Bio-Microeletromechanical systems

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Module No. # 01

Lecture No. # 04

Today, this class on introduction to bio mems and Microsystems. We will be doing lecture number 4 today.

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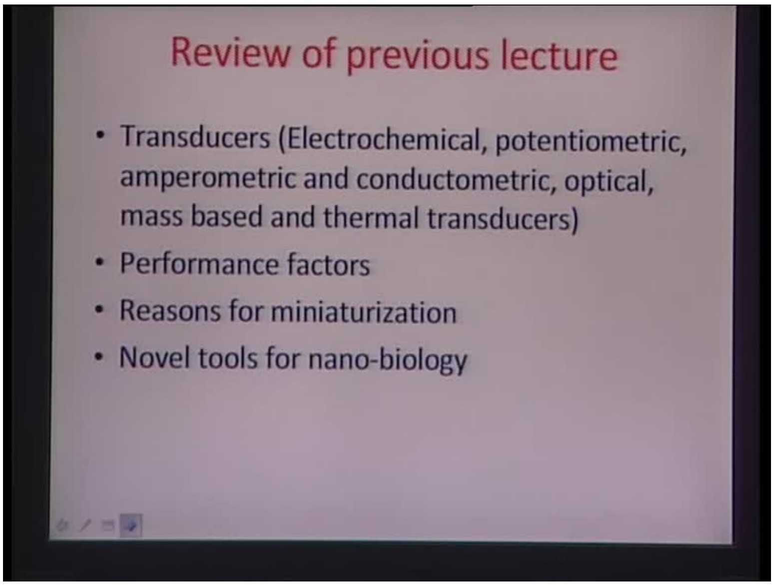

Basically, if you look at what has been done in the last lecture, we talked last time about different forms of transducers and transduction gain is phenomena, where in there is a change in signal from one form to another. So, at length we talked about electrochemical, potentiometric, amperometric and conductometric and so on type of transducers. We also talked about different optical, mass based and thermal mechanisms of transduction process.

So, we are following this. We discussed about different performance factors of different sensors and some of them being sensitivity, selectivity, working life time, etcetera; few may just remember that. Then, we at length talked about what are the needs and reasons really for miniaturizing the sensors into small platforms. Some of them being the due use of reagent volumes which we use for detection, a better thermal control on the devices - especially in biological micro reactors, sometimes control because of very less volume on the diffusional processes, which results in rapid mixing etcetera, when you have this thermal cycling action taking place so on so forth.

Then, we discussed some novel tools of nano biology, where nano biology is essentially the area where we really study about single cell behavior, in terms of processes, like translation and transcription, signal in between different cells so on.

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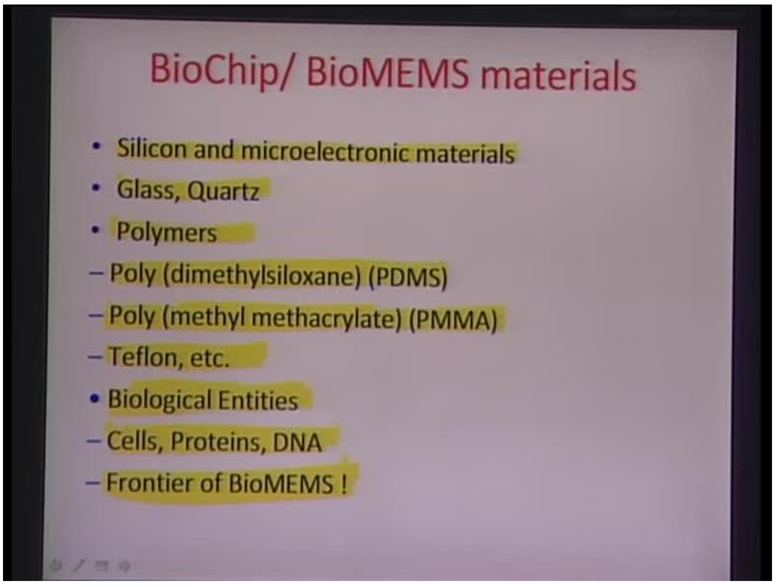

Today, we are going to look at more into the micro systems engineering. We are going explore some of the materials that are used for designing these bio chips or bio memes kind of plat-forms. We are also going to talk about some of the fabrication processes which are related to realizing these architectures, which essentially has fallout of the silicon industry; it can be directly translated on to making features which are small in the micro domain etcetera.

We are also going to look into some of the alternative technics using polymers which are available, where we can do in a very easy and inexpensive manner fabrication of such micro devices.

If we look at some of the materials which are used for bio chips or bio mems device fabrication, we start with the first material that is silicon and essentially all the processes which are borrowed from microelectronics.

The other important material that is being used often is glass and quartz; one of the reasons why that is so, is that because we are talking about transduction processes and sometimes transductions means chemical to optical signal transduction. Therefore, essentially a transfer into medium like glass or quartz is very much required for covering these devices. Typically, therefore, glass and quartz forms an important material for fabrication of some of these bio chips.

Alternative materials like polymers - we have been talking about this often because we are talking about biological entities or biological systems - they tend to be very happy in fluidic environment and also while in the presence of carbonaceous materials and polymers being carbon rich materials. Then, phases of these BioMEMS devices are slowly shifting from silicon based processes into polymer based processes.

One of the other important aspects of polymer is their ease and inexpensiveness of fabrication. Some of the important polymers that we use often for such techniques are this wonderful, a silicon rubber called poly dimethylsiloxane PDMS, which we used for process called replication molding, which I will be talking in next few slides.

PMMA poly methyl methacrylate, which is also an E beam resist is very often used for realizing some of these small features in structures and then there is teflon, which is a very highly hydrofluoric substance; if you put at droplet of water on to a normal teflon surface, the contact angle that the droplet has is in the range of about 120 degrees; it shows about how super hydrofluoric teflon surfaces are. So, these are sometimes used, especially for optical application; sometimes, teflon's reflect index being lesser than water or lower than water can use very well into micro architecture to form optical wave guides.

So, these are some of the alternate routes that biomems or biochips are fabricated with; then, there is this whole new area of trying to realize the devices using biological entities themselves and this is really one of the novel franchisors in the area of biomems. In most of the research, which is done now, mostly is how to realize devices using molecules like cells, proteins, DNA so on and so forth.

Essentially, the whole idea is that these biological entities tend to behave well in the presence of other biological entities like cells, proteins, DNA so on. So, we have this concept of making filters using one or more y-shaped DNA molecules, where you could probably, someday, be able to actually a molecule by molecule filtering. So, there are several interesting novel concepts in this particular area.

So, let us look into some of area fabrication aspects and we start with what silicon has to offer as fallout of the microelectronic industry. So, this topic is all about the formation of structures that could be used to form sensors - actuators - using some of the conventional silicon processing techniques like etching, deposition, photolithography, oxidation and epitaxy, so on.

