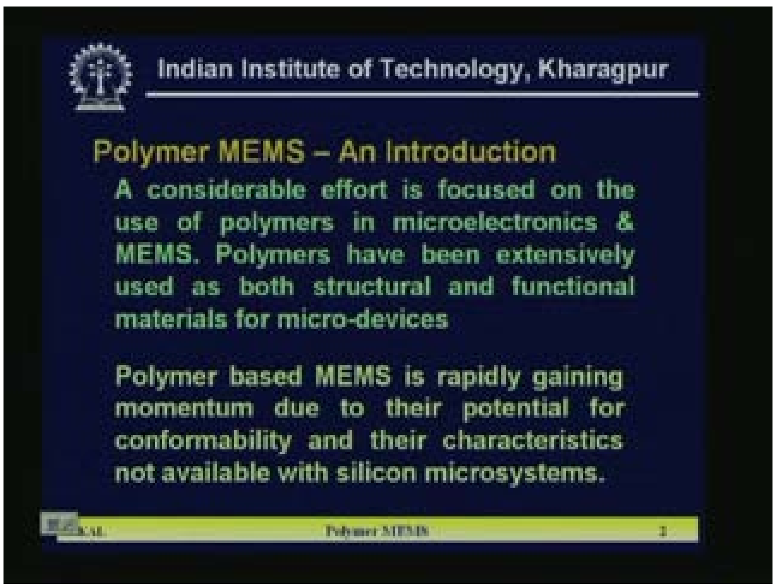
MEMS & Microsystems
Prof. Santiram Kal
Department of electronic & Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. # 29
Polymer MEMS & Carbon Nano Tubes CNT

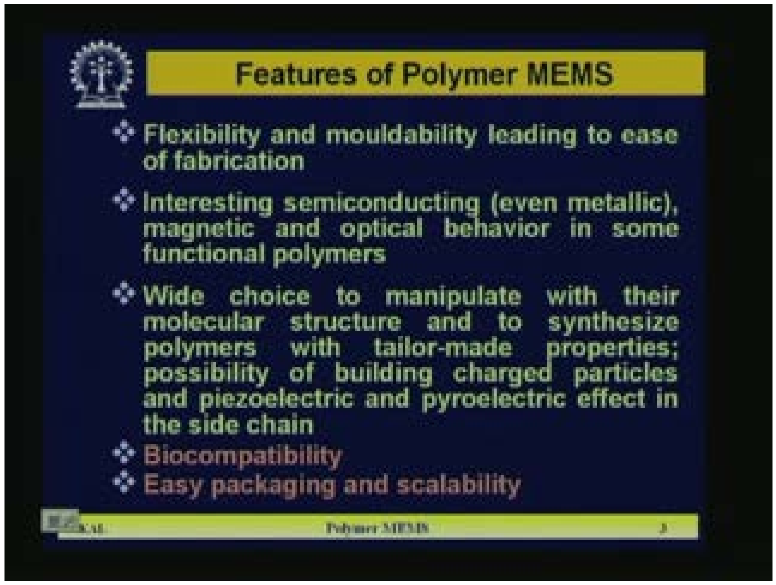
Topic is polymer MEMS and carbon nano tubes. It is a very interesting topic and very recent one also. Carbon nano tubes you might be heard the name of you might be acquainted with the term corbon nano tubes. And that has got enormous potential in today's micro technology. We will discuss on carbon nano tubes. How these are synthesized? How it is coming into MEMS devices? Before that we will spend some time on polymer MEMS. Till now we are discussing on silicon MEMS mainly but I will deviate from that because polymer MEMS has got enormous potential in comparison to silicon. So far as cost point of view and some other advantages are there which I will highlight in today's lecture.

(Refer Slide Time: 01:41)



So polymer has drawn considerable amount of interest in recent years in microelectronic and MEMS. It is extensively used as both structural and functional materials for micro devices. Functional material means this material can be transformed into high conductive material so that you can use it as a conducting line. These polymer materials can be used as ferroelectric material polymers can be used as ferroelectric material. That is why it is known as functional materials and structural means which is used for making certain structure. It will not be used for certain achieving or getting certain function in the circuit. Earlier idea was that the polymers and these organic materials they cannot be used as functional material. But in the recent years they have proven their ability with certain synthesis mechanism and now people are trying to incorporate these materials into the functional devices also not only as structural materials. Polymer based MEMS is rapidly gaining momentum due to their potential for confirmability and their characteristics not available with silicon microsystems. Certain characteristics which we get in case of polymer, which is never achievable in case of silicon and that is why it is gaining its momentum.

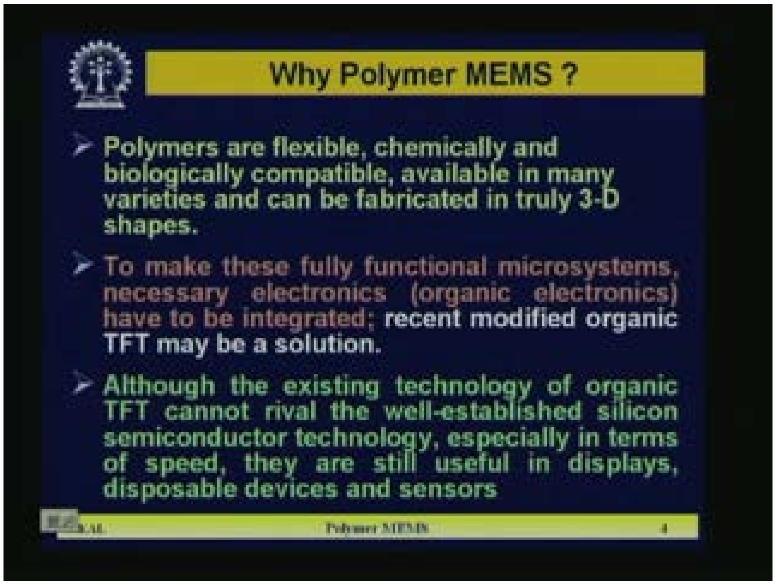
(Refer Slide Time: 03:29)



Now let us see the specific features of polymer MEMS. First point means positive point in case of the polymer MEMS is its flexibility and moldability leading to ease of fabrication. It is a highly flexible material polymer and you can mold it according your requirement or design which is not possible in case of silicon. Because silicon is a single crystal material it has got certain crystallographic access. If you do the micromachining so you will get this structure. As for the crystallographic plains, some plains will be etch some will not be etched and depending on that you can get it. So if you want to have any curved surface, regular curved surface it is not possible in case of silicon. Some bending is not possible in case of silicon bend is smooth bending flexibility is not available in case of silicon, which is there in case of polymer. So that is one advantage. Another important point is that the earlier people used the polymers as just a plastic material. But now it is showing interesting semiconducting properties. Sometimes even it is metallic behavior is also obtained in case of polymer. Also in some of the function polymers we found that they have magnetic optical behavior.

So for magnetic devices optical devices is also polymer can be used. So you will have wide choice to manipulate the polymer material during synthesization, during the development stage of polymer, so that you can have tailor made properties as you wish. That means whether the polymer will show as a metal or it will show semiconductor or it will show as a magnetic material or an optical material or a ferroelectric material a pyroelectric material, that mean tailor made. You can get these materials with certain techniques during the synthesization. That means its properties functional polymers properties can be changed during synthesization. So that is one of the great things which you cannot achieve in case of silicon. So because of that it is gaining high momentum. Even in some cases you can have in polymer charge particles also, like semiconductor. What you get it polymers are biocompatible this added advantage and easy packaging and scale ability is possible with the help of the polymers.

(Refer Slide Time: 06:27)



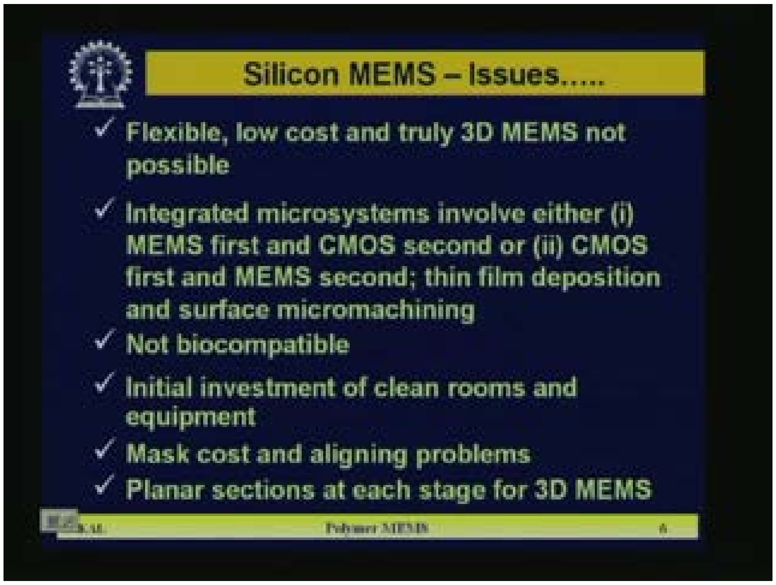
Even then now lot of questions are coming why polymers MEMS. To answer the question why polymer MEMS certain points, I have highlighted here which are mainly polymers are flexible chemically and biologically compatible, available in many varieties and can be fabricated in truly 3D shapes. Second point is to make this fully functional micro system. Fully functional micro system means what? Sensor actuator electronics all will be together then we will call fully functional micro system which was not imagine maybe 10 years back now people have started thinking. So necessary electronics for micro system can be developed from the polymer which is known as organic electronics. That is being integrated into the polymer MEMS devices to have complete functional micro systems. A recent modified organic TFT may be a solution. Organic TFT has already come into the picture.

