Micro and Smart Systems
Prof. K. J. Vinoy
Department of Electrical Communication Engineering
Indian Institute of Science – Bangalore

Lecture – 13
Non-Conventional Approach for Microsystems

Today, I will talk to you about some of the non conventional approaches for building Microsystems.

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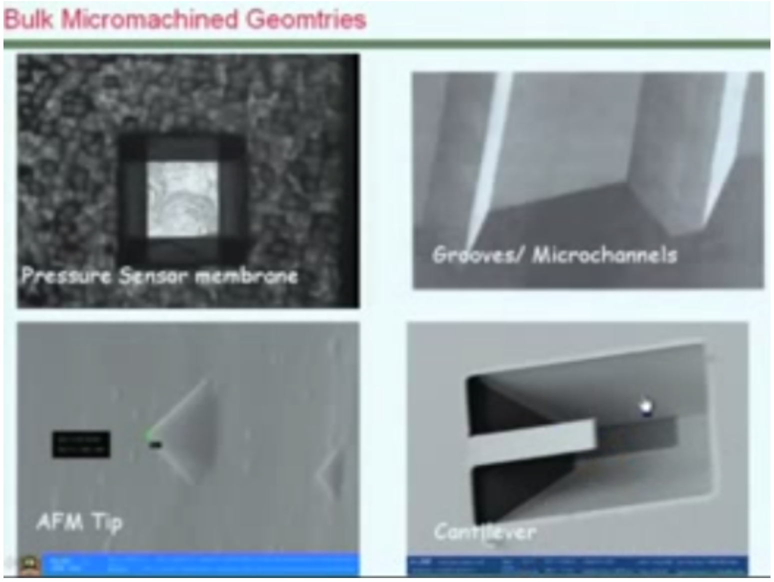

Bulk Micromachined Geomtries

As you may recall, we have talked about bulk micro machining for several geometries microsystems such as for a chamber for the case of pressure sensors to build grooves or channels, to build tapes for a firm and things like that, even for building cantilever kind of geometries with a cavity below such geometrics

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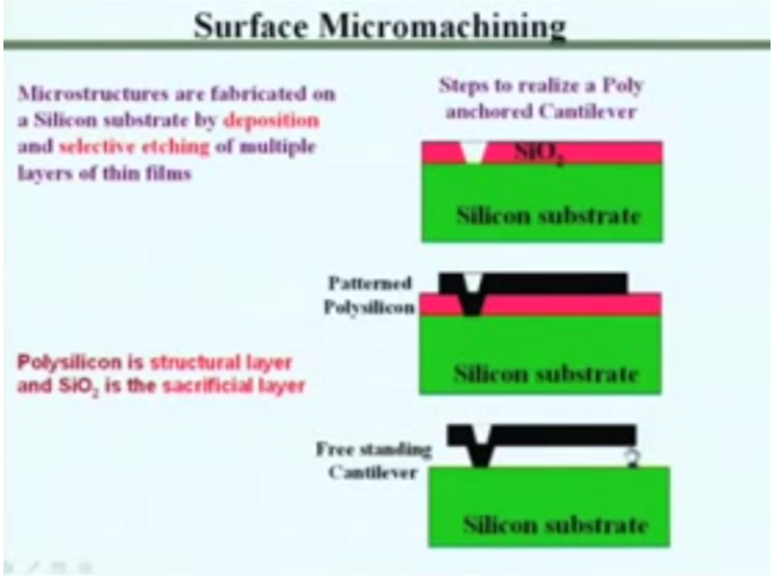

Surface Micromachining

Microstructures are fabricated on a Silicon substrate by deposition and selective etching of multiple layers of thin films

Polysilicon is structural layer and SiO_2 is the sacrificial layer

Steps to realize a Poly anchored Cantilever

We have also talked about surface micro machining which essentially consist of adding at least 2 layers above the silicon substrate. The first layer being called is sacrificial layer which will be etched to create a window for including the anchor for the structural layer and the sacrificial layer will be eventually removed to create room for the structure for example in this case, the cantilever to move above the substrate.