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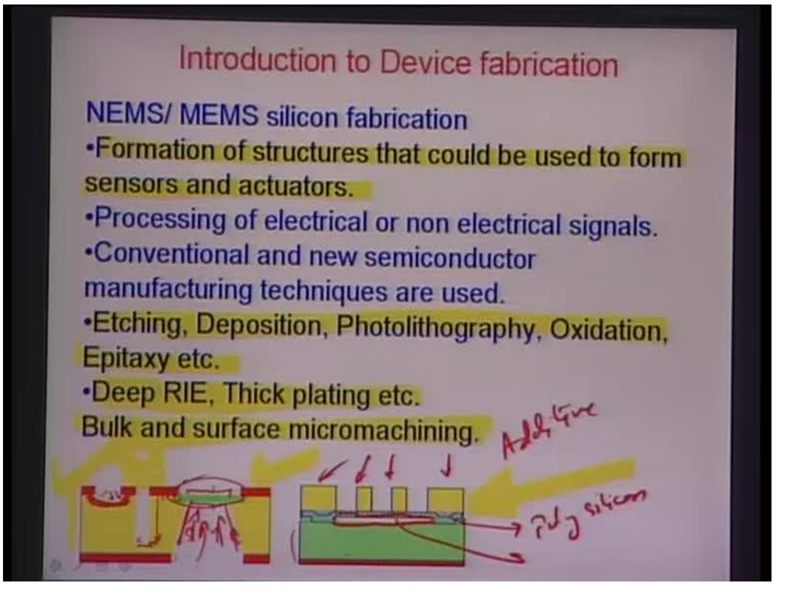

The purpose of these are to make a some kind of processing of either electrical or nonelectrical signal generated by some effect, which is a result of the sensing activity. Essentially, there are other techniques, particularly used for MEMS applications or micro fabrication applications; these two techniques form very important aspect - one is thick plating, where you can make probably more than micron size film by electro plating on to the surface or deep RIE or deep reactive by an etching, where you can use plasma to chemically etch silicon surfaces.

So, as I have been talking about before if you classify this whole area of micro machining, you could actually categorize then into bulk and surface micro machining.

This figure here, on the left, shows what bulk machining would look like and this again is surface machining.

So, if you look at this figure, bulk machining is all about trying to take a way or subtractively remove material from the bulk or the volume of the material. This is essentially, as you see here is silicon is cross sectional view of the silicon wafer. This red layer here, as you see on the top, is essentially a protective sacrificial layer, which is used for preventing the etchant solution or the etchant mechanism to go into certain selected areas over the wafer. Where this mask -, we call it a mask, a hard mask - where this mask is absent or removed, you have this etching effect due to etch material is removed like if you see in this particular zone, this area has been formulated by a cratering effect; an etchant has gone and remove the material through this red mask on the top of it.

So, this is what wet etching typically does; if you look at it closely, you will find out that there is always an undercut in such an etching process, where in the irrespective of how thick the masking material is. There is always a tendency of the material to get removed from underneath the mask to a reasonable extent.

So, the idea is that you have to design the mask, while designing such kind of etching techniques using or keeping this at the back of your mind. So, the mask size has to be typically a little lesser; then the sizes that you would like etch away in the silicon material.

This is not a very interesting example of a high aspect ratio etching, where in glass plasmas, glasses like fluorine and chlorine are used to rapidly take away silicon atoms form the surface, using this masking layer again. The advantage in that kind of a mechanism is there, if you look at the aspect ratio here, these processes can really make high aspect ratio features and structures. So, typically with straight etches that is another advantage.

There are applications, where you need such kind of high aspect ratio structures in MEMS, where you can use RIE based etching. This again is very fine example and this is essentially a thin diaphragm, which has been realized by using p plus silicon, which is achieved by doping of normal silicon.

Essentially, you are having a two sided process, where on the front side, you use some etching action to remove this sacrificial layer on the bottom side, you use first remove the layer and then eat away, the silicon material. So, that we can go all the way up to the p double plus, where the etch stops typically and you are left with very thick film or a diaphragm, which can be used for variety of applications; one application could come off and is the pressure transducer. So, if you have a phezo material deposited, somehow on top of this thin mefdain and even having this the part of the circuit, where there is a pressure from this end; this is always a vibration. It is always bending of the diaphragm due to wish, there is a signal and from that you could calibrate the Ambien pressure available from the closed end of the circuit like this.

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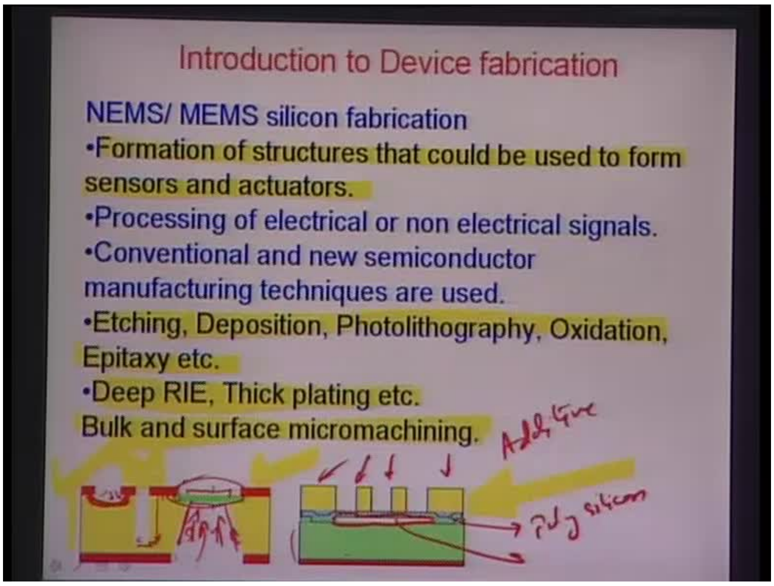

So, these are some of the illustrations we have, you can see how bulk micro machining is being done. Selfish micro machining is on the other hand is an additive process typically, where you are actually building material on the surface of silicon, so essentially these pillars, what you see here are built on a surface of this base wafer; this mother wafer and this is essentially, what surface micro machining is all about.

Another very interesting fact is that is, if you see this particular area here, you find out that it has been nicely carved on the inside of a poly silicon firm. This is actually a poly silicon small layer and use the sacrificial resist layer here, you spin code this resist layer and in a manner that part of the resist stays over; then, use deposition technology to deposit thin film of poly silicon and later on remove the sacrificial material away to realize; this is small embedded micro channel kind of features; however, this is a surface micro machining process because you are considering a thin film, which is able to surround small cavity within itself and thus realizing a small covered micro channel.

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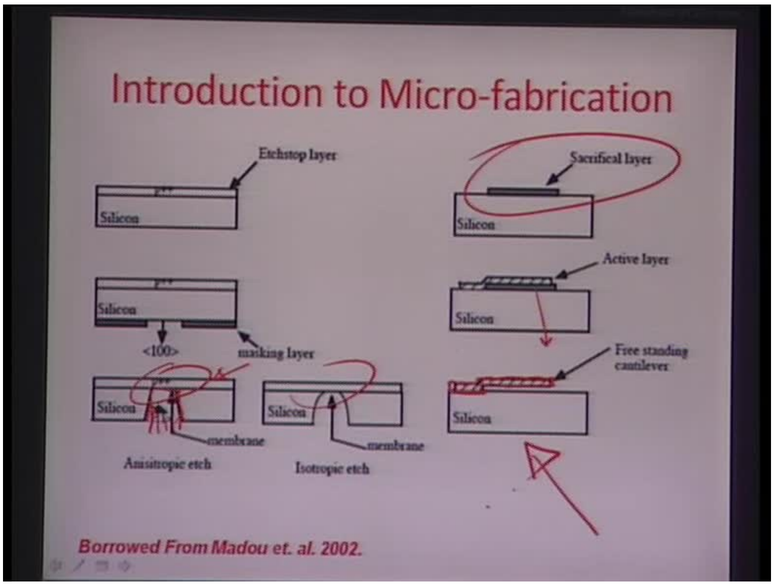

So, there are several important applications of micro fabrications processes. This slide has been borrowed from text book written by Professor Mark Madou, which talks about how the various processes can be integrated together to realize things like, diaphragms, which we have already seen. So, this is the p double plus, thin membrane and you are etching it from the back side, so that the material that you use is essentially an etch stop on p double plus, so that it does not go ahead and so you are left with very thin film here.