TFT is thin film transistor and that has helped a lot, prices gone down drastically. But one point is certain that although the exiting technology of organic thin film transistor cannot rival the well-established silicon semiconductor technology especially in terms of speed, in case of silicon technology. Silicon devices the speed you achieve that is not possible polymer devices polymer transistor. But no problem all circuits are not required high speed there are certain areas where is speed is not at all a concerned. In those areas are mainly in case of displace, in case of disposable devices and sensors there speed is not a major concern. So in those areas you can use the polymer transistors or active devices along with sensors and actuator to have complete functional polymer micro systems.

(Refer Slide Time: 09:00)

Now the advantage of plastic polymers are, they are transparent transparency is there. Large surface areas you can achieve replication easily you can make it. Low cost fabrication process, high volume you can get and prototyping easily you can be formed. The main major point is the low cost fabrication process. For this you do not need the silicon clean room facilities and those expensive equipments are not always required. That much cleanliness which is maintaining in case of VLSI fab. It is not necessary in case of polymer fab. So these are some added advantage. That is why it is very low cost and here the normal lithography is not done. But certain technology you want which is known as a replication. So replication is one of the method by which you can duplicate or replicate large volume production you can get it from polymer devices.

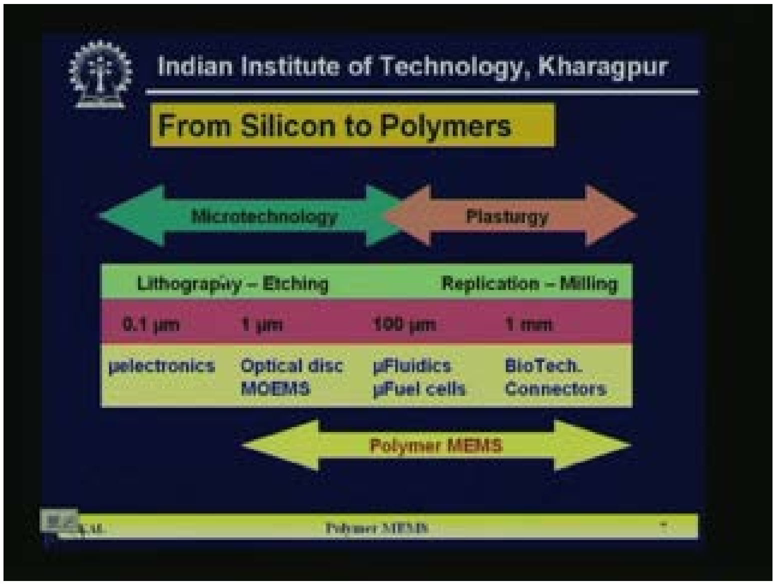
(Refer Slide Time: 10:07)



Now silicon MEMS what are the issues? Why peoples switched over in some cases from silicon to the polymers? In silicon although still we are fascinated with the silicon MEMS, but it has certain limitations. What are those? Flexible low cost and truly 3D MEMS are not possible with the silicon. These are the issue in silicon integrated micro systems involved either MEMS first and CMOS second or CMOS first and MEMS second. That means in some cases for micro system they go for MEMS first, then silicon. Silicon means for functional electronics signal processing circuits that may create some problem. So people go for other way approach. What is that? CMOS first and MEMS second. So then you need to protect the ICs or silicon chips, when you go for micromachining of the silicon sensors or actuators.

Silicon is not at all biocompatible, one drawback. Initial investment of clean rooms and equipment is very high. That is basically for that we are using VLSI fabs that are highly expensive. Mask cost and aligning problems are there in silicon minus planar sections is each stage for 3D MEMS. So if you want to 3D, so 3D you are getting by assembling different small pieces and when you go for small pieces fabrication one question of penalty is coming and the every stage you have to get surface highly planar. So planarization one important issue in case of silicon technology because you are fully dependent on what lithography. If the surface is not highly planar it is very difficult to go lithography process and to get different structure one after another. So those are the some of the issues in the case of silicon technology.

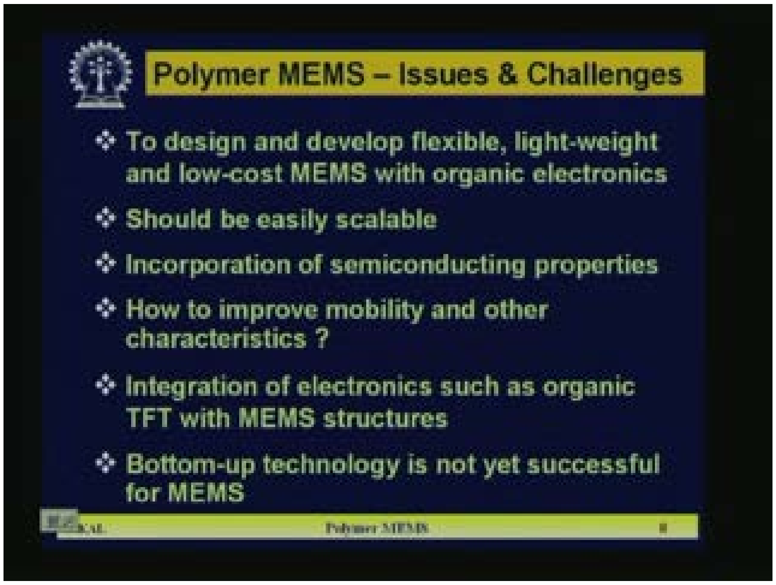
(Refer Slide Time: 12:21)



Now if you move from silicon to polymers then what are the comparisons? Now in this diagram you can see the one side is micro technology, other side is plasturgy. That is basically the polymers related processing. So in micro technology we go for lithography and then etching. That is the main MEMS process in micro technology and if we can go lithography up to 0.1 micron, then we call those areas is a real microelectronics. In case of 1 micron optical disc MOEMS, 0.1 micron means the silicon microelectronic including MEMS. If you go for optical disc MOEMS you need one micron. Now on the other hand if you in plasturgy the main technology is replication and milling.

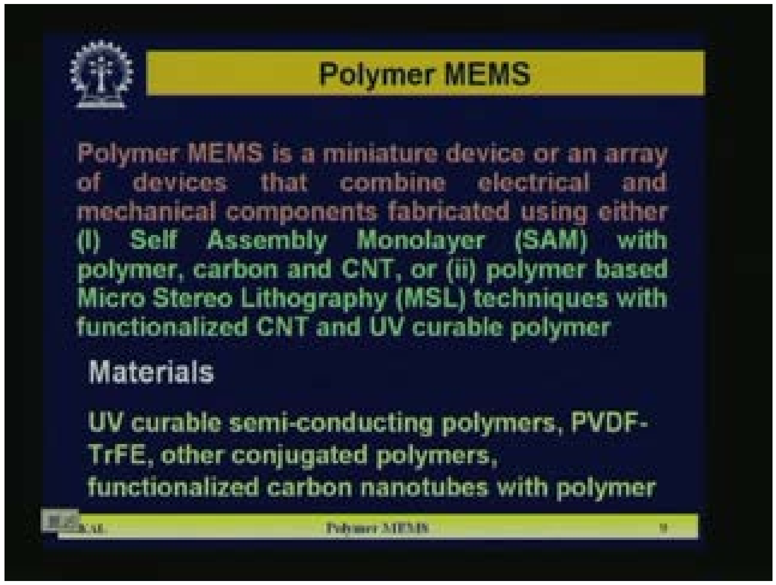
Replication again there if you go for 100 micron, those 100 micron designs are required for micro fluidics and micro fuel cells and if you go for 1 millimeter, those are required for biotechnology connecters. So this area means 100 micrometer to 1 millimeter which normally we get by replication and milling technology. This basically deals with polymer MEMS. That means in polymer MEMS the 1 micron or submicron, those things are not coming into the picture because there is a problem. What is the problem? The polymer molecule itself size is one constant. So there even that 100 micron to 1 millimeter, depending on your application successfully, if you can replicate and make devices that has got wide market potential particularly the cost term point of view.