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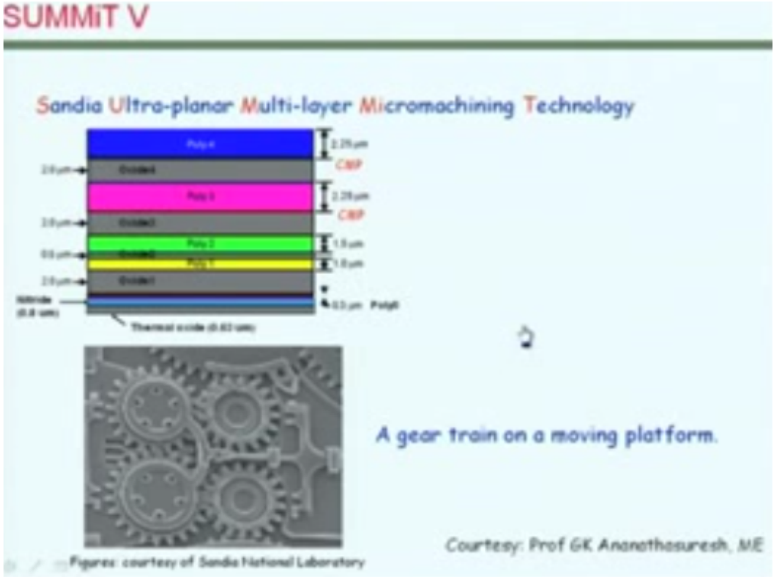

SUMMiT V

Sandia Ultra-planar Multi-layer Micromachining Technology

A gear train on a moving platform.

Figures: courtesy of Sandia National Laboratory

Courtesy: Prof GK Ananthasuresh, ME

We have also talked about extensions of this approach to build complicated looking gear chains and other geometries by including a process known as chemical mechanical polishing that essentially smoothens the surface which would eventually result in completely planner layers to be build above the silicon surface. This facilitates, as you may have seen in other lectures, nearly perfectly looking and complicated geometrics.

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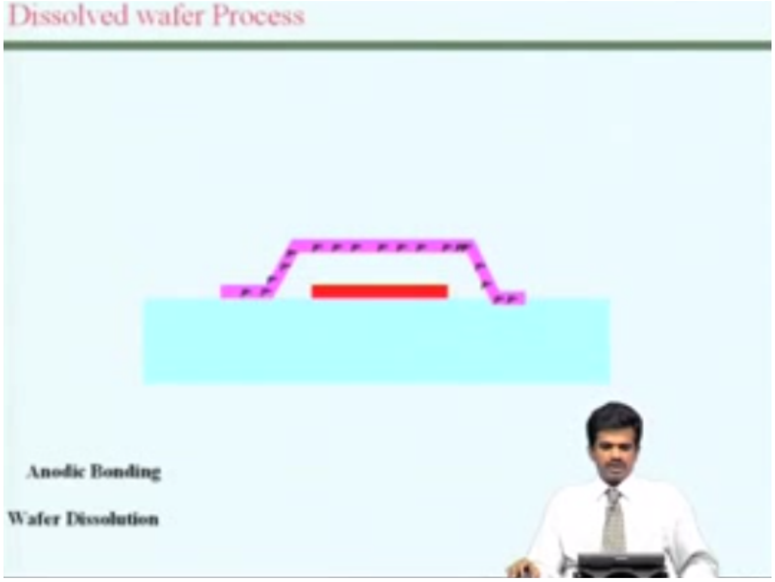

Dissolved wafer Process

Anodic Bonding

Wafer Dissolution

We have also talked about a dissolved wafer process in which we can have part of the device on one wafer and the other part on a different wafer and bond these together and later dissolve a part of the, let us say, one of those wafers to come out with a geometry which would be attached to the other and which can also move by application of external forces.

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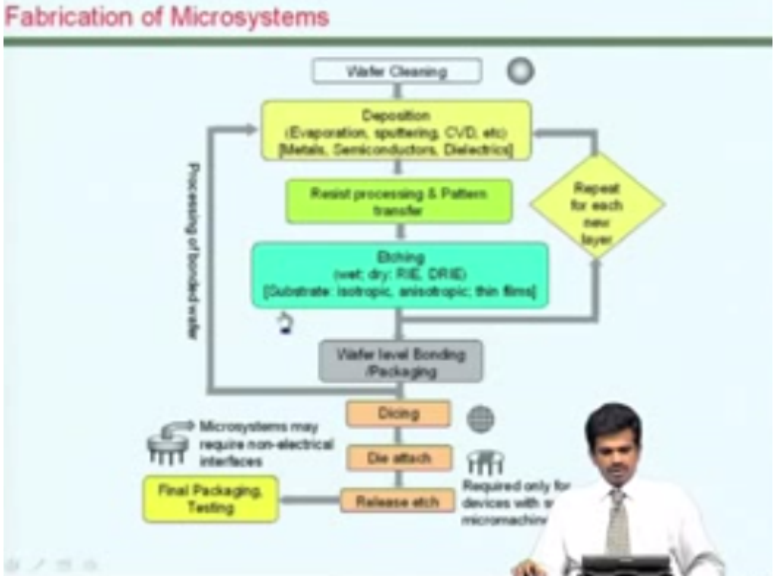

