Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology- Part-2

Module-05
Photolithography

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Welcome to this manufacturing process technology part 2.

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Module five we were talking about photolithography and in context of that I would like to mention that there are two different kind of lithography is that we have discussed one is with you know with respect.

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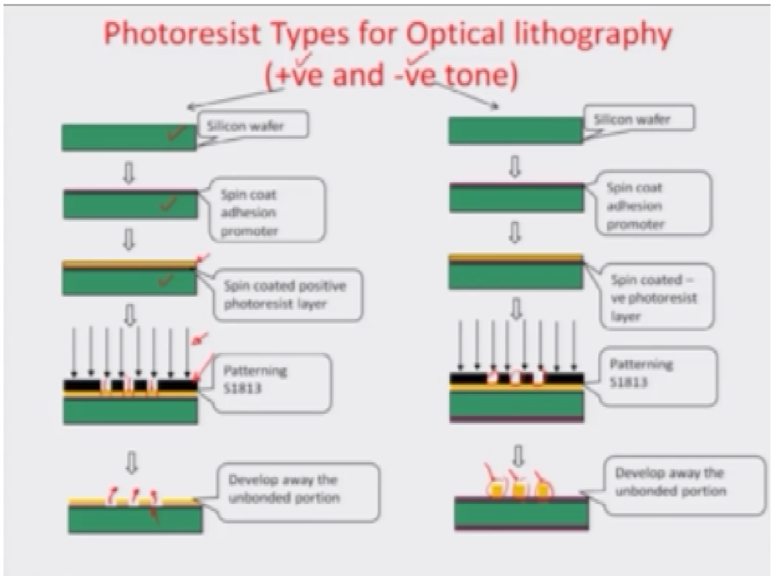

To optical lithography with respect to a positive tone resist and another with respect to a negative tone resist as we have already discussed in a positive tone resist case wherever there is exposure the material gets d bonded and it goes away, so you can see here for example this is a silicon wafer coated with some kind of adhesion promoter layer then you have a you know spin coated photo resist which is actually visible by this yellow layer there is a mask here so this back layer where there are selective exposure at places which have open windows to the light beam which is falling on the top of this mask.

As a result of which there are some chemical changes induced in the zone where light is falling for example in these particular zones and because of that after the dissolution process the dissolve developing process the unbounded resists which actually happens because of the exposure of the light to these open regions it goes way okay, so that is this goes away here and that gives you a sort of a you know sacrificial layer which can be further worked upon for etching etc.

Through the small windows that have been developed in the resist the same you know process goes, on for a negative tone with the only difference that in the negative tone there is a cross bonding effect, so wherever there is exposure in these particular regions as you can see there is a stays back because the resist actually crossbones the remaining areas are dissolved away through a developing solution or developer solution and so these are structures or features which are made because of cross bonding due to exposure, so this is how optical lithography is characterized and in fact if we look at resolution related to optical.

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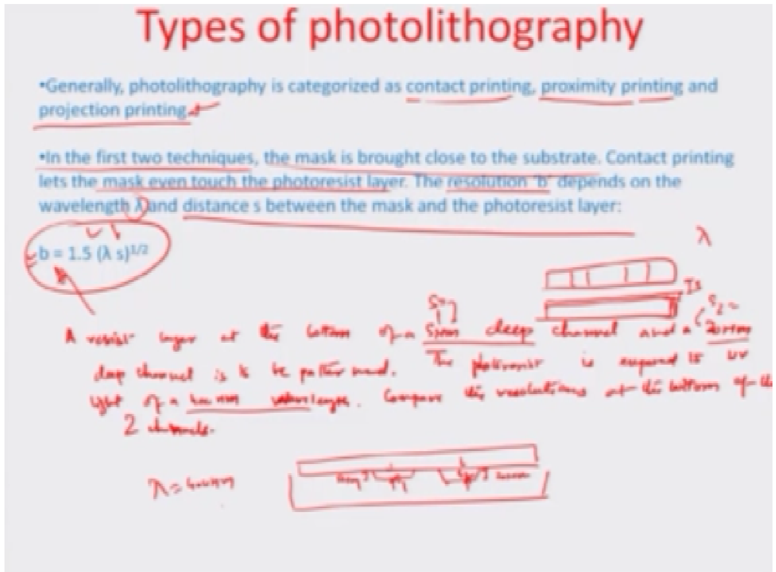

Lithography you can have three different kind of printing processes as I said one is contact lithography or contact printing another is proximity printing or lithography, where there is a small gap between the mask and the wafer and then finally the projection printing or projection lithography wear the mask is quite far away from the wafer, and there is a lot of gap in between so in the first two techniques the mask is brought close to the substrate okay and contact printing let us the mask even touch the photo resist layer the resolution be depends on the wavelength λ.