Similarly, if you try to build micro cantilever, the process to do it is that you build a sacrificial layer here, as you see and then deposit something like an active layer, which is typically having high strength and then, the idea when you take away the sacrificial layer, you are left with this thin cantilever on the surface of the silicon.

So, some of these schemes do help us in realizing structures and features which are very useful, as we will see later in many applications for detection and sensing. Now, this diagram that we have been illustrating is also known as fabrication schematic and all other fabrication flow chart. Typically, all the processing is planned and at the outside such a flow chart is made to give a sequence of processes, which would go into realize the microscopic feature that we are considering.

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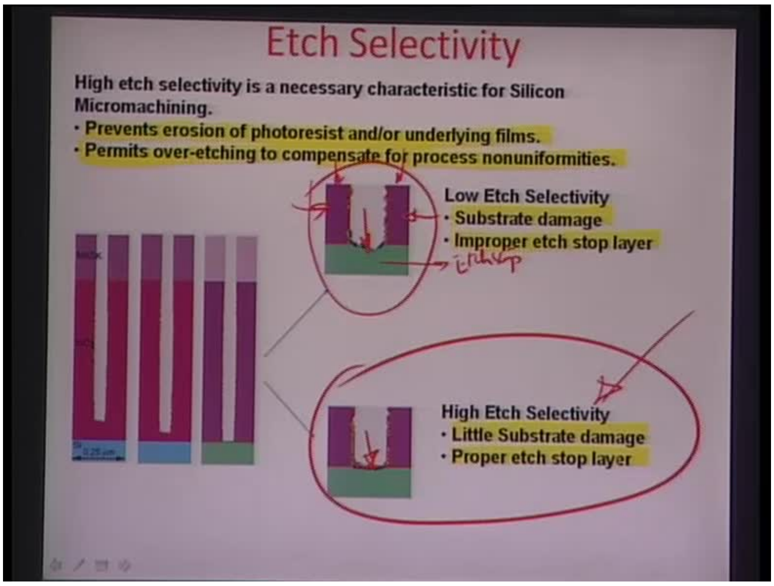

So, at selectivity, this is a very important aspect in fabrication. Essentially, it is the way that an etchant behaves with respect to a surface over, which it is etching and essentially, high etch selectivity is a process or is a property, where in etchant that you are using would be able to etch up to the extent that we want to etch on the silicon. To illustrate, it a little better; if you look at this particular figure here. So, essentially, you have a sacrificial layer, as you can see on both sides here and also covering the silicon wafer for the base silicon wafer from the top and this is an illustration of low etches selectivity. So, essentially when you are using an agent, which slightly eats away the material on the sides and also on this essentially an etch top; this is etch top layer, that means the etching should stop up to here.

But then if you look at this profile which is been generated; the etching go all the way through and it really does not stop at the instance then, it is supposed to stop. So, this particular etchant has a loop etch selectivity on the substrate. So, it causes typically, a phenomena like substrate damage; it basically, because of improper etch stop sometimes realizes features and sizes in a manner that we do not expect them to realize, so the process has a lot of nonuniformities because of in incomplete or because of an improper etching or because of low etch selectivity.

So, high etch selectivity is necessary characteristics for silicon micro machining and the higher the selectivity, is the more it prevent erosion of photoresist or underlying films and permits over etching to compensate for process nonuniformity. On the other hand, if you look at the figure here, on the down here is the process to signify is high etch selectivity.

So, if you look at this process, you can find out very easily and probably, you can differentiate between it is common part, which have just illustrated on the top here. You see the profile , which is generated after the etching, the post etching profile here and the post etching profile here, and you find out that because of the high etch selectivity the surface is little better or little more uniform than the nonuniformities, which you have observe in the low etch selectivity case.

So, if a process has high its selectivity then, it has little substrate damage and there is a proper etch top layer; essentially, thing are in control. So, you can do; what you really want to do on in terms of etching a way or removing material. So, that is what etch selectivity is.

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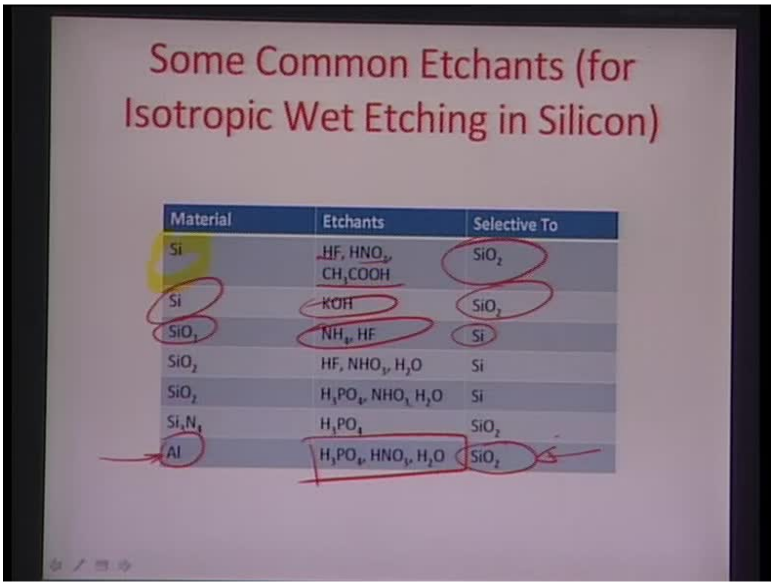

So, when we talk about some of the common isotropic wet etching etchants in silicon, we always talk in reference to, what is the material that used to etch; what is the particular etchant and what is it selective to.

So essentially if you talking about the material silicon; it can be very well etched by these 4 different etching agents: hydrofluoric acid, HNO 3 and CH 3 COOH, and essentially, these etchants are used for etching over silicon, but it is very selective to this SiO 2. Therefore, this SiO 2 layer of silicon dioxide layer can be used is an etch top in these situations. Similarly, if you talk about KOH potassium hydroxide; it can selectively etch away silicon, but at the cost of SiO 2, but it prevented the etching process stops when once it meets SiO 2. There are other etchant which are illustrated in this particular table; when you can probably go through NH 4, HF used for etching SiO 2, but it is selective to Si, so immediately it encounters an Si layer, the etching process stops so on.

So, what is interesting here is there is also such etchants which are used for metals on these silicon or other substrates: one reason, why metals are used, to develop interconnects between the different parts of the circuitry that is being put on such a wafer. Therefore, there has to be some etchant for metals as well, which can make them to the shape and size desirable to form the convicts or the electrical connectivity between two or more components on the wafer. So, if you talk about aluminum phosphoric acid, H 3 PO 4, HNO 3 and water; this combination acts as a very good etchant, but it is selective to again SiO 2, that means, the moment it encounter SiO 2, the etch automatically stops and this can be a very good sacrificial masking layer, when you want to selectively etch aluminum away deposit it on a surface.