Fabrication of Microsystems

Wafer Cleaning

Deposition
(Evaporation, sputtering, CVD, etc)
[Metals, Semiconductors, Dielectrics]

Resist processing & Pattern transfer

Etching
(wet; dry: RIE, DRIE)
[Substrate: isotropic, anisotropic; thin films]

Repeat for each new layer

Processing of bonded wafer

Wafer level Bonding /Packaging

Dicing

Die attach

Release etch

Final Packaging, Testing

Microsystems may require non-electrical interfaces

Required only for devices with s
micromachin

And all these were essentially following a similar set of process sequences of deposition pattern transfer etching and possibly bonding and some of these being repeated several times.

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New Book on MICROSYSTEMS

- Indian (and International) versions
  - Currently available in India
  - Enhanced, International edition to be available in 2011
- Topics covered
  - Introduction
  - Micro Sensors, Actuators, Systems and Smart Materials: An Overview
  - Micromachining Technologies
  - Modeling of Solids in Microsystems
  - Finite Element Method
  - Modeling of Coupled Electromechanical Systems
  - Electronics Circuits and Control for Micro and Smart Systems
  - Integration of Micro and Smart Systems
  - Scaling Effects in Microsystems

In this context, I also wish to talk to you about a recent book on Microsystems that is authored by the team that has put together this lecture series and the narration is currently available and we expect that the International addition to come out in 2011. This book covers all the aspects that have been covered in this lecture serious including introduction to Microsystems and a summary of all the micro fabrication technologies that I have talked to you about.

Modeling and finite element methods especially for mechanical structures. We will also have a chapter on electronic circuits that are required in the context of sensors and actuators. There integration with electronics and packaging and other similar topics.

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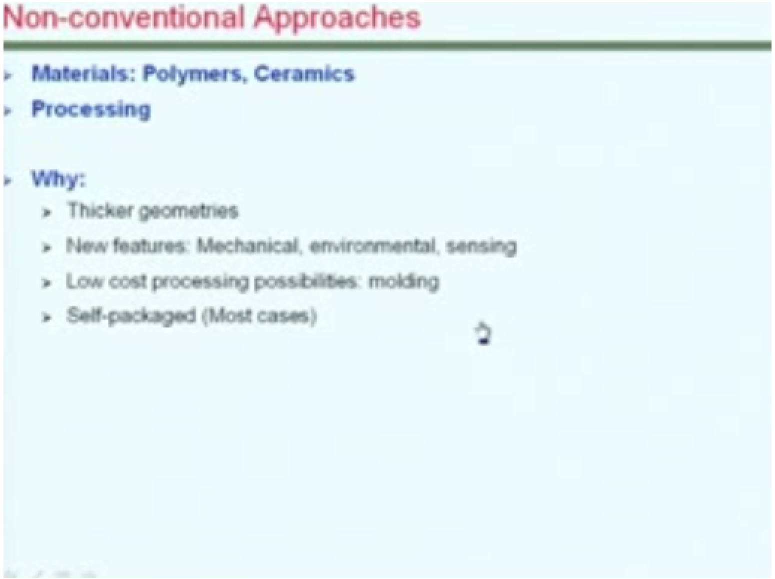

Non-conventional Approaches

- Materials: Polymers, Ceramics
- Processing

- Why:
  - Thicker geometries
  - New features: Mechanical, environmental, sensing
  - Low cost processing possibilities: molding
  - Self-packaged (Most cases)

Coming back to the topic of today's lecture that is on non-conventional approaches. So, whatever we have seen in the previous flow chart, we will treat them as this conventional approach wherein we follow the steps typically followed in a microelectronics foundry and in some cases, treat them or extend them a bit to realize freestanding structures.

In this particular lecture, I would like to talk to you more about materials and methods that are not so frequently used in a typical microelectronics fabrication process. So, this would involve what could be called us non-conventional materials or non-conventional processing some of those materials. The objective here is to make relatively thicker geometrics. So in the context of high aspect ratio geometries that we have talked in another context.

These are in a sense extensions of those. We will see by incorporating these new materials, how some of the new features could be exploited. For example, you all know that most polymers are much more flexible then metals or even silicon. So the low value of Young's Modulus of these polymers would be used to build elastic structures.