Through the formulation be equal to 1.5 λ s to the power of half where s is the distance between the mask and the resist layer, so if there is a mask somewhere here and there is some distance X you know of the resist layer with respect to the mask layer and there is a wavelength of light λ that has been used in the resolution which is basically the minimum distance over two differently spaced objects can be visible completely without interfering into the into each other is domain is given by 1.5 $\lambda s^{1/2}$ let us look at how this influences the decision making process for developing a mask.

So let us say a resist layer let us have a practical example problem that resist layer at the bottom of a 5 microns deep channel and the 20 micro meter deep channel is to be patterned the photo resist is exposed to UV light of a 400 nanometer wavelength, so we want to compare the resolutions at the bottom of the two cases of the two channel, so let us look at the problem of how we develop you know the resolution in both the cases so in one case as you have seen in the problem statement.

The S is basically 5 microns because it is a deep channel meaning thereby let us say there is a wafer and you made a channel in this wafer in one case this depth is 5 microns another case this depth is about 20 microns, so the mask layer is always going to sit at the top and this difference between the mask layer and the depth of the channel is what the S distance is so in one case s 1 is 5 microns another it is 20 microns and.

So obviously the resolution has to change because if I look back at the resolution formula here be equal to 1.5 λ $s^{1/2}$ the s factor here is changing between 5 and 20 microns, so the wavelength λ has been given as 400 nanometers and we typically want to compare.

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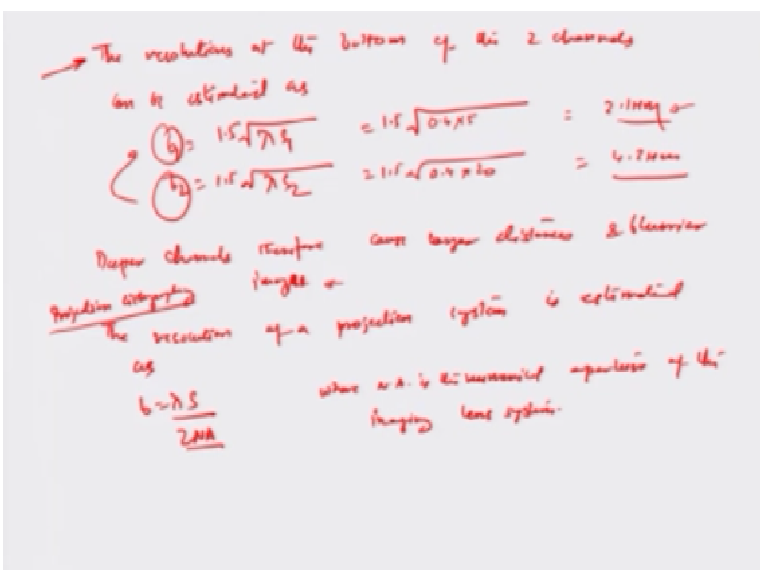

So the resolutions at the bottom of the two channels can be estimated as B 1 = 1.5 √ λs 1 in this case 1.5 times of 0.4 times of 5 microns, so 2.5 2.1 micron and b2 is λs 2 which is 1.5 0.5 20 which is about 4.2 microns, so the resolution as you see is obviously more with the lesser value of B meaning there by two objects closely spaced can be resolved if they are spaced by a distance of minimum of two point one micron in the case the depth is about 5 micron and this increases to 4.2 microns as the death changes to 20 microns.

So deeper channels therefore cause larger distances and Gloria images so it is obvious that you know you will have to plan the depth of the channel in a manner, so that it does not go to an extent of messing up with the minimum feature size which is planned in the layout for the mask so you have to be very careful on planning that aspect of the mask while designing or in this design stage, so the resolution of the projection system for example so this is actually more related to contact or proximity lithography when we talk about a projection.

Lithography this is something where the you know the mask is placed far away from the wafer and in fact one of the reasons, why projection is used is so widely in the industry is that with every contact between the mask and the resist layer which is nothing but a soft polymer there is always going to be clearing away of the resist layer, so in this particular case we are more concerned with a high throughput system where such steering action should not happen and therefore if the mask is kept away.

Which is true in case of proximity or for example in case of projection lithography it is easier to handle without any substantial damage to the photo resist layer, you know coated on to the to the surface so the resolution of a projection lithography of a projection system is estimated as b = λ as π twice NA where NA is the numerical aperture of the imaging lens system, so that is how we define the resolution aspect of lithography.