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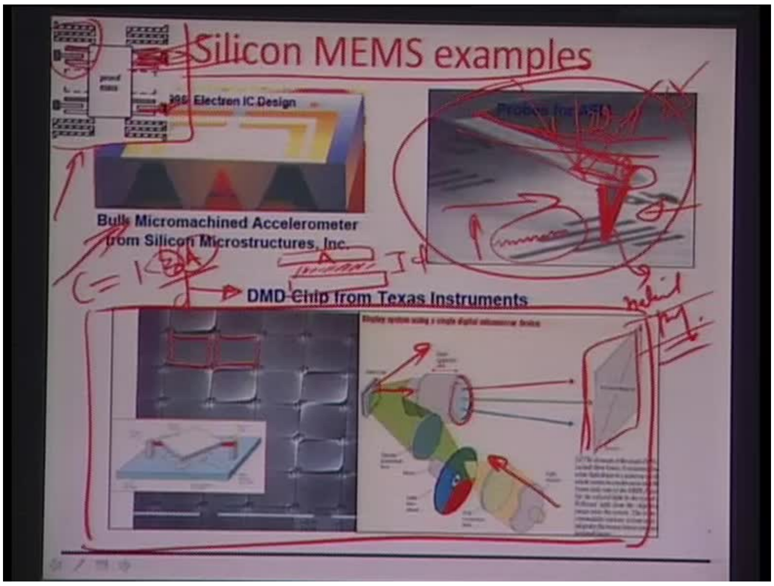

So, these are some basic processes and will be looking into a lot more details; once we come to the actual favication part of the lectures. What I would like to illustrate now, is some of the applications and devices that we often on use in silicon MEMS, and these examples have been borrowed of non from industrial or commercial use, you will probably able to gauge, what utility MEMS has in common day to day life. So, this figure here, if you look at is actually a bulk micromachined accelerometer and this figure has been borrowed from silicon micro structures. So, essentially in this particular device, the basic operating principle is schematically explained in this particular region.

If you see here, there is a vibrating proof mass which means, at this mass is essentially on the top of a pivotal kind of micro structure and it is able to vibrate. So, as if there is a hanging mass with the point support from the bottom and it is able to vibrate like this. So, it has several degrees of freedom; it can probably vibrate in let say, this alpha direction on a perpendicular beta direction and then it also can turn and twists like this. So, this is a wonder full structure, because such structure can be used to gauge very precisely or a very accurately, the change in acceleration, roll, pitch, yaw and these different physical processes. So, what is essentially happens here is; if you look into this particular setup here.

So, these two, as you are illustrated here by the mask that are making a part of the proof mass; so, they are like wings coming out of proof mass. So, this is the proof mass and there are the small wings on all 4 sides; these other structures, which are in between here these is other 4 structures, which are in between here are really on the base of the silicon wafer, so they are not really moving .So, the wings which are along the proof mass as the proof mass oscillates and also move along with the mass.

What happens, as a result is that there is a change in capacitance between the wings and this portion of the device, because of continuous change in distance and interfacial area. If you all recall your physics days, the capacitance can also be return as, K epsilon 0 A by d, where A is the interfacial area of a parallel plate capacitor; d is the distance between them; K epsilon 0 is nothing, but dielectric permittivity of the medium. If you a putting dielectric material in between here, then, it signify greater than unity valley for K and E 0, essentially is the permittivity of free space.

So, as the area between these three structures - the interfacial area, changes because of this vibration of the wings with respect to the static structure and the distance also increases or decreases. There is a change in capacitance and we actually correlate that change in capacitance to things like, acceleration or roll or pitch, yaw and so therefore, this whole concept can be used very sensitively detect acceleration.

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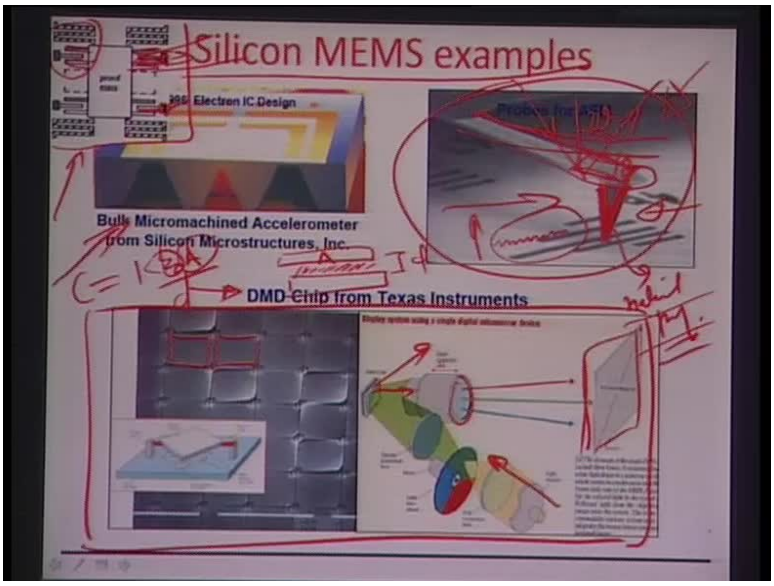

The advantage here is that because of very small amount of proof mass that we are actually considering; even smallest amount of change in acceleration or deceleration related to moving structure can be very easily recorded, because of the small amount of mass that is involved. Therefore, it is a fantastic example of what silicon micro machining can do. This is again a very interesting example, which I keep illustrating; this is one of the corner stones of nano technology. This is the AFM tip - the atomic force microscope tip. The way, it moves on a surface or the way that it is able to gauge a surface, is by rastering on the surface with the very small sharp pointed tip here.

So, it is like a cantilever arrangement; there is a small tip here and this tip actually moves over the surface. So, this is a surface that we are trying to kind of a gauge. So, as it moves along there are two modes of operation; one is called the static mode other is the taping mode. So, in the static mode, what happens is that as it raster along the surface due to the different forces that it encounters between the topography on the surface, which is a rougher smooth, it generates set of vibrations.

One of the first principles that were used for detecting these vibrations are by using a mirror on the top of this AFM proof; shining a laser on the top of that mirror, and so, the idea is that if the tip moves with an angle of theta; the light being here, move with an angle of 2 theta. So, essentially, this used to be bases of finding out; what is the zee displacement at this tip would have as it moves along the rough surface and from that would gauge the average surface roughness.

Now, there is a lot of complicated electronics, which cause into the detecting, what exactly is the zee displacement. Essentially, the AFM image that you see is really a reconstructed image; it is not hands on a real image. So, from these entire zee displacements pull together in software, you would be able to gauge, what the surface roughness is like as the AFM the scans on the surface.

There is another mode, which is simultaneously used in lot of applications; it is called a taping mode, in which essentially the tip here is having a natural frequency of vibration. So, you are basically exciting the tape in that case while it raster’s over the surface. The idea is that if it comes too close or too far away from the surface and there is a change in force; these forces between the tape and the surface could be due to many reasons. It could be due to wander walls forces of interaction between the nucleus on one and the electron on another; it could be some repulsive force because of the electron repulsion so on, so forth.