Several ceramics material that you will see being used in the context of Microsystems are there because they have peculiar sensing characteristics or they could be exploited for building sensor devices or even actuation devices. We will see, especially in the context of polymers, there are several low cost processing possibilities. For example, molding, you are familiar with which could be used for replicating large number of parts.

In most cases that you will see today, the device need not be packaged separately and may not also contain much of electronics built on silicon for their operation.

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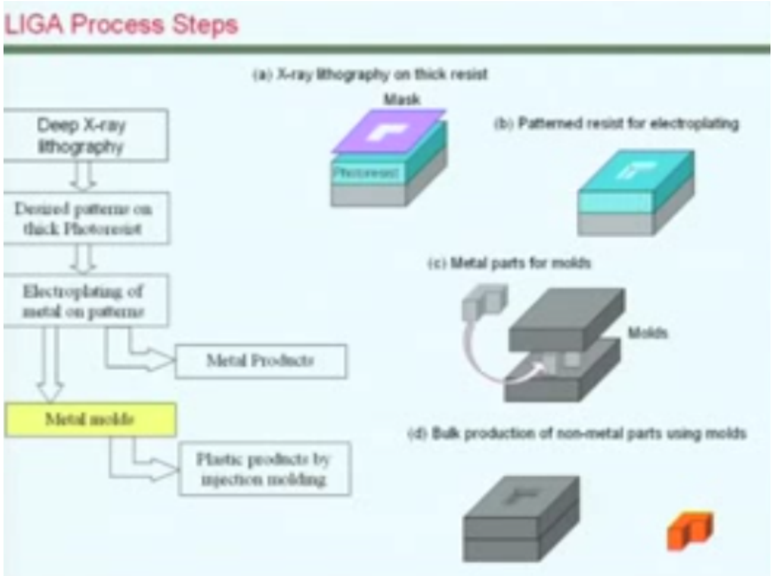

LIGA Process Steps

Deep X-ray lithography

Desired patterns on thick Photoresist

Electroplating of metal on patterns

Metal Products

Metal molds

Plastic products by injection molding

(a) X-ray lithography on thick resist

(b) Patterned resist for electroplating

(c) Metal parts for molds

(d) Bulk production of non-metal parts using molds

The LIGA process has been explained in another lecture in more detail. It essentially starts with a silicon kind of, conventional kind of a process, wherein you do apparent transfer but in this case, it is done using an x-ray lithography. Why x-rays are used, because we would want to have vertically a thick geometries. So the photo resist has to be thick and to expose its thick resist, optical lithography may not work deep into the resist.

So we would need to use x-rays for this purpose and we played through the hole that is created to create a template which will be used to building molds and which could eventually be used for replicating a large number of parts.

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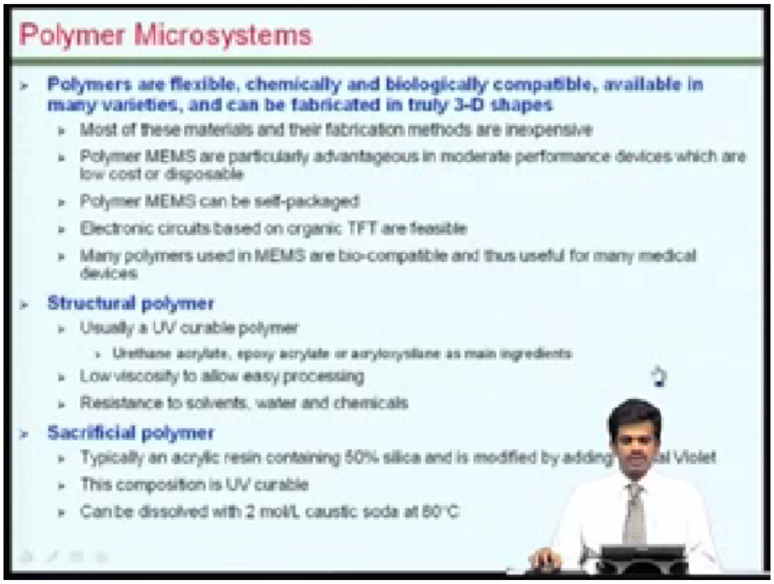