(Refer Slide Time: 14:33)



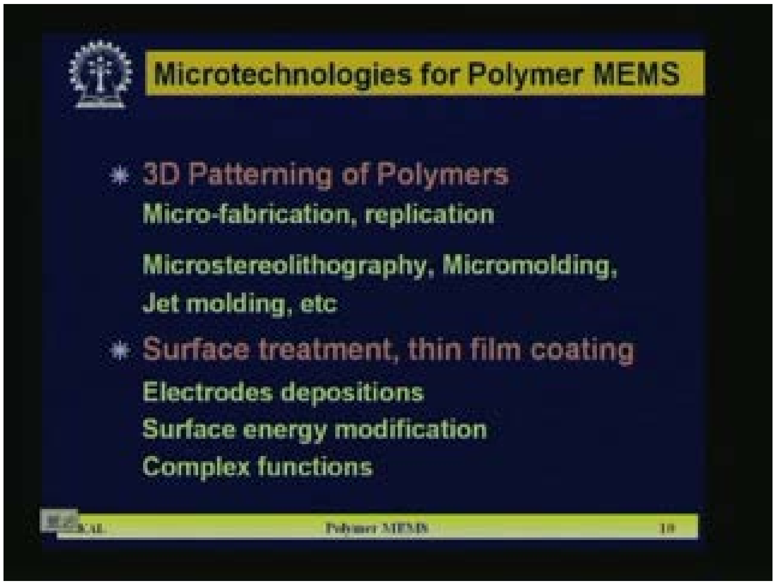
Now what are the polymer MEMS issues and challenges? Earlier I told you the silicon MEMS are issues and challenges. Now let us see in polymer MEMS what are the issues and what are its challenges and how can we circumvent those challenges and problems. In polymer MEMS what we follow? We design and develop flexible light weight and low cost MEMS with organic electronics so that is the main objective. It is easily scalable but the challenge is incorporation of semiconducting properties. It is not so easy although it is possible. But these are the challenge you have to face incorporation of semiconductor properties. If you incorporate then if you want to have high quality devices, so you have to improve the mobility characteristics of the carriers inside the polymer material, so this is one challenge. How to improve the mobility and other characteristics of the devices. And next challenge is integration of electronics such as organic TFT with MEMS structures, this is another challenge. Bottom up technology is not yet successful for MEMS in polymer MEMS. Top down approach is not possible but bottom up approach is not possible in case of polymer MEMS. So these are some of the issues and some of the challenges in case of polymers.

(Refer Slide Time: 16:23)



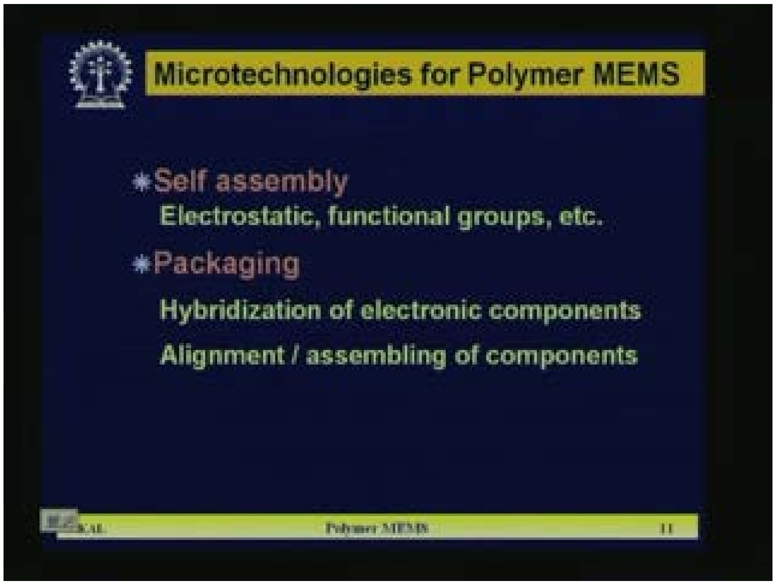
Now what are the technologies? Polymer MEMS miniature devices, they require combination of electrical and mechanical components fabricated using basically two technology. Because in MEMS you have to have some mechanical components other than electrical components. So these two methods are one is self-assembly monolayer which is known as SAM with polymer carbon and CNT. CNT is a carbon nano tubes it is not form a CNT and the second approach is polymer best microstereolithography with functionalize CNT and UV curable polymer. These are the two methods which have followed for getting polymer MEMS. Microstereolithography already I discussed in micromachining lectures there again I will give you some information on that and along with MSL we combine the CNT and UV curable polymer. You have to have certain polymer which can be cured using ultraviolet radiation. So materials we use for getting those MEMS are PVDF, TRFE and other conjugated polymers, functionalize carbon nano tubes with polymers. So these are some of the material issues which we have to properly build up and develop the technology for getting those materials.

(Refer Slide Time: 18:10)



Now microtechnologies for polymer MEMS. What are the different steps which we have to expert ourselves? One is 3D patterning of polymers; it requires micro-fabrication, replication, microstereolithography, micromolding, jet molding, and etcetera. 3D patterning of polymers means these are the topics which come under 3D patterning. That basically micro-fabrication, replication, microstereolithography, micromolding and jet molding. Next topic surface treatment thin film coating. So for getting electrodes for connection and contacts we have to go for thin film coatings on polymer. So electrode deposition because polymer material you cannot treat it. Very high temperature so low temperature electrode formation techniques have to be standardized. Surface energy modification that is one issue we have to look into it complex functions, if we need complex function in polymer devices, that is another issue is coming into the RND level we have standardize that before going for polymer MEMS.

(Refer Slide Time: 19:34)

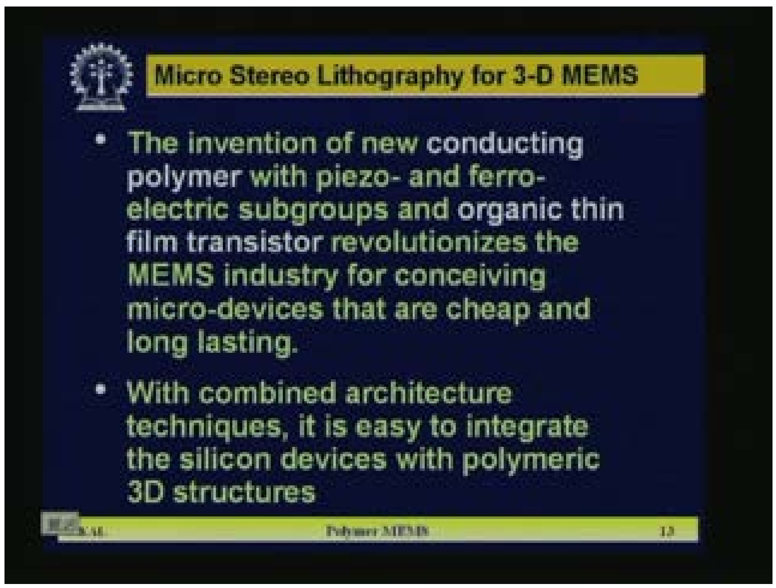


What are the other microtechnologies? Self-assembly and packaging. Self-assembly will involves electrostatic functional groups will be there. You have to assemble those different; some are purely mechanical, some are electrostatic in nature, some are functional groups like say the ferroelectric property and pyroelectric property you may get it. So those things are properly assemble to get the complete micro system and last is packaging. Hybridization of electronic components alignment assembling of components. Those are issues in the case of proper packaging of those polymer devices.

(Refer Slide Time: 20:15)

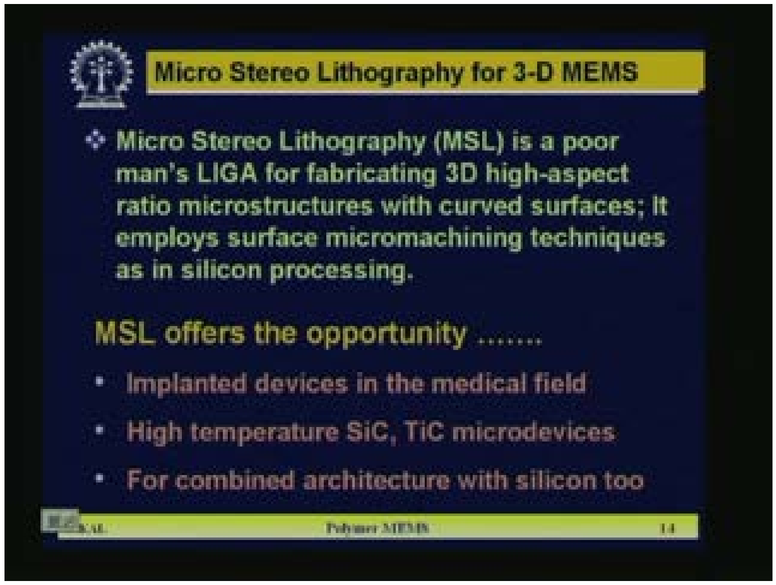
So now other than micro technology one is there in the 3D patterning. We told you that microstereolithography is one of the important micro technology which is being used in case of polymer MEMS. Now let us spend some time on the again on microstereolithography for 3D MEMS. This particular technology or is a popular bulk and surface micromachining for silicon MEMS. But this MSL which is conventionally used for silicon MEMS are not suitable for real 3D objects with high aspect ratio. Some technique we know for getting high aspect ratio is the LIGA process which can create micro structure with excellent aspect ratio also. But all this process which is used, all this process means either the surface of bulk micro machining or microstereolithography, even they are not at all suitable for curved surfaces. If you want to have curved surface with regular curvature, that is not possible on those conventional methods for silicon.