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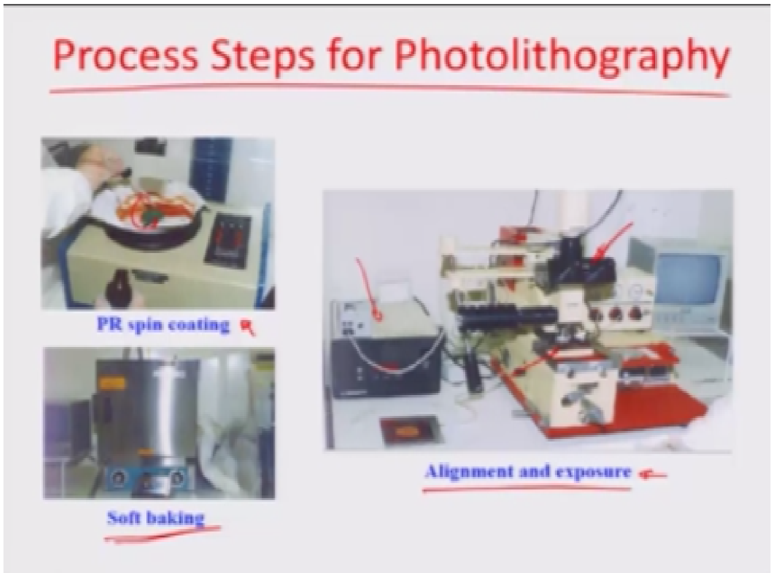

Let us look at some of the process steps involved in the lithography, so this is actually a real laboratory setup where you doing photo resist coating or spinning on the wafer so typically this is a spinner which actually vacuum sucks the wafer as you can see at the center here and rotates the wafer at a certain rpm while dispensing the resistor on the , so that is just actually goes along and formulates a flat layer over this particular wafer you have a soft breaking state where the resist which has been applied to the surface of the wafer is now being heat treated and the solvent is evaporated.

So that you have a harder layer of resist more amenable to lithography because you have to remember that the mask has to be a line with respect to this hard layer and there should not be any tackiness on the surface then there is alignment and exposure which means that you have a mask which is being now laid out exactly over the resist coated surface with almost zero distance in contact lithography which you could actually see through a microscope right here by positioning the mask and moving the wafer in the z-axis.

Towards the mask so that you know you could see the wafer very closely and obviously the z-axis is driven by a system where after a contact is established between the wafer and the mask the system does not anymore you know the there is no other Z movement at that particular so there is a sort of a decoupling of the locking mechanism and you know through a pressure between the mask and the wafer the idea is to not break the wafer so that is why that is a very needed step there are there is a controller here which controls the exposure time and that is in fact a shutter based exposure which happens in this case after the alignment and exposure.

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After the alignment which is performed in this manner there is a mask loading step you can see the wafer sitting right here the mask which is actually here goes and sits on the top then there is alignment between the mask and the wafer after the wafer has been loaded okay so this is the Chuck I am sorry this is the chuck and this is the wafer and then you have the exposure.

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So you have now completed the exposure step you have a development process here were through development you can actually have via and cavities of the pattern coming off in the resist surface use that as a H window and further etch the wafer surface so that you could have features imprinted.

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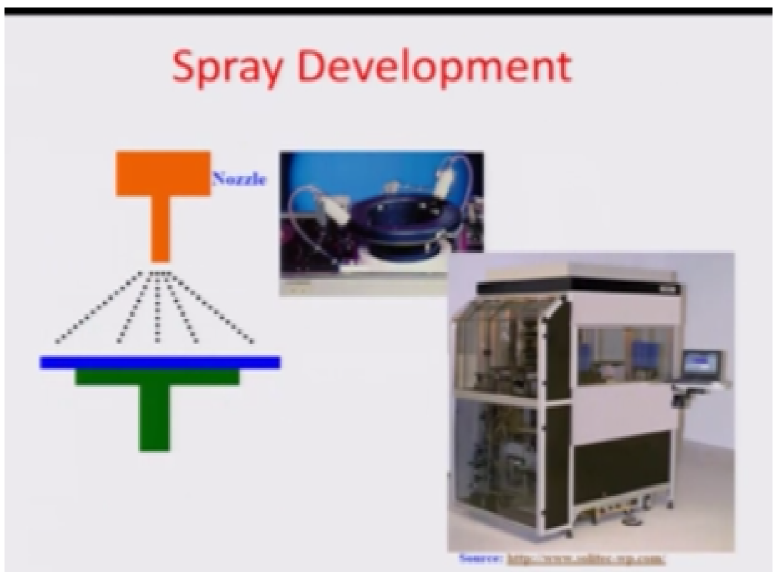

On different regions on a high-throughput machine you know you can do the same by spraying developer solution and by having multiple wafer stacked up and sort of you know doing this process in a automated manner more on a projection lithography more on projection lithography principles.