Polymer Microsystems

- **Polymers are flexible, chemically and biologically compatible, available in many varieties, and can be fabricated in truly 3-D shapes**
  - Most of these materials and their fabrication methods are inexpensive
  - Polymer MEMS are particularly advantageous in moderate performance devices which are low cost or disposable
  - Polymer MEMS can be self-packaged
  - Electronic circuits based on organic TFT are feasible
  - Many polymers used in MEMS are bio-compatible and thus useful for many medical devices
- **Structural polymer**
  - Usually a UV curable polymer
    - Urethane acrylate, epoxy acrylate or acryloxysilane as main ingredients
  - Low viscosity to allow easy processing
  - Resistance to solvents, water and chemicals
- **Sacrificial polymer**
  - Typically an acrylic resin containing 50% silica and is modified by adding [illegible]al Violet
  - This composition is UV curable
  - Can be dissolved with 2 mol/L caustic soda at 80°C

Polymers are becoming to be very popular choice for building many low cost Microsystems. As you all know, these are flexible and in most cases, chemically and biologically compatible and are available in many varieties and can be fabricated into really 3-D shapes. We have seen molding and other approaches of plastics. Most of these materials and their fabrication methods are relatively far less expansive.

And you usually do not even use them in clean rooms, so that kind of an infrastructure will not be required to build most of the Microsystems that you will see using polymers. Polymer Microsystems have particular advantages when you only are looking for moderate performance devices with the key point low cost or disposable characteristics. We do not have to worry about packaging these separately unlike silicon-based devices which are typically fragile.

There is an increasing possibility of incorporating polymer Microsystems with organic thin-film transistors. Not much work has been done on this, but there is serious possibility of such an integration. So it is possible to have a completely integrated Microsystem without silicon. Many polymers as I have alluded to earlier used in Microsystems are biocompatible and therefore can be directly used for medical applications.

Polymers come in various forms; and therefore, their applications can also be of various forms. In fact, it is possible to identify structural polymers or polymers which would work as structures for Microsystems or even sacrificial material. So the surface micro machining that we have seen in the context of silicon could be extended for building polymeric Microsystems made entirely of polymeric materials.

So we can choose UV curable polymers which could be eventually used as structural materials or could be eventually dissolved without actually effecting some or the others. So, it is possible to select some of the materials in such a way that exactly similar to how we build poly-silicon based structures on silicon substrate. We will see some of these as we go by in this lecture.

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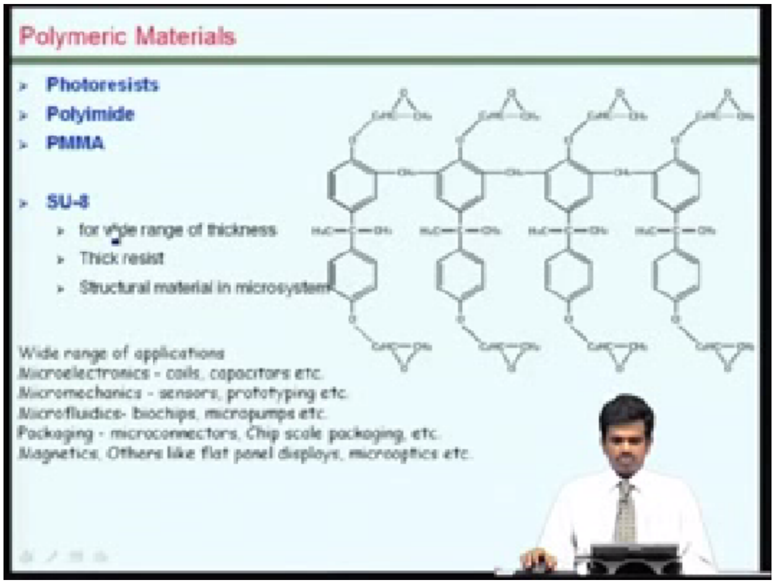

Polymeric Materials

- Photoresists
- Polyimide
- PMMA
- SU-8
  - for wide range of thickness
  - Thick resist
  - Structural material in microsystem

Wide range of applications
Microelectronics - coils, capacitors etc.
Micromechanics - sensors, prototyping etc.
Microfluidics- biochips, micropumps etc.
Packaging - microconnectors, Chip scale packaging, etc.
Magnetics, Others like flat panel displays, microoptics etc.

Photoresists are very commonly used in silicon foundries. Polyimides and PMMA are also used to a lesser extent. One material that is fast becoming popular for various applications in Microsystems is known as a SU-8. This is, if on resist and it comes with different viscosity levels which could eventually be used for a wide range of thickness. This can be used as a structural material in Microsystems and as you could see here, it has this kind of chain of polymeric chain, which essentially consists of this 8 rings usually and hence this 8 in this name.

A wide range of applications have been developed based on SU-8. In micro electronics, in microfluidics, in packaging and even by incorporating other material into it, it could even be used for as magnetic films.