(Refer Slide Time: 21:45)



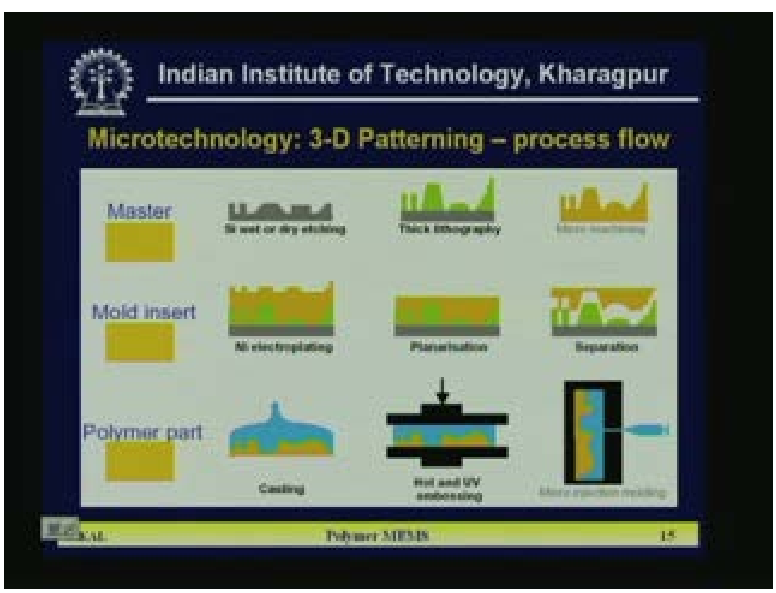
Now the invention of new conducting polymer with piezo and ferro electric subgroups and organic thin films transistor revolutionizes the MEMS industry for conceiving micro devices. That is cheap and long lasting. Two properties highlighting here highlighted here. One is conducting polymer, other is organic thin film transistor. With combined architecture techniques it is easy to integrate the silicon devices the polymeric 3D structure. Now this is basically the hybrid nature combine architecture. Silicon MEMS and polymer MEMS wherever you need certain function and certain properties which polymer cannot give, then you have to go for silicon and then the issues are coming whether silicon and polymer together can be integrated properly and you can make certain packaging 3D real combine architecture whether you can get it or not. These are the various aspects on which lot of RND is going on.

(Refer Slide Time: 23:03)



Now microstereolithography MSL. As I mentioned earlier is a poor man's LEGA for fabrication 3D high aspect ratio micro structures with curved surfaces. It employs surface micromachining techniques as in silicon processing. MSL offers the opportunity for implanted devices in the medical field. High temperature silicon carbide, titanium carbide, micro devices or combine architecture with silicon too. These are the 3 opportunities we can get from MSL. Implant devices in the medical bio MEMS area medical field. High temperature is a silicon carbide titanium carbide materials some ceramic MEMS also I mentioned. Those micro devices are sometimes possible from the using sorry possible using MSL techniques and recently the combine architecture silicon and MEMS is also visible

(Refer Slide Time: 24:11)

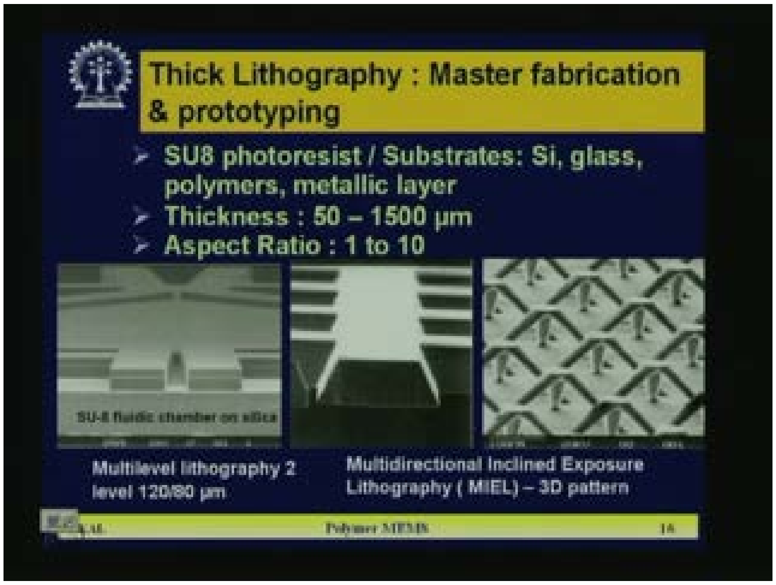


Now I will show you some of the process flow normally used in case of polymer MEMS. So you can see here the first diagram which shown silicon wet or dry is etching. So similar micro structure you can get in silicone dry or wet etching. You can see here you cannot get here the smooth curved because all the structure you got by bulk micromachining are some crystal surface, crystal pieces. So that is shown in the first drawing silicon wet and dry etching. Now the second one which is a thick lithography where along with this some steps you may get some bend with certain corners; gradual corners. But if you go for the micromachining with certain techniques we can get the bend like that, I told you that bending or shaping like round, shaping, etcetera you can make it with small square also. But gradual bending or curvature is possible using the polymer kind of thing which is shown in the second row. Here what has been done? First the basic structure is there, it looks like this which is bottom and which is greenish color. On top of that you just nickel electro plating. That top is the nickel electro platting then you planarize it.

During the planarization what has been done? You can just remove some of the top portion of this material; mold material. Then what you do you separate it out separation. Now if we separate it out from the basic base material then you can have this structure like this which contains either regular group curvature and all sorts of different patterns is possible. That is a mold insert. But these are with certain trouble we can get the some kind of some kind of the curvature along with the discrete globes. But in the bottom one which is the polymer part that you can see is a lot of freedom here. So you can see here what is being done, with the structure first base structure. You get it dye kind of thing, and then you put the polymer blue color is a polymer you dip it. Just drop some amount of polymer on the surface of it. Then what is being done, and then you just press it. The polymer is highly flexible with this, the metal part you can see the arrow it is a pressing. After pressing that means it is known as hot UV embossing emboss with pressure in presence of ultraviolet radiation.

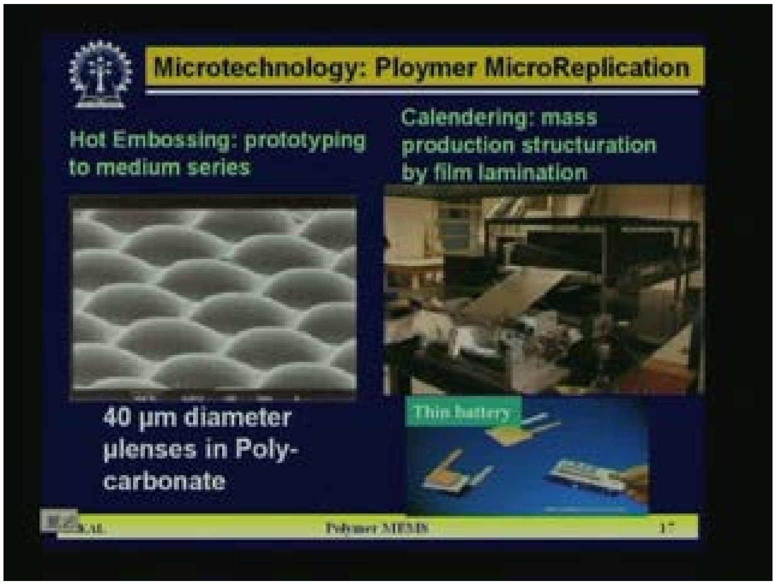
Now you can see when you release it you can separate both this structures which is a solid base and the polymer thing which is at the top. So you can have any kind of flexible structure. This is one kind of technology which is used in polymer part. That means here no nothing like the photolithography or etching technique is done here. Another technique is also followed which is known as a micro injection molding. What is that? The whole structure you put it in an enclosure then through a nozzle kind of thin needle you can inject the polymer into that. So that polymer will go inside and it will be deposited a field the complete group with high pressure. So you can get the mold as structure you as flexible structure you wish. Isn’t it? So these are the differences between the silicon dry and wet etching structure and you can see at the end here. The micro injection molding and hot UV embossing in case of polymer. The bottom two are in case of polymer and earlier is that several modification of silicon technology which either you use photolithography or you can use the molding or the electroplating also.