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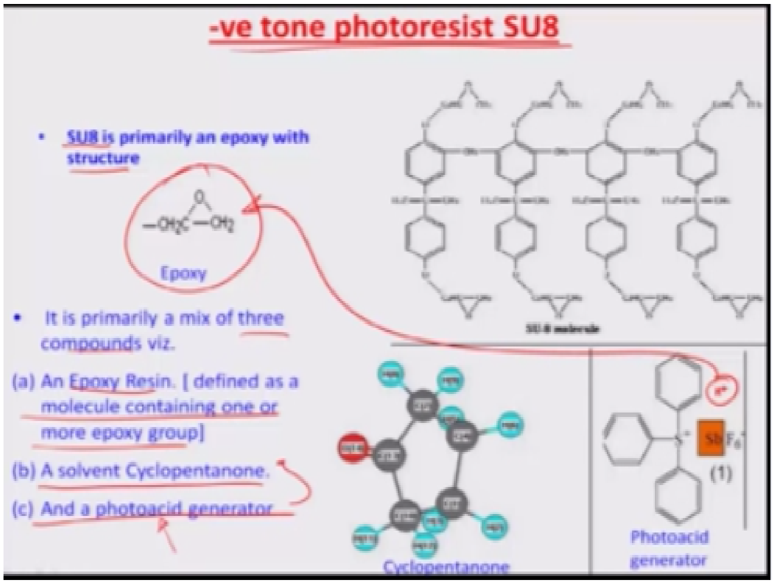

And let us look at the basic theory behind the photo resist and this is about su8 which is actually a negative tone photo resist so you have a epoxy like structure of the resist and it primarily composes comprises of three different compounds one is the epoxy resin defined as a molecule containing one or more epoxy groups a solvent which is used for mostly carrying the epoxy resin throughout the coated surface there is something which needs to provide the fluidity so that there is a overall coverage of the resistor on the surface.

And then there is a photo acid generator which is mixed into this epoxy resin and the cycloid pentane on the solvent so once this coating is done you know the photo acid generator can be photo exposed to furnish positive hydrogen ions of protons and the protons can play around with this epoxy ring right here by opening it so that you could actually have a cross bonding structure.

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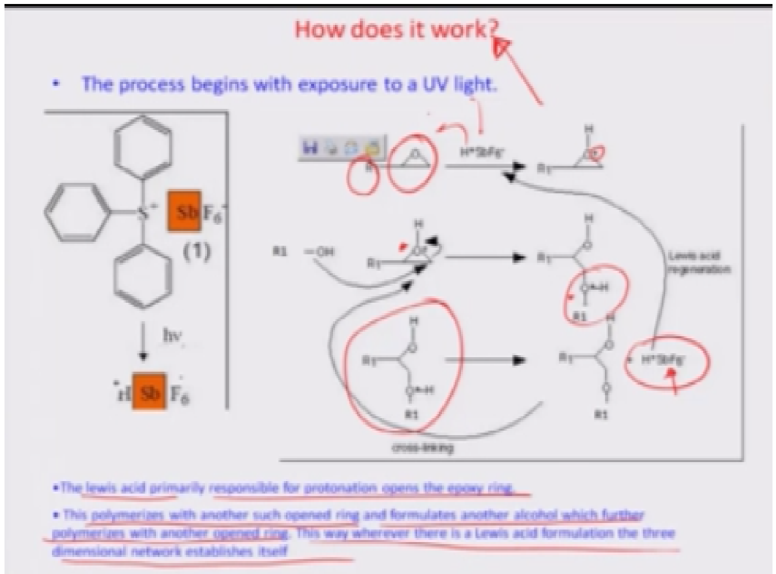

So let us look at what happens here for example this is an epoxy ring with a R-group there is a proton there is a protonation which is happening because of exposure to the UV light of this acid photo acid generator it is a weak acid is a Lewis acid and so this proton is responsible now for opening this epoxy ring so that it cross bonds with another such open ring together okay and proton comes off at the end of the day.

So there are series of these reactions where there is a dangling bond created here a dangling bond created somewhere here and across bonding between the two the proton actually comes off again and this cross spotting effect is exercised wherever there is an exposure to the light and there is a throw of the H+ or the proton you know from the photo acid generator, so the processes involved Lewis acid which primarily is responsible for protonation and opening of the epoxy ring this polymerizes with another such open ring formulates another alcohol which further polymerizes another open ring.

And this way there is a Lewis acid formulation of the three dimensional network which establishes itself so that is how the photolithography process really works.