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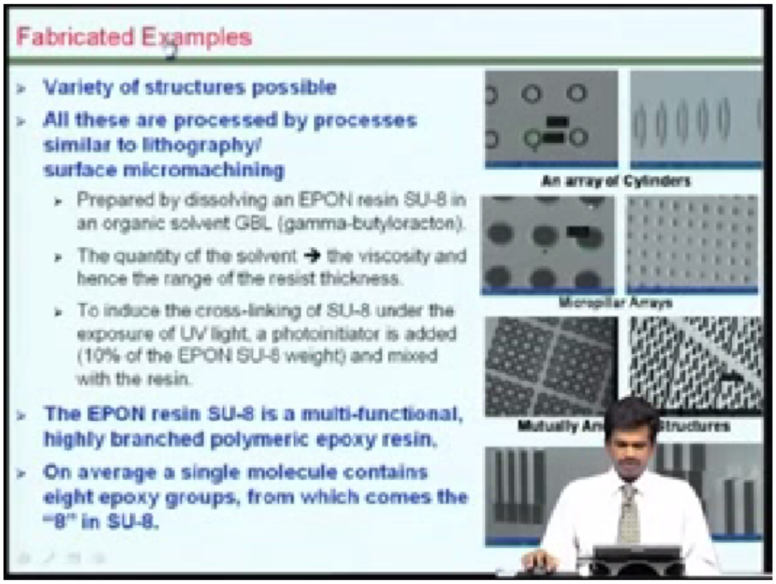

Fabricated Examples

- Variety of structures possible
- All these are processed by processes similar to lithography/ surface micromachining
    - Prepared by dissolving an EPON resin SU-8 in an organic solvent GBL (gamma-butyloracton).
    - The quantity of the solvent → the viscosity and hence the range of the resist thickness.
    - To induce the cross-linking of SU-8 under the exposure of UV light, a photoinitiator is added (10% of the EPON SU-8 weight) and mixed with the resin.
- The EPON resin SU-8 is a multi-functional, highly branched polymeric epoxy resin.
- On average a single molecule contains eight epoxy groups, from which comes the "8" in SU-8.

There are several examples that can be shown based on fabrications with SU-8, can build cylindrical geometries with reasonably high aspect ratio, can have pillars, we can have cross connected structures, can have (()) (14:59) cantilevers or beams, all made of SU-8. The process steps are somewhat similar to the photoresist that you are familiar with. We essentially dissolve the resin of SU-8 in an organic solvent and then based on the composition of this.

We can control the viscosity and hence the thickness and this has been coated on the surface and it is essentially exposed to UV light as in the case of photoresist and which will eventually enable the cross linking of the polymers and one can get a highly branched polymeric epoxy resin on top of the substrate surface. So, this is the process and everything is quite similar to what is done for the case of photoresist in a typical silicon founder.

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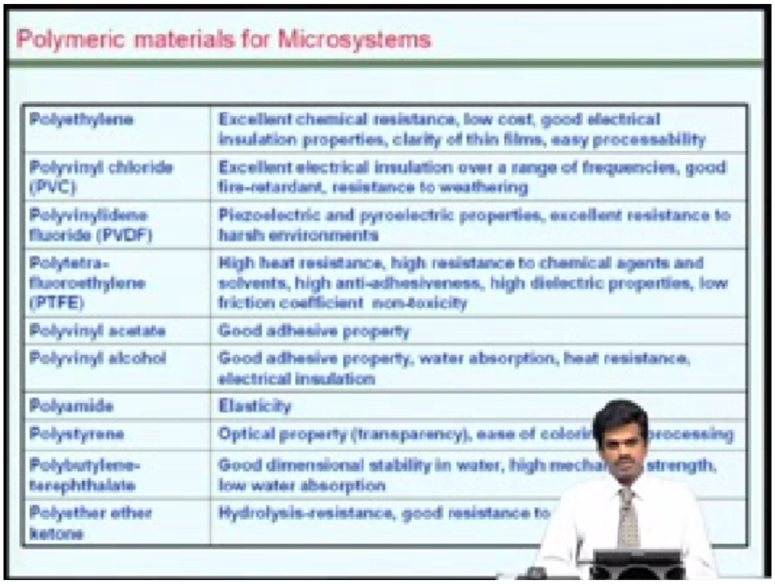