(Refer Slide Time: 28:57)



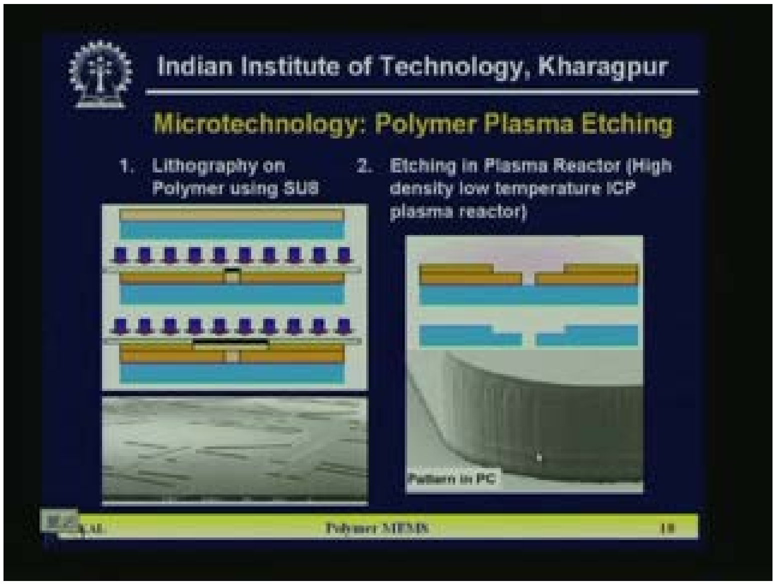
Now thick lithography master fabrication and prototyping. There we normally use a Su8 photoresist and substrate to use silicon, glass, polymers, metallic layers, and etcetera. Thickness normally varies 50 to 1500 micrometer aspect ratio you can get, 1 is to 1 to 10 aspect ratio you can get it. So some of the photograph shown here. In the bottom is SU8 fluidic chamber on silica there we have used double lithography. First part you define the pattern bottom and the second is first is a 120 micrometer thickness and top up 8 it another lithography follows where 80 micron structure is made using Su8 photoresist not normal photoresist which is used for VLSI technology. And in the right side you can see here some other devices with multi directional incline exposure lithography which is known as MIEL to get the 3D pattern. So you can say here some of the structure is bends like structure you can see angle with some angel it has been patterned. So that is possible with the help of MIEL technique which is multidirectional inclined exposure lithography. Not directly perpendicular rays are incident on the top of the photoresist and you expose it and you get the pattern. Is an inclined exposure and that is the multidirectional inclined exposure technique which some times used for getting similar kind of structure in MEMS.

(Refer Slide Time: 30:45)



Now polymer microreplication. Some technique is shown hot embossing technique in the left side. You can see some microlense in polymer carbonate polycarbonate. Polycarbonate micro lens are shown here in this diagram and that has been fabricated by hot embossing prototyping to medium series. So hot embossing technique is shown in earlier diagram. So that technique is use to get this polycarbonate micro lenses. In the right side the calendaring the mass production structurisation of by film lamination. This is one thing is going on in mini industrial kind of thing. So thin sheets are just like the metal sheet is coming some polymer sheet is coming on top of some substrates and using this lamination of different polymer films, you can have certain thin battery. Some batteries are shown here in the bottom picture you can see those have been fabricated using polymer the lamination, polymer technology. Both functional and structural polymers have been used to get similar kind of devices.

(Refer Slide Time: 32:05)



So now microtechnology polymer plasma etching. That is also another area where people are working and that is one in normal lithography on polymer using SU8. You can see the first is a the structure is like that is a base material on top of that SU8 photoresist is coated. In the second you put the mask and is irradiated this arrows are shown radiation, UV radiation and after that you can have the structure. One structure is a bottom whole and then again you put another SU8 resist and again you put another mask then you can get this pattern and you can get after etching removal of this material you can get like that. This structure you can get it. And after this can also be fabricated using the plasma reactor, high density low temperature ICP plasma reactor. That is also possible for removal of the certain resist through a mask SU8 resist and there also polymer mazes can be seen using the a reactive etching of certain plasma gases inside a plasma reactor. So that is also used in some of the fabs where the polymers is pattern using the plasma technology.

(Refer Slide Time: 33:27)

Now here some of the devices are shown where the surface of the polymer has been modified. So one is you can see here optical coating on CD. Some CD is on top of that, some optical is made that is using polymer and that polymer deposition is done with the help of PECVD, PVD or CVD. And hydrophobic coating in some cases. In some devices you need some kind of hydrophobic coating. So that will not react with the moisture. So for that the electrodes has to be deposited some polymer materials thin coating is being done and here in the bottom some transparent electrode on PC. So that is also shown some transparent electrode and they use the Parylon, Teflon and they modify the surface energy of the coating to get that transparent nature of the. So bio-compatibility enhancement is another issue which people are working on that.

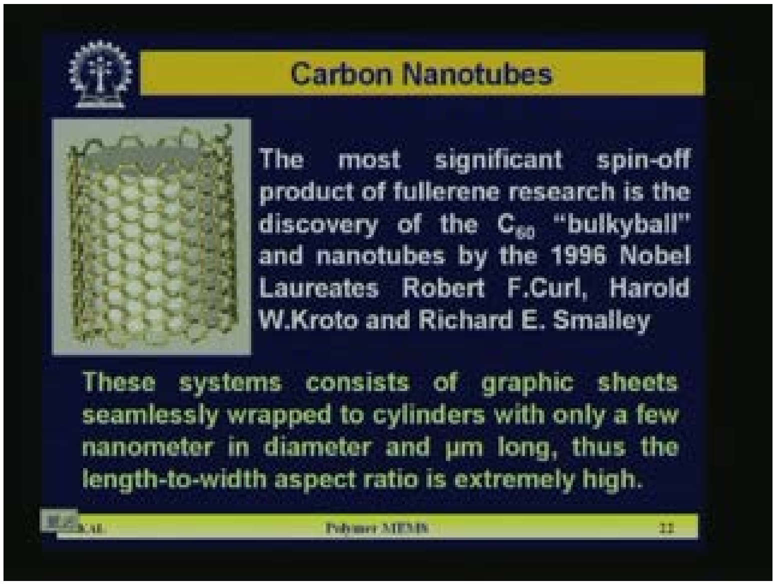
(Refer Slide Time: 34:43)

Now polymer surface micromachining. You need to study either structural or sacrificial polymer. In case of structural polymer which are basically used as a structure of the devices, not as sacrificial layer which may be removed later on. So electroactive polymer or ionic conducting polymer, they are known as EAP or ICP they are UV curable and they provide mechanical strength structural integrity and electrical conductivity. So this materials are used for structural purposes. New generation of ceramic side group materials which are ferroelectric and piezoelectric materials at nano scale. They are made using sol-gel technique hydrothermal technique microwave calcining technique and sintering. Microwave calcining and sintering that is on technique hydrothermal is another technique and sol-gel is well known technique. Using these techniques we can some new generation polymer which has got ceramic side groove functional blocks which is the ferroelectric or piezoelectric in nature.

(Refer Slide Time: 36:01)

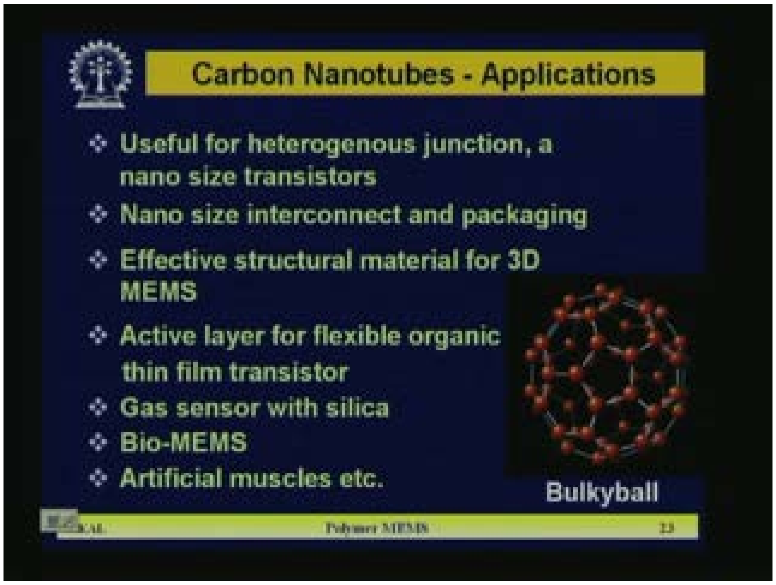
For structural polymer, I mentioned structural. For sacrificial polymer we use acrylic resin which contains 50 percent silica and it is modified by adding some crystal violet it is another chemical. This composition is dissolved with 2 mol per liter caustic soda at 80 degree C. So when you design some polymer for sacrificial purpose we have to give its etching composition. So that is 2 mol per liter caustic soda at 80 degree C is there. The etching solution of acrylic resin which content 50 percent silica and crystal violet be chemical. So these are the structural and sacrificial polymer.