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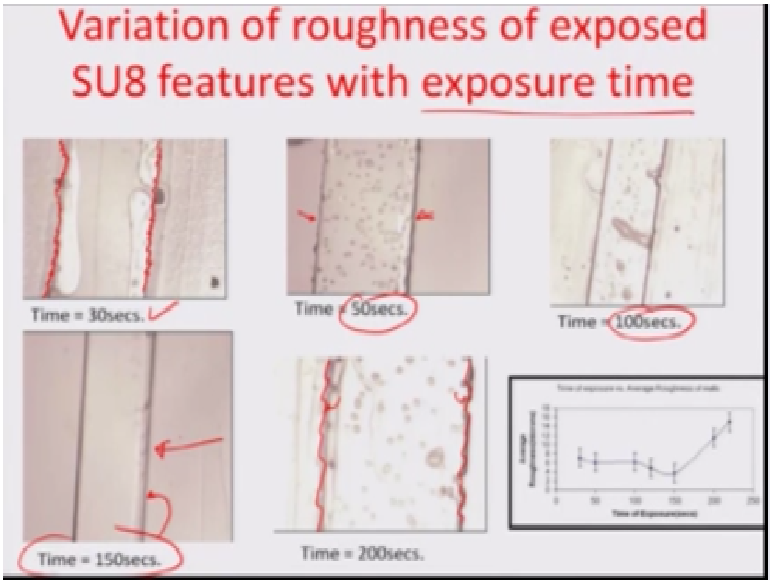

And you know it is a very important issue to do a time balancing of the development step for an sorry the exposure step for example if the exposure time for 30 seconds you could see these portions eat in a way and a rough surface meaning thereby not enough time has been given for the protons to diffuse out into the region where it is supposed to be must increase it will be better the edge is little sharper again you know even sharper and then probably the best edges come off here beyond which you can see that.

Because the exposure time is more now the protons are diffusing out of the region which have been exposed and there is always a rough edge because of this so there is a recipe making which is involved in this photolithography process almost always wear all these parameters including the exposure time the development time etcetera and even the way you are heating is to be looked into in great details and many experiments done to give you a good resolution of the printing process.

And these are now standardized and you know the fabs which are there for doing all this lithography driven work has very standard protocol where you will have a high quality maintained within a controlled environment because of the repeatability of the chemicals used and the environment and the heating which is being applied as stimulus to structure these resist materials, so that is how you do you know negative tone photo resists and lithography what is the next step basically which is actually about the etching process.

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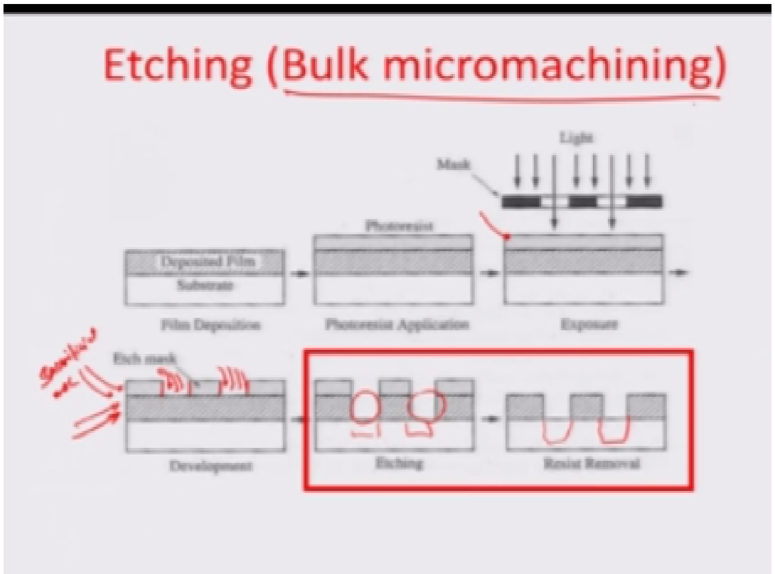

So supposing we have developed a photo resist layer and a mask which is a sacrificial mask or H mask as you can say over this layer which is actually hatched you know and it is probably something which is to be attacked by a chemical or an acid so the sacrificial layer merely provides windows or regions across which such exposure can happen selectively so the etchant can Rush in through these windows.

And then can affect the hatch to layer and you can see the hatch layer go away here so that you are opening this hatched layer for further etching on this particular surface so the idea is that you have a material which is acting as a hard mask material which is the soft mask that you have made for a chain and through the soft mask you are imprinting onto the hard mask and using the hard mask for doing further high aspect ratio etches into the final structure.

So that is how you do bulk micromachining I think I had mentioned this at the very beginning of the alternate processes or the advanced processes that we were teaching that how bulk micromachining is a subtractive process.