Polymeric materials for Microsystems

Polyethylene	Excellent chemical resistance, low cost, good electrical insulation properties, clarity of thin films, easy processability
Polyvinyl chloride (PVC)	Excellent electrical insulation over a range of frequencies, good fire-retardant, resistance to weathering
Polyvinylidene fluoride (PVDF)	Piezoelectric and pyroelectric properties, excellent resistance to harsh environments
Polytetra-fluoroethylene (PTFE)	High heat resistance, high resistance to chemical agents and solvents, high anti-adhesiveness, high dielectric properties, low friction coefficient non-toxicity
Polyvinyl acetate	Good adhesive property
Polyvinyl alcohol	Good adhesive property, water absorption, heat resistance, electrical insulation
Polyamide	Elasticity
Polystyrene	Optical property (transparency), ease of colori rocessing
Polybutylene-terephthalate	Good dimensional stability in water, high mecha strength, low water absorption
Polyether ether ketone	Hydrolysis-resistance, good resistance to

Other polymeric materials that could be used include polyethylene, which has very good chemical resistance, it is low cost material, you see it everywhere and good electrical insulation properties and it is transparent and can be processed relatively easy. Polyvinyl chloride is also an electrical insulation material and has good resistance to weathering.

PVDF is a polyvinylidene fluoride and has piezoelectric properties and hence can be used in place of ceramic materials such as PZT that is lead-zirconium titanate which are used in piezoelectric sensors and actuators. So PVDF based sensors and actuators could be made and which is essentially a highly pliable, flexible polymeric material. Other materials include PTFE, polyvinyl acetate, polyamide, polystyrene, polybutylene terephthalate, polyether ether ketone and the like.

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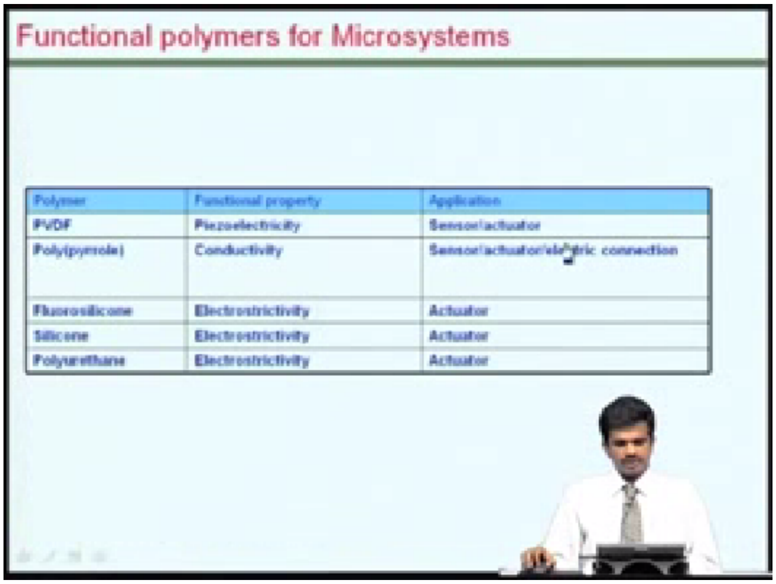

Functional polymers for Microsystems

Polymer	Functional property	Application
PVDF	Piezoelectricity	Sensor/actuator
Poly(pyrrole)	Conductivity	Sensor/actuator/electric connection
Fluorosilicone	Electrostrictivity	Actuator
Silicone	Electrostrictivity	Actuator
Polyurethane	Electrostrictivity	Actuator

As I mentioned, PVDF has very good piezoelectric properties. There are other polymers such as polypyrole which has very good conductivity characteristics and hence could be used to make the electrical connections just as conductors, in fact, the conductivity of polypyrole can be controlled by doping as you do in the case of silicon or polysilicon. Other interesting polymers which has sensing or actuation applications include fluorosilicone or silicon which has electrostatic characteristics which have been explored in the context of building actuators.

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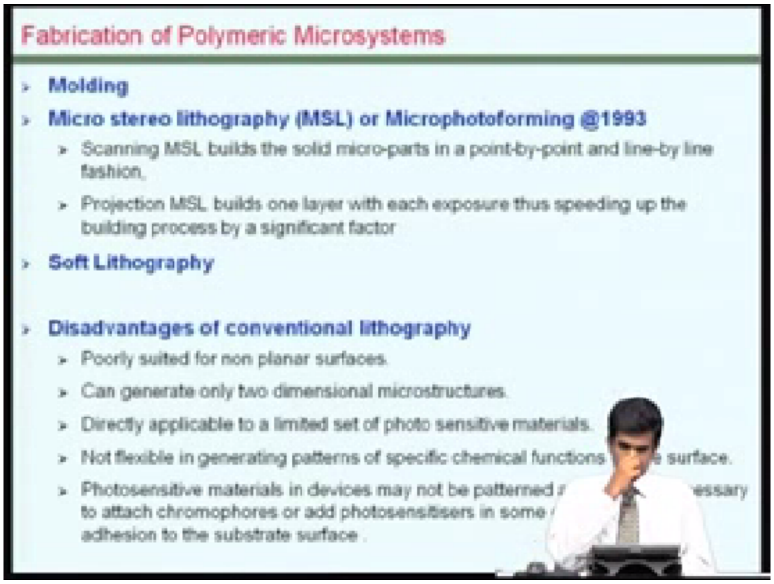

