask and you know we ask a vendor to print this mask, it is very important to mention whether we are going to print it as dark field or we are going to print it as clear field okay.

Now the masking methods you know once we have the mask and while we are doing the UV exposure, the different techniques that are available, 1 is the shadow printing and the second one is the projection printing. In shadow printing, the mask is relatively closed to the surface of the substrate and in projection printing the mask is little bit far away from the surface of the substrate okay.

And in projection printing, we would have an optical system between the mask and the substrate so that the resolution can be further improved by adjusting the numerical aperture of the optics okay.

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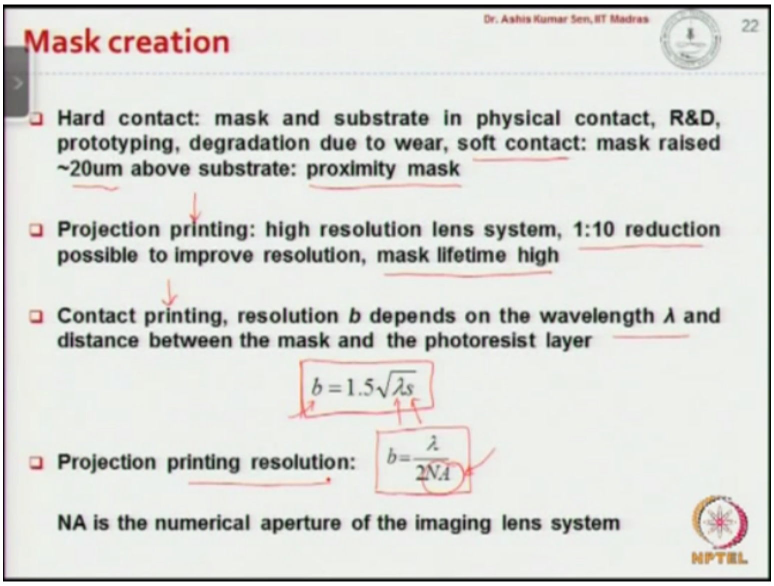

Again the hard contact mask, so in hard contact the mask and the substrate are in physical contact okay. So actually we are putting the mask in physical contact with the substrate and this is typically used in R&D or in academic environments where the variability of the mask is not a concern because it is coming in contact with the photoresist. Over a period of time there would be scratches and you know wires would be developing on the surface of the mask.

And in hard contact there will be physical contact, in soft contact the mask will be actually you know lifted about 20 micron above the substrate and this is also known as proximity mask. So the mask is not actually in physical contact but there is a gap between the mask and the surface. In projection printing, we are using a high resolution optic system typically 1:10 deduction is possible to improve the resolution.

For example, if you want to create a feature which is one micron in size on the substrate, we can create a mask that has a line width of about 10 micron and still we will be able to do that using the lens system that will provide 1:10 deduction okay. So 10 micron on the mask will appear as 1 micron on the feature okay and in this case since we are not talking about physical contact between the mask and the substrate, the lifetime of the mask will be very good.

So let us look at the resolution of the contact printing. In contact printing where you know either we talk about hard contact or soft contact, the resolution b would depend on the wavelength lambda okay and the distance between the mask and the photoresist layer. Always even if in hard contact, there will always be a gap between the mask and the photoresist layer.

So that would also affect the resolution in addition to the wavelength okay. So this is the formula that we can use to find out the resolution of the pattern if you know the wavelength and the gap between the mask and the substrate okay. So what do we see here is the resolution is highly dependent on lambda okay and it is difficult to go for a feature which is considerably less than the wavelength.

However, in projection printing the resolution can be decided or controlled by adjusting the numerical aperture of the lens system so b will be=to lambda/2*numerical aperture. So we can control the numerical aperture of the lens system to control the resolution of printing in case of projection printing.

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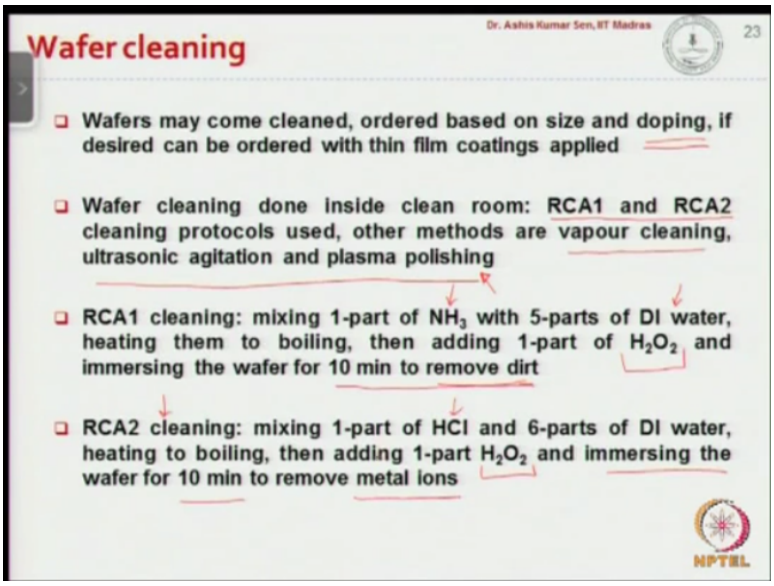