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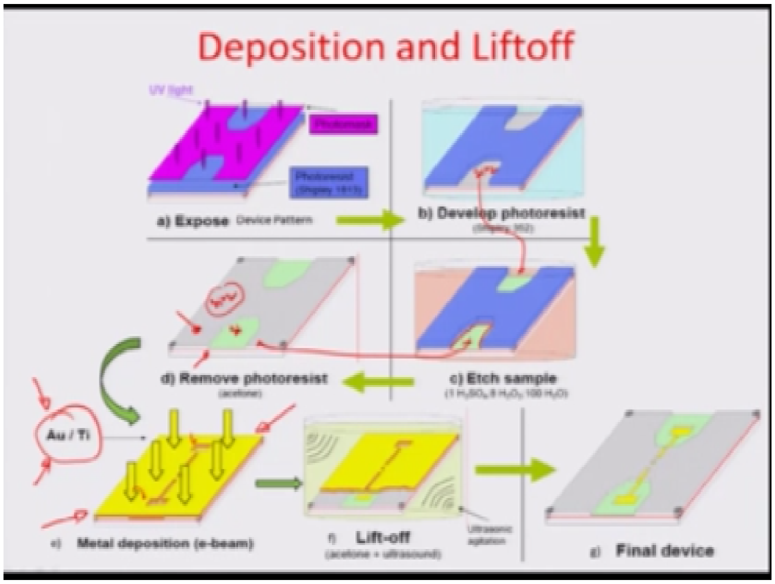

So typically you can also do deposition and left off so that you have thin features in one case as you saw here because of the masking and the photo resist there is actually a removal of this gray region which is the sacrificial mask you know the hard mask and you expose the green region with it so you have this green you know region which is being sort of selectively etched out because of the sacrificial or the or the hard mask which has been printed on the top of this could be a combination of for example ψ O2 and a ψ.

With the right combination of etch and as I said illustrated earlier you etch the sio2 create this window and then start etching the ψ with another asset okay so you can actually have this kind of a structure and from here to here as you Sio2 has been etched from here to here as you see the SI has been etched after removing of the photo resist etc, I can use this for a different alternate protocol where I can again make a sputtered film sorry again make a photo lithographic film or a resist film on the top with another set of lithography.

Where it removes these regions typically and then deposit metal which can be deposited by a variety of ways means which will cover in a little bit later topic one of them is called thermal evaporation another is called sputtering now so there is a deposition of a metal vapor typically whether it is in plasma form or it's in passive form on the top of a wafer so you are depositing this gold titanium layer on the top.

And because of which you know there are certain selected regions which are the cavities are shown here which is having the deposits of these gold titanium and then you remove this layer away so that you know the golden titanium has adhering capability to this green SI substrate later on so they adhere the gold and titanium in this region and this is how you do printed electronics so you could actually use this mask the sacrificial resist mask for actually printing this kind of structures on the surface of the silicon wafer.

This is actually your final device, so with this photo lithography and a combinatorial of various processes like in one case you saw the etching process how he combined with the lithography another case you saw the deposition process again which combined with the lithography and then the liftoff process you are able to generate various micro machine features of micros machine the structures by assembling these processes together.

So these are one of the most advanced sort of first generation advanced micro electronics processes through which you could achieve structuring or featuring at the micron scale, what I am now going to look into is another little different aspect which is about polymers and there is a huge initiative nowadays about how to work with advanced machining processes on polymers or how to actually make you know the micro structuring on polymer surfaces.

And for that we would like to look into this small sub topic of polymer micro electromechanical systems.

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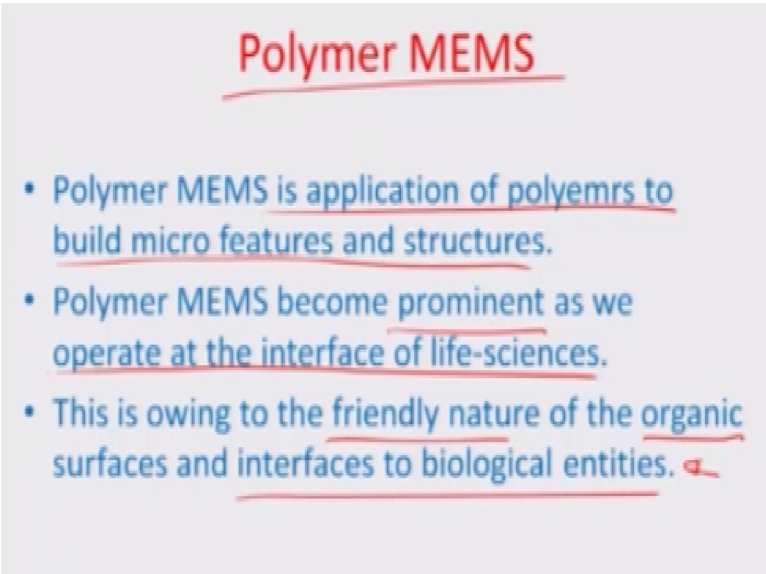