(Refer Slide Time: 36:51)



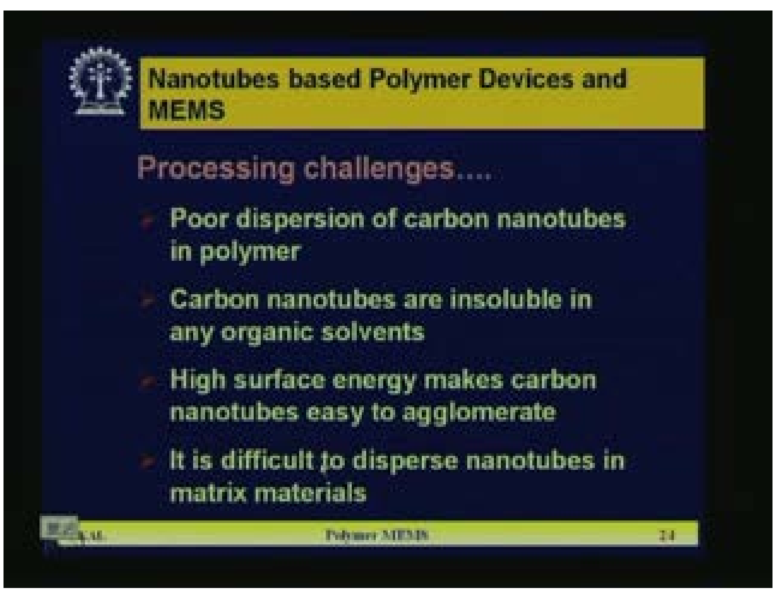
Now I will just give you some idea on carbon nanotubes is a very recent one and this particular the material I can say is a magic material some people are called it is bulky ball and for that in 1996 Robert F Curl, Harold W Kroto and Richard E Smalley got noble prize for this carbon nanotubes is not very far away phenomena. Recent phenomena in 1996 and basically is a product of fullerene research and they discovered C_{60}. C_{60} is the carbon nanotube, this composition and that the picture of the carbon nanotube the assembly is shown also left side. This systems consists of graphic sheets seamlessly wrapped to cylinders with only a few nanometer in diameter and micron in long. Thus length width aspect ratio is extremely high. You can see here few nanometer in diameter each of the C_{60} atom and they are formed a chain and they are wrapped just like a cylinder of few micron length. So nanometer in diameter to micrometer in length. So automatically aspect ratio is very high the carbon nanotubes.

(Refer Slide Time: 38:34)



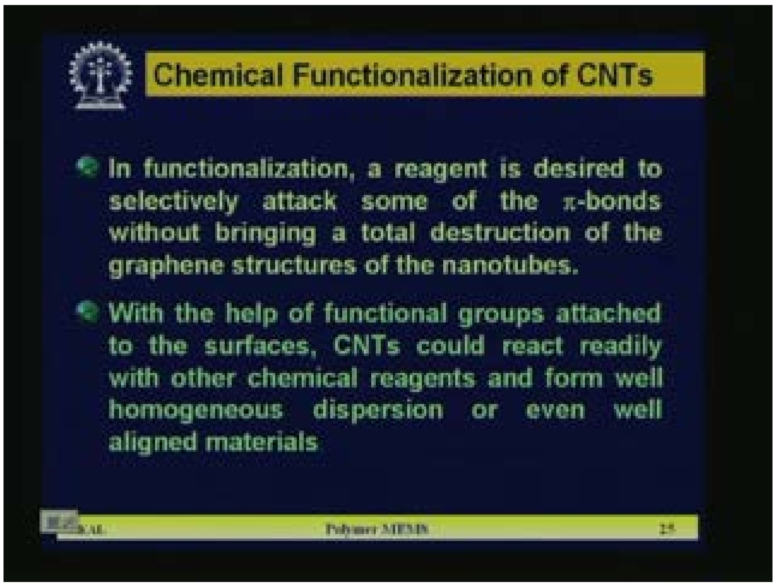
Here is shown is the bulky ball. If you look into the one structure of C_{60} configuration, it looks like that. So it is easy some time call as a bulky ball. Its applications are innermost is useful for heterogeneous junction. A nano size transistor between nano electronics is also coming in future nano devices lot of research is going on. So you can make heterogeneous junction nano size transistors using carbon nano tubes. Nano size interconnect and packaging also possible. Effective structural material for 3D MEMS. Active layer for flexible organic think film transistor, application of the carbon nanotube. Gas sensor with silica enormous application in Bio-MEMS, artificial muscle you can create with the help of the carbon nano tubes.

(Refer Slide Time: 39:41)



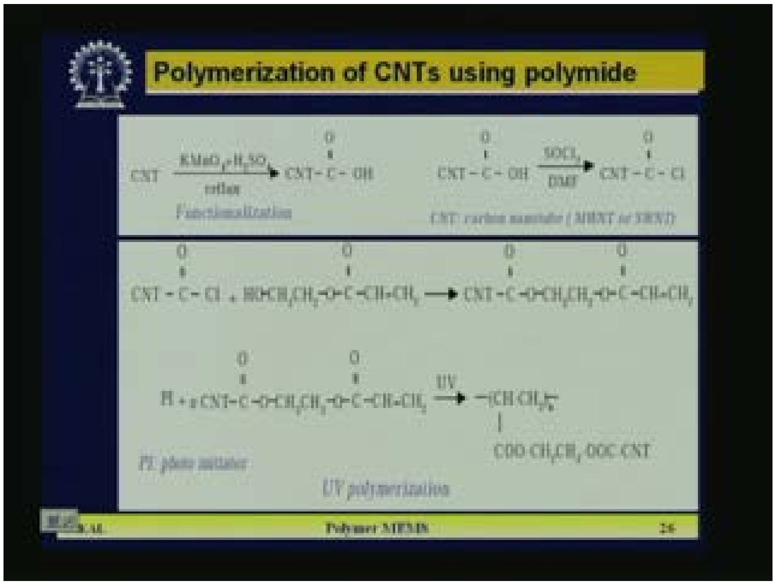
But there are certain challenges of processing or getting this carbon nanotubes. Because of certain problems, what are those? Poor dispersion of carbon nanotubes in polymer we want to integrate Carbon nanotube in the polymer but we are facing challenges because the dispersion nature of carbon nanotubes is very poor in polymer. Carbon nanotubes are insoluble in any organic solvent that is another problem another challenge. High surface energy makes CNT easy to agglomerate. Carbon nanotube is having high surface energy which prevents CNT to easily agglomerate. It is difficult to disperse nanotubes in the matrix materials. These are few of the challenges rather processing challenges of CNT.

(Refer Slide Time: 40:42)



Now chemical functionalization of CNTs. How it can be done? In functionalization a reagent is desired to selectively attack some of the pi bonds without bringing a total destruction of the graphene structures of the nanotubes. With the help of functional groups attach to the surfaces CNTs could react readily with other chemical reagents and form well homogeneous dispersion or even well aligned materials. That is the techniques people are following. So it is just some of the functional grooves of attached with CNTs with other chemical agents. Because it is not easily dispersed into the polymer and we get certain mixtures, synthesize material which can show certain desired properties.

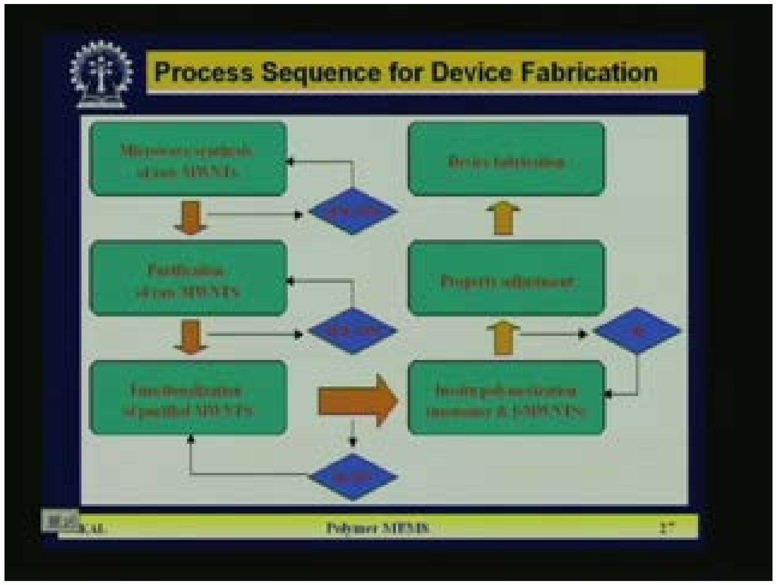
(Refer Slide Time: 41:48)



Now these are the functionalization reactions which are shown here. You can see here the CNT in presence of $KMnO_4$ and sulphuric acid, reflux reaction you will get, the structure shown here. The carbon is CNT and then carbon then 1OH function group on oxygen function group and now this first CNT is functionalized like this. So this functional material in the next step is used again for getting multi wall nanotubes or single 1 nanotube MWNT or SWNT stands for multiwall nanotube or single wall nanotube. Now with $SOCL_3$ $SOCL_2$ you can get CNT CO the OH group is replaced by chlorine group. Now after replacing the chlorine group the CNT, that function functional group is again reacted here with some other functional organic material here which you can see here the CH_2 CH_2 O C CH CH_2 with oxygen. This is some organic functional group is added with the CNT and chlorine mixture and you get this particular function.

Now this particular material is exposed to radiation with a help of photo initiator. So use some photo initiator and combine with this group and then photo initiator means some another chemical composition used which will react with this functional group in presence of ultraviolet light. That is why we call it as a PI, means photo initiator. So after the ultraviolet relation we get certain the carbons CNT along with some organic functional groups are attached with that to have certain desired properties. That is why I told you that polymers and CNTs that property can be made tailor made by changing this, the synthesize a synthesis chemical which you is it here. And if you understand the proper synthesis mechanism, so you can change its properties also different application different proposes.