So, there is the variety of forces which come into play. So, as these forces are executed on a vibrating temp; there is a change in the fundamental frequency of vibration because of that; from that you could gauge, what is a surface roughness, which AFM trying to measure. So, it is one of the most fascinating tools probably, that this MEMS technology has given to the field of physical sciences and we all probably know how important the AFM is, in terms of gauging very small, fine structures at the submicron to main.

Another, very fascinating example of how silicon MEMS used in the industries is this digital micro mirror device chip form Texas instruments. The common laboratory projector, because of which essentially, I am being filmed and I am able to give this lecture is based on the MEMS technology.

Essentially, the idea here is very simple that you have so called a mirror, which is pivoted on these two pivots on both sides; this mirror has an electrical imprint on its back side. So, we are talking about the small plate here - the shine plate here made of metal, which has an electrical connection on its backside. The base over which these pillars use for pivoting this mirror or resting also has simultaneously electrical connections on its surface.

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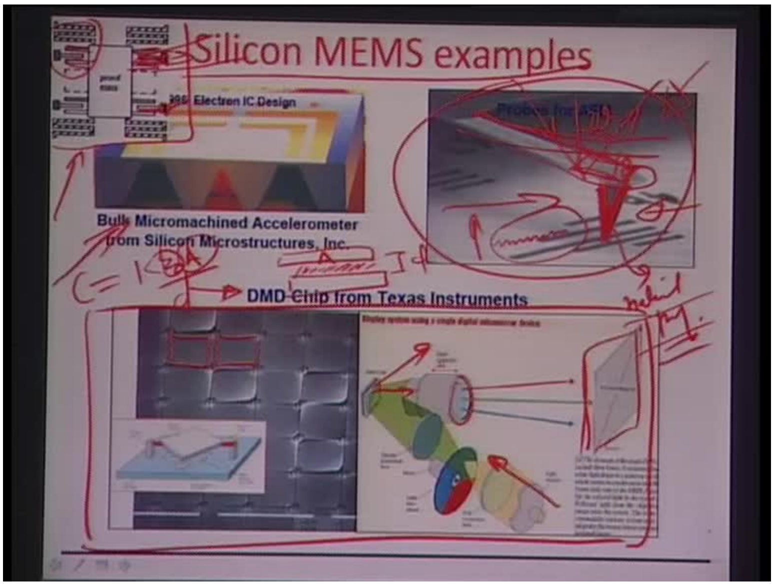

So, if you are considering this thin film, which is hanging between 2 pivotal points and there is a surface on the bottom; there is an interaction going on between the electrons placed on the backside of this mirror or this film; the surface of the silicon material, because of this electrical force, there is a tendency of the mirror to rotate about the pivotal point. So, if you look at this particular structure here is very fantastic way of rotating; the rotation takes place over these 2 edges here

Essentially, there is an array of a such mirrors and these mirrors are very tiny; let us say about 10 micron into 10 micron or so; it corresponds to pick cell; when there is a light beam which is a reflected off this mirror, we can actually deviate the light beam into the path of the image or outside the path of the image by reflecting this mirror.

So, in one instance may be the beam which is coming from this particular source, goes into one of these mirrors here; the mirror is able to deflect the beam through the lens on to the screen for the projection. In other instance, because of this electrical actuation, the mirror goes out of view and the light is not passed through the lens in the process.

So, what we are trying to do is switch on and off the various picks cells. So, one of this mirror forms 1 pick cell and there are millions of pick cells which makes an image. So, if there is a tendency of this mirrors to rotate and out focus, some pick cells would switch off and so therefore, the image on a computer is in a digital manner, transfer such a device - DMD chip form of device, where these light beams are used for switching off and on various pick cells on getting signals 1’s and 0’s and digitally an image can be transfers from a computed to a projective.

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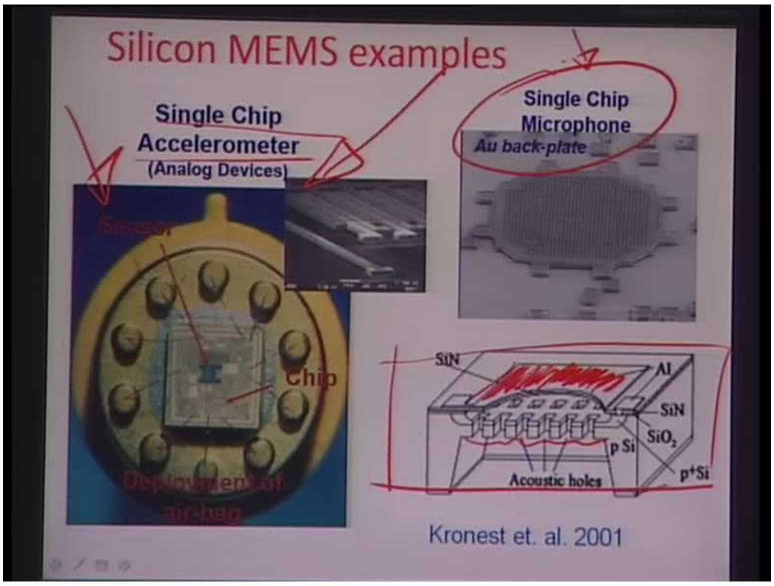

So, these are the some of the examples are commercially available silicon MEMS. Let us, actually look into a little more of what other applications are possible. This is a fascinated example borrowed from analog devices and analog devices is one of the commercial companies, which sells a lot of these accelerometer chips. Essentially, all the auto wheels have mechanism, where in there is an accident prevention by actuating a balloon. Wherever, there is a crash; there is a safety mechanism in most of these auto wheels, where there is a air bag which comes out; we call it, the air bag technology, but it is an air balloon which comes out and prevents driver from crashing into the staring.

These accelerometer chips here are essentially used to control a sense, such accelerations; the moment it crosses a certain limit, where there is a tendency of this driver to be driven and this happens only on a high speed auto wheel is suddenly brought to a rest huge deceleration there.

So, in that case, it opens a nitrogen bottle and it suddenly fills the air bag and the air bag comes out in the steering area, so that crashes prevented between the driver and the staring wheel. So, such devices are very successful, commercially available and repeatable and these are potential application of MEMS. Another very interesting application is this - single chip micro phone. The small button mike, which I am actually using for speaking today, is essentially based on MEMS technology.

So, if you look at the basic structure of such a mechanism; it has a perforated diaphragm at the microscopic lens scale; there is a piece of material on the top of this diaphragm. The idea is that whatever, we are speaking; what is speech really; why it is that if I am saying something; you are able to hear. So, sound wave is set of compression in where if action. So, when you are trying to communicate; we are trying to move the air from our mouth by various movements of our tongue and creating a series of this compression and redifaction, which goes or emanates from my mouth; that waves goes ahead and you are able to get the same sensation; your hear is essentially a transducers which tries to get a signal based on that.

Now, if you look at the same process in a silicon microchip; this diaphragm here is a very thin and very sensitive. Vibration based mechanism, where these compression and vary, if action be really actuated into electrical signals and that is by means of this phezo layer, which is staked on the top of this perforated diaphragm. Therefore, whatever we are speaking is converted into electrical signals and they transported long distances; then, can be again reconverted back, by again similar kind of diaphragm, which produces the inverse effect, that means electrical signal is converted back into mechanical vibration and that is, what a loud speaker essentially does.