Or polymer MEMS and micro structural so polymer MEMS is basically the application of polymers to build micro features and structures and basically it is become very prominent more because you know you operate these devices mostly nowadays at the interface of life sciences and all these living cells or all these biological systems which are living they tend to be very happy in sort of you know sort of an organic environment.

And silicon by itself has to be modified quite a bit and its surface to accommodate living forms you know we should be able to give signals and you know MEMS devices could eventually be used to record the signals which is the basic application to understand biology of things which are happening at a very small scale so therefore the induction of polymers automatically comes in because of this issue about compatibility of the biological systems.

And so basically it is gives a friendly nature to the interfaces of the biological entities and that is why organic you know surfaces of polymers are quite preferred.

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So if we look into how you know the choosing criteria's would be defined so obviously biocompatibility is one of the major issues in choosing the polymer material that is to be fabricated for MEMS it should be transparent particularly with the visible spectrum because obviously in some cases we need to transducer the signal which happens within the chip into a different form like optical sick which would need a complete transparency of the cover you know which is enclosing.

The organ is a particular organism and the chemistry around the organism in a small scale it should be rapidly able to get fabricated and then for two definable so obviously the rapidity and photo define ability or more or less synonymous with each other so if you can further define it and for to define many at the same time obviously the fabrication technique becomes very rapid fabrication technique.

You have chemical modifiability which is one of the other criteria's for choosing such materials and out of all these different criteria's for generating an alternate material for doing micro structuring or MEMS work the possible choices with emerge are PDMS poly dimethyl siloxane again a very you know good polymer which comes in two phases but it reacts and bonds as an epoxy and maintains it keeps a mix makes a rubbery membrane.

Bbut you can actually microstructure this membrane by putting it through or making it through a micro molding process hydro gels which are actually again very useful choices for supporting biological entities or in biomedical devices and you can microstructure them very easily PMAA, which is actually e-beam resist polymethyl methacrylate. So you could write very, very small using this polymer and some other materials like Teflon or SU-8 where these are really the MEMS you know structures for example issue it is a resin as I showed you earlier so the negative tone resist photo resist which is comprised of an epoxy resin, okay.

And Teflon which is again you know it is sort of a patented material by DuPont but this is one of the high hydrophobic surfaces that is provided through Teflon, so therefore some of these materials are ideal choices based on the strategies of choosing as mentioned above and some polymer micro structured chips are shown right here this is the lab on chip developed by Caliper technology is another by a Clara technologies which does amino chemistry so these are some of the sort of applications of MEMS based microstructures for doing biomechanical analysis.

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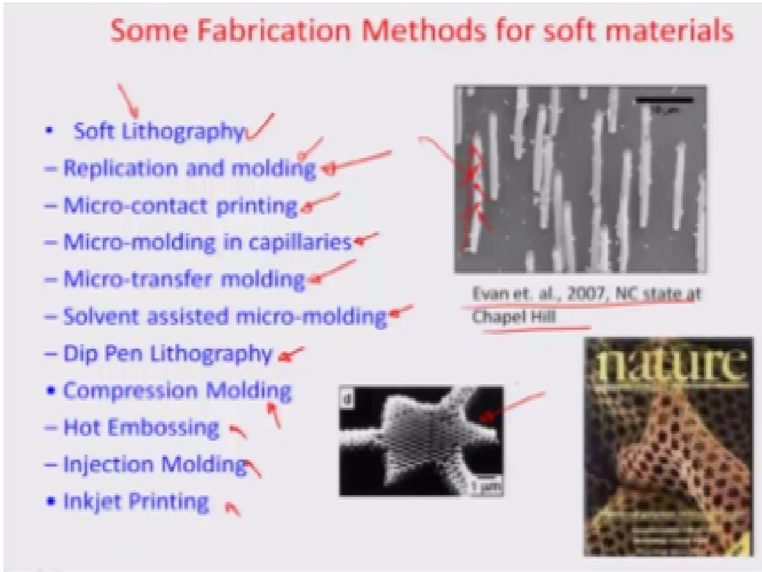

So the if you look at the strategies that were used or developed for fabricating again some of these features so the first strategy that is used is falling within this ambit of soft lithography it was developed by the White sides group at Harvard and it talks about taking a soft material and trying to use a pattern to replicate or micro mould the soft material. So the various ways of doing soft lithography and the first strategy which developed abney show for starting this whole area is known as a replication molding which was done with this siloxane polymer PDMS as mentioned in the last slide.