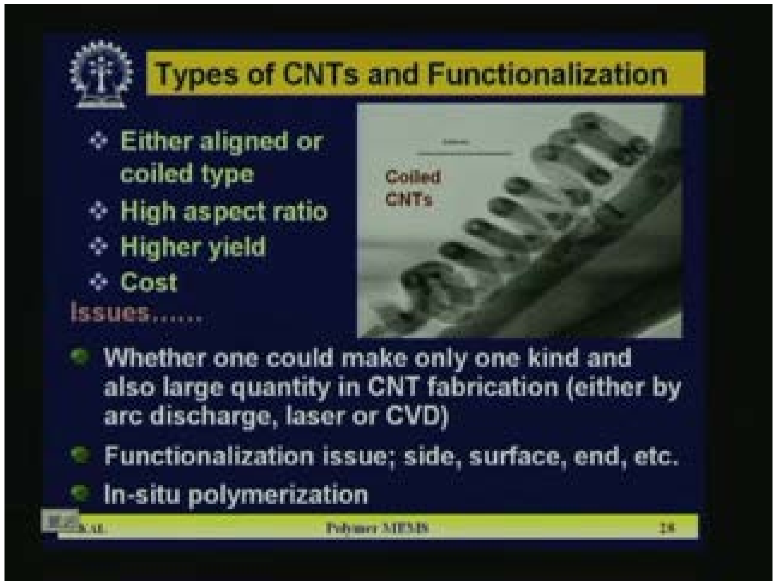
(Refer Slide Time: 44:11)



Now what is the process sequence of device fabrication for using the CNT? That is the first microwave synthesis for raw multiwall nanotubes and then during that continuously you have to monitor by seeing the structure using SEM scanning electron microscopy and TEM transmission electron microscope. So using that continuously, do that, then purifications of raw MWNTS which you get the multiwall the nanotubes that you have to purify and that purification procedure continuously you have to go for SEM and TEM. The next step is functionalization of purified MWNTS. Functionalization means what I showed in the last viewgraph using some organic or some other chemical composition, the function functional property of the complete composition is changed that is known as the functionalization. It depends on you requirement which you use that have to mix with it and you have to go for certain reaction either using photo initiator or by certain other mechanism. And after that whether the functionalization is proper or not that you can judge by seeing the arch or XPS.

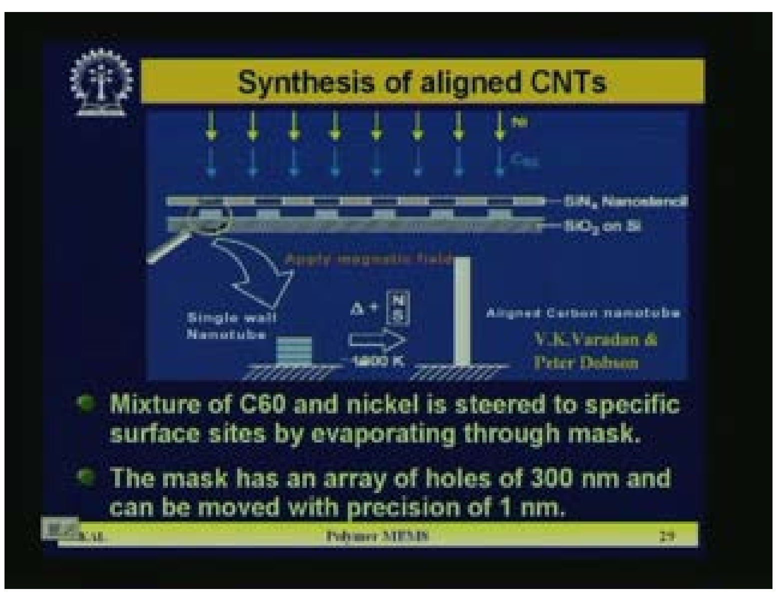
These are some characterization tools, then in situ polymerization of monomers and functional MWNTS; functions MWNT you got in this step. Then you go for property adjustment property can be adjusted tailor made property you can make it and after that you can go for fabrication of the device. So you can start from first the synthesis of the nanotubes multiwall nanotubes, then purify it, then functionalize it, then polymerize it and then property adjust by adding some other chemicals and then the material you get that can be used for device. So in this way you can have your tailor made approach to get certain desired properties of the polymer materials along with using the carbon nanotubes also as well you can integrate the carbon nanotubes with polymer.

(Refer Slide Time: 46:43)



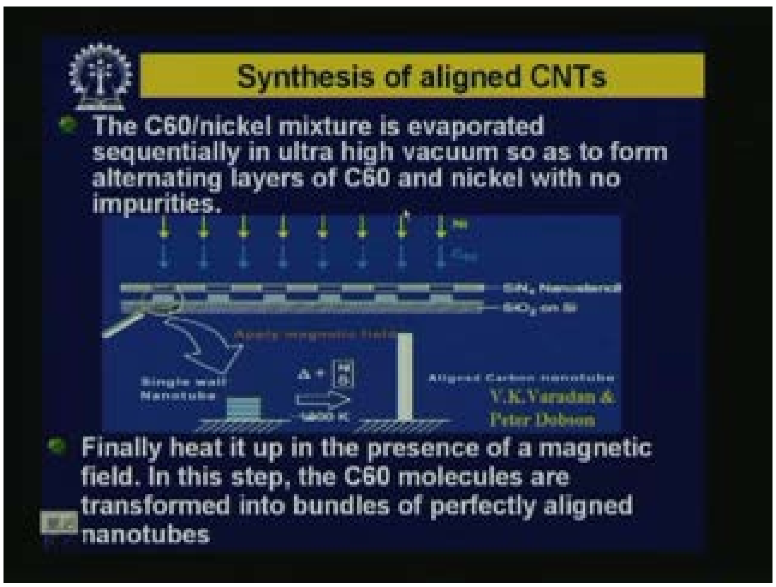
Now different types of CNTs are available because you can functionalize the material in different way. They are either the aligned or coiled type which is shown here. Some kind of coiled carbon nanotubes are shown in this diagram. You can adjust the aspect ratios, high yield and cost it depends and which type of CNTs you are going to create and which kind of functionalize and reaction you are going to adopt. But here the issues are whether one could make only one kind and also large quantity in CNT fabrication either by arc discharge laser or CVD. Functionalization issue are there side surface an end because shape these are the issues in situ polymerization. This is another issue during the CNT functionalization and different function getting different functions of the CNTs.

(Refer Slide Time: 47:54)



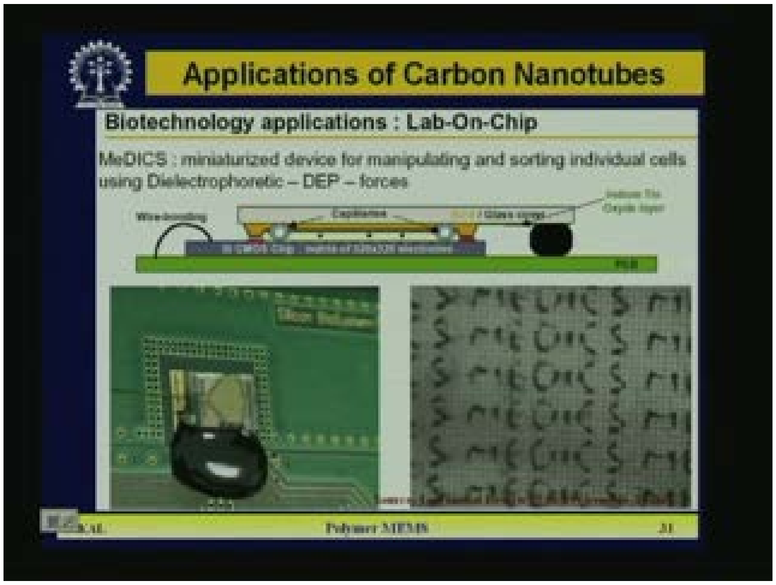
So now here you can see how the CNTs are synthesized. You can see here in that top diagram, so first you can, if you want to have the whole device on silicon dioxide or silicon, then on top you can have you want to decompose or you have to synthesize the polymer with CNT. Then C60 and nickel is basically forced through some of the wholes and those wholes are nearly hard 300 nanometer. So you can see here initially C6 C60 which is a carbon nanotube, then nickel layer by layer and if you do like that these are the windows through which you are making the reactions here through that coming and after that you are getting the nanotubes like that, single wall nanotubes. Then in presence of magnetic field and the 1300 K temperature. You can sinter it and you can have the aligned carbon nanotubes like that, with the application of magnetic field. So mixture of C60 and nickel is steered to specific surface sites by evaporating through mask. That is done here. The mask has an array of holes of 300 nanometer and can be moved it precision of 1 nanometer. So that is done at the top.