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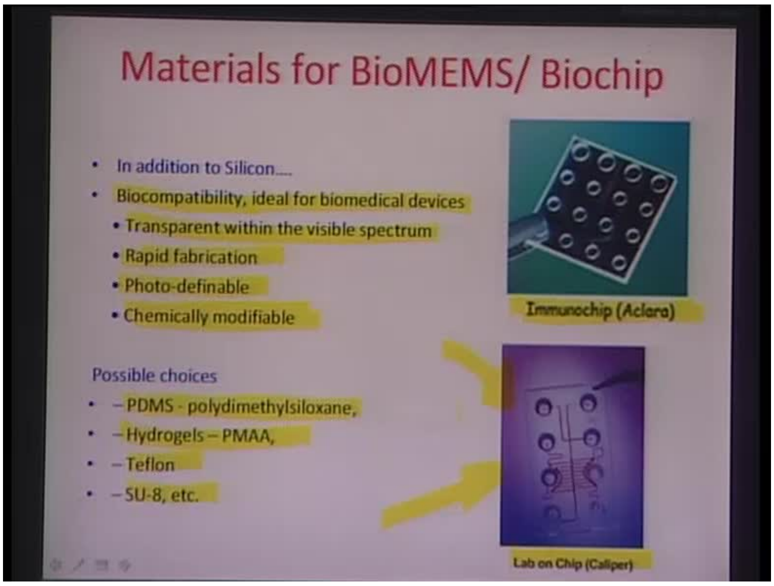

So, that is a very fine example of what again silicon MEMS can do single chip micro phone. So, after discussing this, I would like to shift my focus little bit to polymer MEMS. Specially, MEMS with the prospective of biology, because the area that we are mentioning is BioMEMS or biochip, so, as I indicated earlier in addition to silicon because of the bio comparability aspects; there is, huge demand of polymer based micro systems. So the possible choice, is that I mention before; I am going to retreat here are polydimethylsiloxane, as you can see here in this hydrogels, a very interesting polymeric systems, which are used for making this BioMEMS kind of device, PMMA - poly methyl methacrylate, teflon and SUA; it is an negative tone photoresist. In our first lecture, we talked little bit about negative tone resist does; it is basically something which gets exposed to light and gets cross bonded and it can remain.

So, what are the requirements or what are the material selection criteria's for realizing BioMEMS or biochips. So, one aspect of course is bio comparability, whether the material, we are using is an ideal material for the biological entities to keep happy and function in a normal manner. Then, optical transparence again within the visible spectrum is a very important aspect of such systems. Basically, materials the most of the translation processes, where we convert a chemical signal into an optical signal involves the reading and reading of light. So, optical clarity or transparence is really one of the major issues, which we should consider in material selection for BioMEMS devices.

Rapid fabrication again, how rapidly you could manufacture. We had manufacture many of those MEMS devices within a short amount of time; polymer being expensive; there is a tendency of the industry to make mostly reusable chips therefore, they have to be produced at a great weight to keep up with the phase of diagnostic requirements of the industry. Then, the poly material or material should be search there is photo definable; the way that micro features or micro structures a translated a majority or done mostly through light as a means therefore, photo definability or ability to be defined by using light or photons is a great criteria, which is a very important for selection of materials.

Also, because we want to study chemically active species, is the material that we are using should be chemically modifiable therefore, we do not want materials, which are inherit in nature. They should be easily being able to get modified. So, there we can attached recognition elements using covalent linkage or may be using cross agents and therefore, chemical modifiability again is a very important aspect of these devices.

So, if you look at these technologies, the Immune chip from Aclara technology is again is an example, where plastic cartridge is used for doing immunological tests. Similarly, this is an illustration from Caliper technologies, so Lab on Chip platform, where in micro channels and features are used to do lot of diagnostic, but again if you look at it is a transparent plastic that is used; several such devices are available.

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So, once we have the selection criteria will define; the next question is, how in case of polymers, we can fabricate these devices. Suppose, we really started with white sides group will back in about, early part of the 90s and these approaches also known as soft lithography. So, essentially there are several processes, which have come as a result of this basic replication and molding technique, which I am going to illustrate in details.

So, there are various approaches replication and molding, micro-contact printing, micro-molding in capillaries, micro-transfer molding, solvent assisted micro-molding, dip pen lithography and then there are other approaches like, a compression molding, which in compasses hot embossing an injection molding and also nano dip pen lithography and then you having inkjet printing.

So, a bunch of these processes or a combination of such processes is sometimes very useful for realizing MEMS devices. So, some illustrations, that is reflected here; this is a work done by, Evan et al from North Carolina Chapel Hill , back in 2007, where he talks about the fabrication of structures and features, which are about 80 or 90 microns in length and almost 2 to 3 microns in size; they are like Cilia.

We have been talking about Cilia, if you may remember, while we were talking about nose as a sensor; Cilia are here like Moiety. So, how we make it, we use this material PDMS as poly dimethylsiloxane; then try to increase the strength by making some nano particle at addition to the material. With this high strength material, we can replicate material once it is in the liquid form and over some kind of a dye and then, solidify the material and pull of the die to realize the Cilia.

So, the idea here was in this paper that wanted to use iron based phero magnetic additive, for trying to move the Cilia around with the external magnet. The idea can be used for providing locomotion of species like of the same range bacteria. Typically, bacteria also float around in the solution by this here like tentacles called Cilia sometimes, which lets it go by with the periling action of the cilia.

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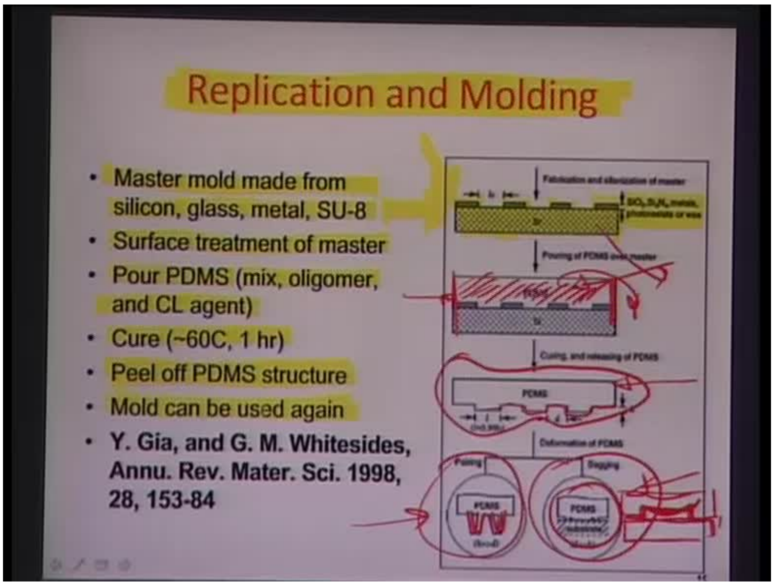

Now let us talk about the details of these processes one by one. Replication and molding again and I would like you to focus, now more on to these this figure here, on this right of the slide. So, the processes starts with something called mold; this mold essentially made up of silicon, wherein by using variety of processes like may be wait etching, lithography and wait etchant. You could realize the small features on the top of this silicon wafer.