You know once we fabricate the mask, the first step would be once we fabricate the mask and we have the wafer ready, the first step would be to clean the wafer and the some of the wafers that we can order from manufactures they already come clean and we can order you know depending on the size of the wafer that you want and also in some cases if you are interested in the electrical properties we can also control the doping of the substrate that we order.

And many times, we can also you know go for wafers which have already thin film of coating, for example on a silicon wafer if you are going to have a oxidation layer then already we can ask for a specific wafer with some thickness of oxide layer on it okay. So in any case, we have to clean the wafer, typically the different procedures available to clean wafers. RCA1 and RCA2 cleaning protocols are widely used.

And although there are other methods like wafer cleaning, ultrasonic agitation and plasma polishing which is a dry cleaning procedure. So RCA1 and RCA2 are widely used you know for cleaning wafers. In RCA1, we would be mixing 1 part of ammonia with 5 parts of DI water and heat them to boiling temperature and then we add 1 part of hydrogen peroxide and then immerse the wafer for 10 minutes okay.

And that procedure the RCA1 cleaning procedure will remove the dirt from the wafer. Then we go for RCA2 cleaning procedure where we mix 1 part of HCL with 6 parts of DI water and then heat them to boiling and then add 1 part of hydrogen peroxide. So here we are using ammonia, here we are using hydrogen chloride and then immerse the wafer for 10 minutes to remove the metal ions okay.

So the purpose of RCA cleaning 1 is to remove the dirt and the purpose of RCA2 cleaning is to remove the metal ions.

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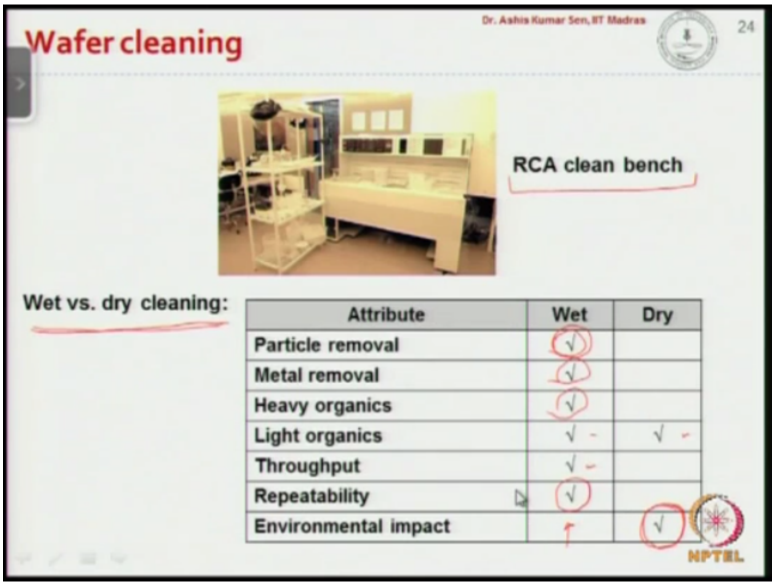

So this is a typical you know clean bench that is used for RCA cleaning and here we contrast wet and dry cleaning okay. So the different attributes for example for particle removal wet cleaning will be better. So here we contrast wet versus dry cleaning and there are different attributes, for particle removal we will go for wet cleaning, for metal removal also wet cleaning is preferred.

For heavy organics, wet cleaning is preferred. For light organics, we can either use wet cleaning or dry cleaning. The throughput of the wet cleaning is much higher as compared to dry cleaning and the repeatability of the wet cleaning is also better. The only down side of the wet cleaning since we are using you now the chemicals that are not environmental friendly. The dry cleaning has very good environmental impact okay.

It is not hazardous to the environment whereas the wet etching is hazardous to environment. So with that let us stop here. We will continue our discussion on microfabrication later.