There is micro contact printing, there is micro molding in capillaries, micro transfer molding solvent assisted micro molding and then you have dip pen lithography and then some of the forms like compression molding hot embossing, injection molding, and inject printing which together leads to this area of soft microstructure of fabrication okay. So let us look into some of these processes here now there is a very interesting example of what can be done with high aspect ratios plus structures of polymers.

These are small Celia like structures which are probably several tens of microns tall and about probably less than a micron and a submicron range diameter and they are all you know sort of a composite between a polymer and some magnetic material and you can actually turn and twist the cilia or based on an external magnetic field by virtue of the inclusions which are now included in this polymer phase right about here.

These again are structures related to similar to that of a geckos feed and it shows the complexity of mother nature you know which has been completely replicated on to a piece of polymer. So let us look into some of these soft lithography processes, so let us look into the first process that is the replication and molding process this was again as I pointed out done by white sides group.

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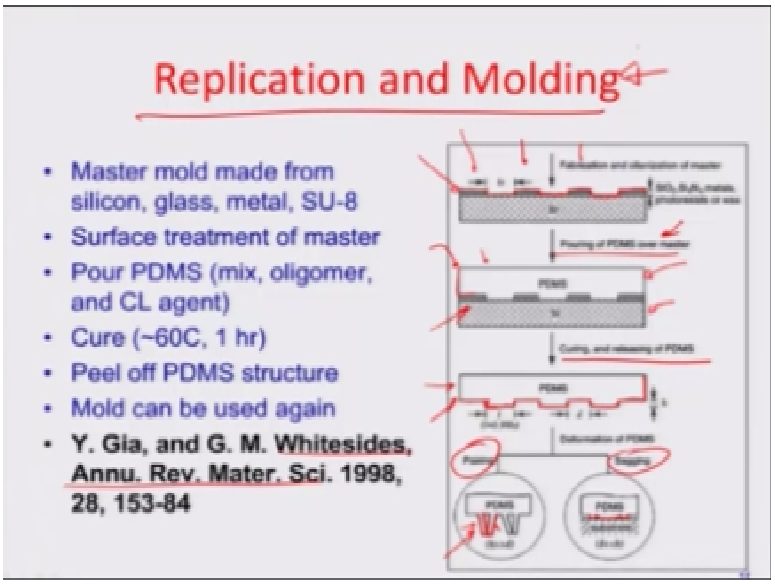

And in fact this process was reported for the first time in this annual review of material science in 1998, which talks about how a small micro pattern which is generated through lithography or some other you know microelectronic means I have given a lot of these examples in the last few slides okay, is so this such a pattern we just taken and silanized on its surface, so there is a thin molecular layer of material which makes this surface highly hydrophobic in nature and so you can think of it is like the talc powder used in casting processes which is used for separating the cast out of the remaining portion of the mold.

I had done this while talking about the first generation casting strategies in the last manufacturing process technology part 1 modules earlier. So here after doing the silanization so you have a thin film of sort of a mold release film you can say, you pour the polymer on the top and this polymer typically comes from into in two different phases where mixing the two phases together would bring a quick setting of this polymer and there would be it sort of a bonded network which would make this polymer become rubbery over time also if you can heat catalyzed this bonding process the polymer becomes rubbery much earlier in comparison to a passive rune drying process you know which happens.

So there is some solvent which needs to be tried for the molecules to be cross bonded, so this polymer is poured now after mixing over this particular micro mold and then heat cured and then after this heat cured the robbery membrane can be removed of the silicon mold and typically the idea here is that the mold should be reused again and again so that is why it is more like a rapid you know fabrication strategy, so as you can see the rubber actually formulates a negative of the pattern which was there on the surface of the micro, mold okay.

So there is a negative impression of what is there on the micro mold, on the pattern and so this pattern again can be planned in a manner so that it is useful. There are certain aspects which need to be known for example the aspect ratio should be such that it should not pair up. For example, these are two so high aspect ratio structures as you can see but the moment you release the pattern although it will get released but then there is a tendency of these hanging parts to sort of pair up with each other which should not happen and similarly if the patient.

If the aspect ratio was very low then there could be a tendency of this you know the part of the structure to sag and collapse and so therefore you need to choose the aspect ratio in the right manner when we are talking about replication and molding. So I would like to now conclude this module at this stage the interest of time in the next module we will talk about a few more of these polymer MEMS processes, thank you.

Acknowledgement

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