So, these features are the mold and as you all are aware probably, that mold is something, is a shape that is used for getting in prignated on to a liquid, which later on can solidify and take the inverse shape or the negative shape of the mold.

So, once this mold is realized and this mold can be made using; these features here that I have been illustrating here, can be made using silicon dioxide, silicon nitride, metals, photoresist, wax so on. The thickness of this could be really very small in the micron range; was this mold is done then; you pour this liquid material called PDMS - polydimethylsiloxane and what PDMS really is?

So, PDMS is actually a silicon rubber. It has 2 components: one is the recent part and other is a bonder or a cross binding agent or cross linking agent. We mix these two components in a certain ratio with may be 10 parts to 1 part of the recent to the cross bonder or 5 parts to 1 part. The cross bonder is always a lower in volume than the basic resin. Once the unique property of this material is that once after thorough mixing is heated to a temperature of about 80 to 82 degree Celsius for about close to 40-45 minutes; it cross links the polymer matrix and develops a rubbery kind of membranous structure. What is also important to know about this material, PDMS is that it can actually replicate very high aspect ratio structures.

So, suppose you have a 25 paisa coin and you want to replicate; what is there on one side of the coin, which is essentially some kind of features coming out, you almost have seen. So, if you can replicate this, you pour the PDMS heat cure it; then, remove this and you will be amazed to see that whatever features are there on this - 25paisa coin, are the negative of those features are transferred on to the PDMS surface in tou tou, so, it is just verbatim transferred.

So, that is the beauty; these PDMS is material, which goes into all the crevices, be it short, narrow, whatever and try to replicate everything very accurately. So, if you look at this slide (Refer Slide Time: 41:14) back again, the PDMS in liquid form is poured over this mold material. There are walls on the side, which can prevent the flowing back and therefore, the new heat curate; the PDMS develops a rubbery kind of material in this particular area; then you can use, you can remove this PDMS from the mold. Thus, the PDMS is left on the surface with and negative of the impression form the mold.

Now, these two steps need a little bit of preprocessing, because sometimes, it is a very important especially if the PDMS layer is thin to keep it in 1 piece as you are removing; therefore, we use these agents called mold release agents. This master, when you fabricate, you ensure that you treat or you pretreat the surface with an agent like, tri methyl chloro xylene or some agent, which can prove preferentially do salinization on the surface and make the surface hydrofluoric in nature.

Therefore, the idea is that you put molecules and you put some crops or linker or molecules I would to say; not likers on the surface of the mold, which is able to kind of fight with the PDMS molecules; it kicks it back. So, the only way to do that is to lower both the surface energies, so that you can separate or you can have an easier separation. PDMS, by the by, is a very methyl rich material with the lot of CS 3 groups on the surface and if you look at the contact angle of a PDMS material; it is about 108 degrees or so.

So, you get the inverted replica of what you want to develop as a mold and therefore, the mold is planned in a manner, which is exactly the negative of what you want is features impressions on to the PDMS surface. Mold can be defined by photolithographic means, where you prepare a cat file exposed a way use scarify a layer do etching or some other processing mechanism and then mold is realized.

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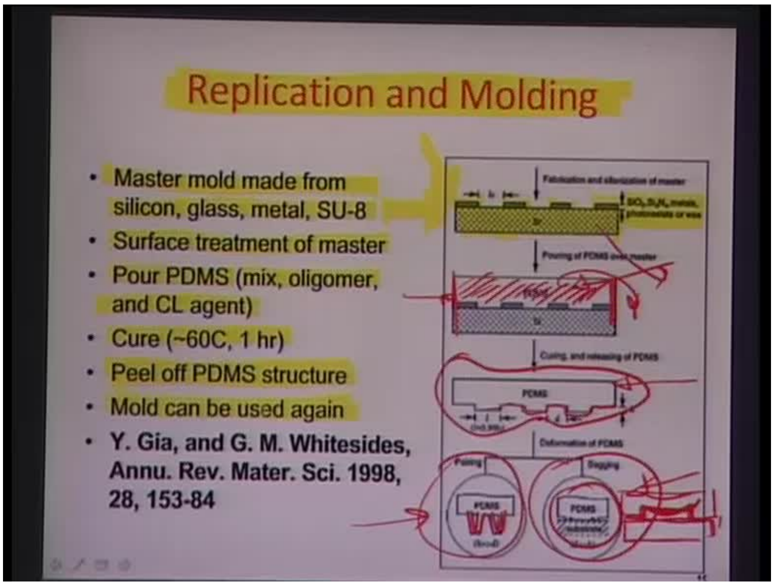

Some issues with this processes is that you really cannot go using normal PDMS over a certain aspect ratio, because if you look at these two products; in this case, there are these long standing arms of the PDMS material. If they are just hanging by themselves there is a tendency to kind of adhere to each other; one property of PDMS that it makes fine reversible bonds with any surface; that is near about it.

So, if you put it on glass surface or silicon surface; it results almost immediately in reversible seal. So, that is, beauty of this particular material; it being soft; it can confirm to the surface of interest very accurately. Typically, remove on air which comes in between while this reversible adhesion is going on very quickly.

This is an other pit fall that if you want to develop the PDMS in the form of a chamber and then, you bond that upper layer of PDMS with the flat surface, you have to be careful about the aspect ratio here, because if it is too high, then this kind of a problem may happen. Because of the weight the PDMS may sage down like this and adhere to the surface; you are left with a blocked reaction chamber is essentially or a blocked chamber essentially, so the processes steps again highlighted here.

So, you start with the master mold made up of silicon, glass, metal, SU-8 so on and so forth. You surface treat the master by using a salinization protocol, where you put some groups which kind of repel, the PDMS material; you mix the oligomer and the clearing agent. Then, prepare or the PDMS and cure the PDMS on the top of this cured or salinized mold and then, you hear it from 60 to 80 degrees for about 1 hour or so and then peel off the PDMS. So, that whatever features are there on the surface of the mold get replicated and then, another advantages of this processes is the mold really can be re used again and again.

So, that is, why it is extremely rapid also. It is identical to saying that 1 mold can be used 20 times or 30 times. So, you do not have to make the mold again and again; you can just keep on pouring, clearing, peeling off and then gain reusing it. So, it is very crinomical and very rapid process. The process was developed by white sides group again way back in 1998, when we reported that this kind of techniques can be used for micro devices fabrication.