(Refer Slide Time: 49:29)



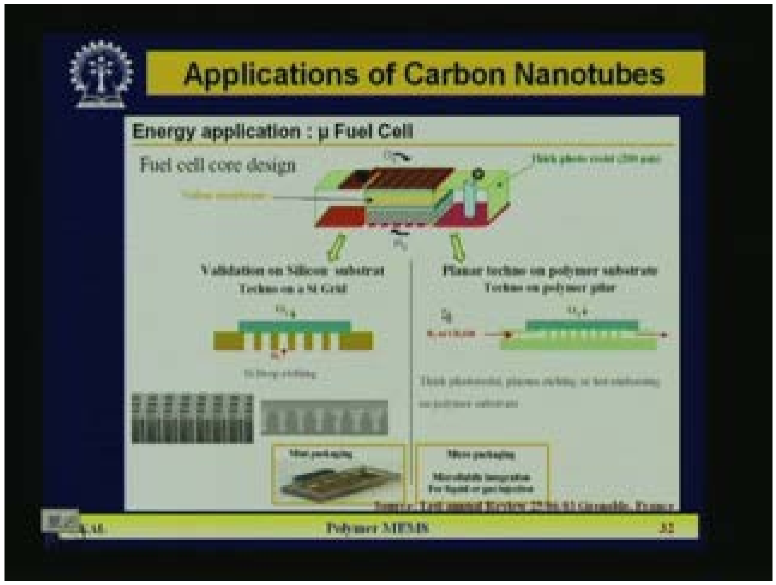
Then the C60 and nickel mixture evaporated sequentially in ultra high vacuum so as to form alternating layers of C60 and nickel with no impurities which is shown here this particular diagram, shows that stacked layer of those nickel and C60. Finally heat it up in the presence of a magnetic filed this is done here. Heat it in presence of magnetic field in this step C60 molecules are transformed into bundles of perfectly aligned nanotubes. After that you will get the bundles of carbon nanotubes which are perfectly aligned. So although I just told you within 2, 3 slide. But complete technology is not so easy. It is really difficult to get the single wall or multi-walled carbon nanotubes with proper functionalization.

(Refer Slide Time: 50:31)



Now I will just mention some of the unique applications of the carbon nanotubes. One in the biotechnology application is there. So there the miniature is device for manipulating and sorting individual cells using dielectrophoretic which is called DEP forces. That means its purpose is the sorting individual cells which is known as lab on a chip, sometime is referred to lab on a chip. That sometimes people use the carbon nanotubes is structure of the whole things is like that. So here the in SU8 is used CNTs are used and bottom silicon CMOS chips are used. Lot of copulated microfluidics, basically it is a combination I we can say hybridization approach. The silicon polymer the CNT SU8 and some other inbuilt materials are used for getting the lab on a chip application. Some of the photographs are shown, this has been taken from Laity's annual report fans they are working in that area and other application I will show you at the end.

(Refer Slide Time: 51:45)



That is energy application micro fuel cell. So micro fuel cells are made recently using the carbon nanotube technology so there is very complicated process of altogether. So oxygen and hydrogen are the main sources of energy which can be combined and can be made a fuel cell using two techniques. One technique is silicon substrate technology on silicon grid; another is a planar technology on polymer substrate technology on polymer pillar. So is a two way they are do one is a organic approach or is conventional silicon approach and in both cases they are able to get some micro fuel cell and that is also obtained from Laity annual report well-known fans. But the synthesis of the a the carbon nanotubes lot of work is going in VK Burdens groups at Penn state. So they are synthesizing using microwave techniques and other techniques and they are changing its property by proper by adding proper functional polymers, polymerization and in that direction there also trying to make certain solar panel. Using the polymer and carbon together, so whose efficiency they are expecting much better the conventional solar cells available now.

So that they can integrate together in any solar panel which is an urgent need any of the solar research. Solar means space research, particularly space recharge lot applications are there. Low cost high efficiency fuel cell or solar panel is possible. They are predicting using this polymer and carbon together along with some TFTs is organic TFT for making some electronic circuits. So these are some of the a points which I highlighted today is incent train in the MEMS research including combining polymer and CNTs also. And if you want to have further knowledge further idea on those particular interesting topics, you have to consoled literature and there lot of informations are also available on the web. You have to consult those information for getting further details and more knowledge in the area of the polymer MEMS and CNTs. But at the end I will like to say the CNT has really lot of potential and people are exploring to exploit. Those the potentials of CNTs for different kind of applications. So today I am stopping here. Next time we will discuss some other interesting topics. Thank you very much.

(Refer Slide Time: 54:56)

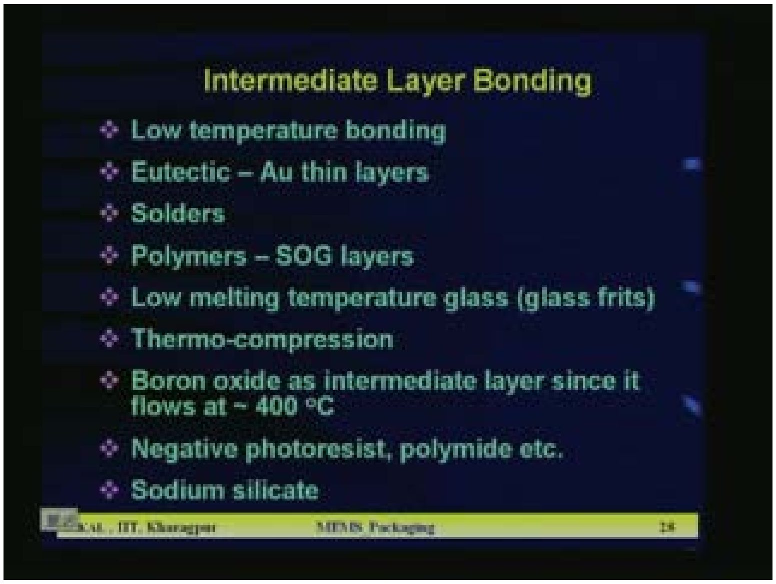
Preview of next lecture

(Refer Slide Time: 55:04)

Lecture No. #30
Wafer Bonding & Packaging of MEMS

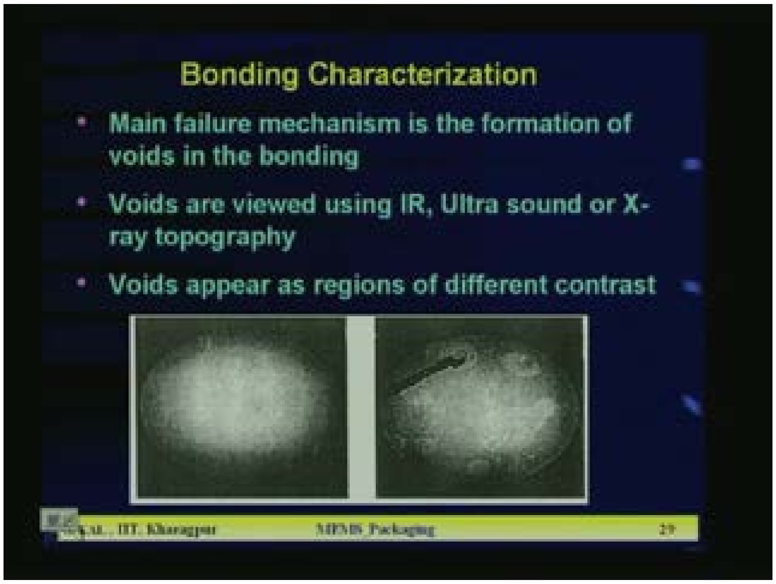
Today's topic is wafer bonding and packaging of MEMS is very important topic. Because in this particular point there is a lot of difference between the conventional VLSI bonding and packing and MEMS devices bonding and packing. In case of VLSI we have seen that bonding means this silicon chip is bonded with the encapsulation and after that you go for the wire bonding to different leads. But in case of MEMS it is not the same as the VLSI chip bonding and packaging. The major difference here is that in case of MEMS, 2 or 3 even multiple layer of wafers has to be bonded together to get the complete structure. And in that case the total thickness of the wafer will be more than 1 millimeter in some cases. In that case the total height of the device is not very small and another point in case of MEMS devices in many applications you need the outside environment should be reflected into the devices. For example in case of pressure sensor, the bonding and packing should be such that the device should be exposed to outside pressure or environment.

(Refer Slide Time: 57:02)



Very good quality the anodic bonding or fusion bonding techniques there are low temperature bonding basically you eutectic gold thin layers. Eutectic bonding means eutectic epoxy apparently use it and then you press it and may be 100 to 150 degree C you can heat it and you will bonding; but that is not very rigid bonding. So that is also used polymers may be used for bonding very soft bonding. Low melting temperature glass which is glass frit one example I showed you using the glass frit. Thermal compression bonding sometimes people use it boron oxide as intermediate layer since it flows at 400 degree C. Some people are using boron oxide because at 400 degree C boron oxide soft and it flows and then it helps bonding due to wafer. Negative photoresist polyamides are also used sodium silicate is another material which is used for bonding.

(Refer Slide Time: 57:54)



Now if you go for characterization bonding the failure mechanism is the formation of voids in the bonding, so that you have to get rid of the voids. Voids are viewed by IR ultrasound or x-ray topography. You can see it in picture in the left side there is no void and right side picture there are some void and it appear regions of different contrast you can see. So there means here some voids are there. So with this just we will stop today and I gave you a small overview of the bonding technique mechanism and which is good. What are the various aspects and low temperature bonding high temperature bonding may be chosen for different requirement of the MEMS devices and packaging. So let me stop here today. Thank you very much.