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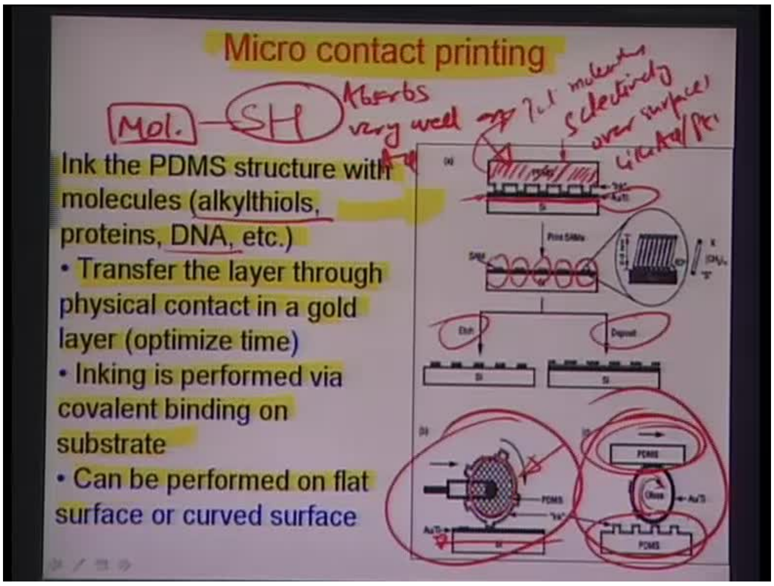

The next process, there I would like to illustrate with this micro contact printing; it is again a very important process for the biological industry. So, in these cases what you do; if I would like to seek an attention to the figure. So, you would start with again a

PDMS stamp. This is, if you look at the PDMS stamp, which is develop by replication or molding kind of technique. Here, the basic purpose of micro contact printing is to put molecules selectively over surfaces, like gold may be or platinum. So, the whole idea is that you start with the PDMS replica and then, you coat this PDMS replica as you were seeing this region here with some kind of a molecule, which you would like to transfer.

Now, they can be several kinds of things that you could do for this transferring. You could actually transfer alkylthiols; you could transfer thyolated DNA or thyolated proteins on to the surface. So, something the molecule, which has a feature, where in there, is absorption of part or a group of the molecule over the surfacing question. Then, you have this silicon surface which is coded with a thin film as you are seeing here on the top of gold and titanium.

What you are talking here, is that the titanium is used as an adhesion layer for the gold. So, you have a small film of titanium on the top of the silicon all through; let me just try to draw it here, probably this region. Then, beyond that you have another thin film; this black film of gold. This is a very highly stabilized structure and what you do is; this micro contact printing essentially a stamping process. What happens in a rubber stamp? So you take the stamp, you put it on an ink pad and you press it on a ink pad. So, that the ink gets transferred on to the stamp surface. Then, you take that stamp over on a piece of paper; put the stamp and wait for the paper to absorb the ink from the stamp surface by capillary effects. Once it is done you remove the stamp; you find out that whatever was there on the stamp the negative of it has been printed on to the paper.

So, this is an identical process. Here, instead of the paper, you are using gold film on the surface and instead of the ink, you are transferring thyolated molecules. So, some of your way are that molecule with the thyole group, that means, SH absorbs very well on gold surfaces. So, here we take the molecule and we press the stamp against the gold and waits for the whole, the reaction kinetics - the reaction of absorption to happen fully and there is a certain time constant with which it happens and waits for that time and then pull off the stamp so, that the molecule, which were there on the stamp get transferred on to the gold surface as small heaps.

Now, so there is a MEMS amount of use of this process. Especially, when we are talking about hybridization arrays, where there is a requirement of making realizing a library of different capture probes for capturing different target DNA molecules, we need in a sense surface on which we can put the small heaps of molecules of certain types. Then, we also should be able to know, what is there on which column or which row of this matrix or array of molecules that we are created.

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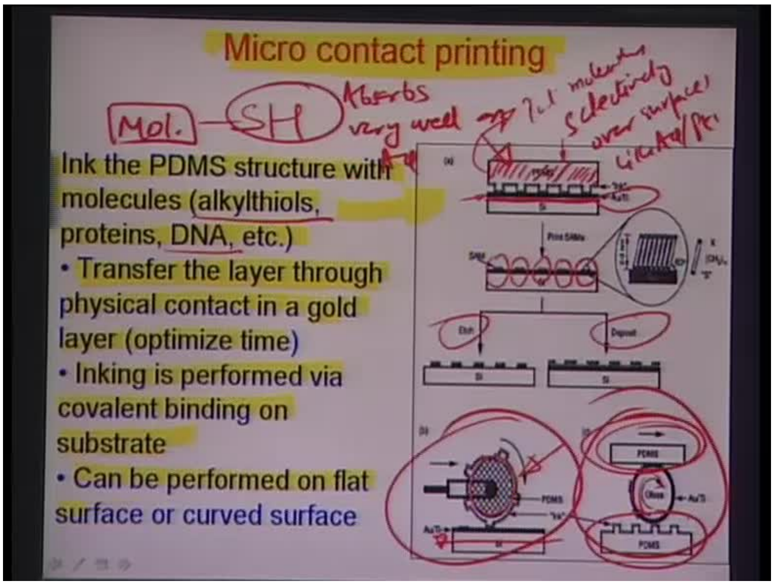

So, micro contact printing is a very important process for that kind of application; in sign sensory technologies, micro contact printing is used off and on for such applications. You could use this process for etching away or depositing; etching away, means that you have a layer of this molecules already predeposited on the top of gold surface from which we are probably taking gold coated stamp putting it on and taking away some of the molecules. So, that is etching and deposition is a reverse where your action leaving the molecules on to the surface.

So, there have been some intelligent design so for or modification of this process, wherein high through put a formulation of this molecule lying out and the surfaces realize. This is one instant, where there is roller mechanism, which actually picks up the molecules from some source probably and then, it delivers rapidly on to a surface which also moves in a directed conducive the direction of rotation. Similarly, there is this mechanism again, where you can see the molecules are been transferred from the PDMS stamp on to this PDMS by a central cylinder, which essentially picks up the molecule and places the molecule on this particular upper PDMS structure.

The next step, the following steps are involved in micro contact printing. You ink the PDMS surface with molecules, alkylthiols, proteins, DNA; transfer the layer through physical contact in a gold layer and optimize the time, so that there is a good amount of time for the option to fully take place. Then, the engine is performed because of that covalent binding on the substrate or the substrate or the physic absorption on the surface and it can be performed on flat as well as curved surfaces.

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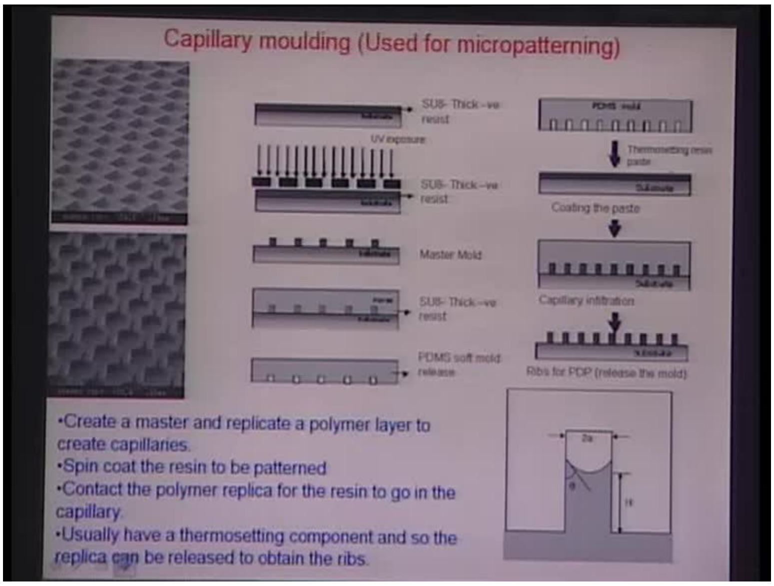

Another important soft lithography process into question; the other process, which is very important and sometimes used in display technologies is capillary molding. Essentially, the concept is again similar. The next process talking about is capillary molding used for micro patterning. Probably, this subsequently some other soft lithography techniques will cover in the next lecture.