Fabrication of Polymeric Microsystems

- **Molding**
- **Micro stereo lithography (MSL) or Microphotoforming @1993**
  - Scanning MSL builds the solid micro-parts in a point-by-point and line-by line fashion.
  - Projection MSL builds one layer with each exposure thus speeding up the building process by a significant factor
- **Soft Lithography**
- **Disadvantages of conventional lithography**
  - Poorly suited for non planar surfaces.
  - Can generate only two dimensional microstructures.
  - Directly applicable to a limited set of photo sensitive materials.
  - Not flexible in generating patterns of specific chemical functions surface.
  - Photosensitive materials in devices may not be patterned essary to attach chromophores or add photosensitisers in some adhesion to the substrate surface .

Fabricating structures with polymeric materials is relatively easy. One can use various molding possibilities to replicate large number of parts using polymers. I also talk about an extension of lithography kind of technique known as micro stereo lithography, which is used for forming 3-

dimensional structures of micron scale made of polymeric materials. There are couple of varieties of these and we will see that in details as we go by.

In another context, I talked to you about soft lithography and we will see how this compares with the conventional lithography processes. So to look at it more closely, the first thing that we need to understand is what are the real limitations of conventional lithography. Obviously conventional lithography approaches are useful for planer surfaces. We do the pattern transfer from a hard mask and the surface to which it is transferred should be parallel to it to get good reproducibility.

So using the conventional lithography, you can only make 2-dimensional microstructures and we have seen that how this could be achieved to get somewhat marginally 3-dimensional, I would put it as, surface micro machine geometrics. It is not always possible to generate patterns of certain specific chemical functions above the surface. You have to deposit everything all over the surface and then pattern it separately.

In photosensitive materials in devices, may not be patterned as it may be necessary to attach additional function materials into this to make it to cure under this photo UV exposure that is required that is required in most cases of the conventional lithography.

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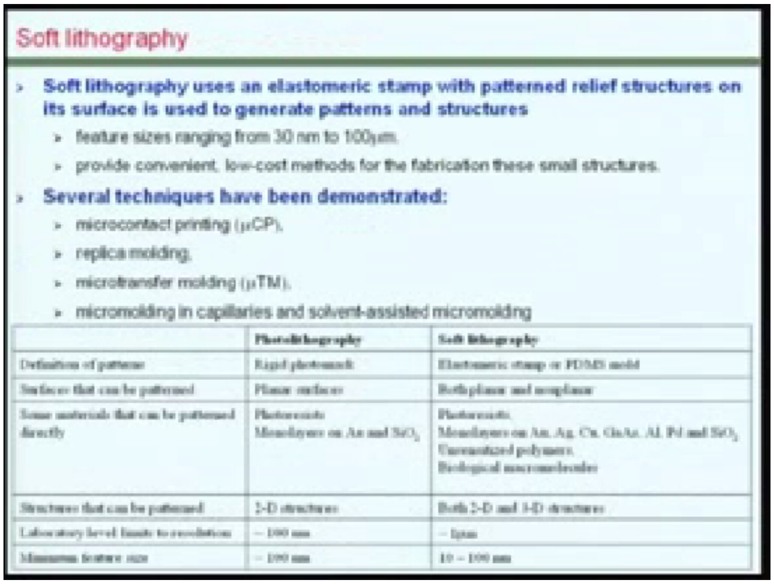

Soft lithography

- **Soft lithography uses an elastomeric stamp with patterned relief structures on its surface is used to generate patterns and structures**
  - feature sizes ranging from 30 nm to 100µm.
  - provide convenient, low-cost methods for the fabrication these small structures.
- **Several techniques have been demonstrated:**
  - microcontact printing (µCP),
  - replica molding,
  - microtransfer molding (µTM),
  - micromolding in capillaries and solvent-assisted micromolding

	Photolithography	Soft lithography
Definition of patterns	Rigid photomask	Elastomeric stamp or PDMS mold
Surfaces that can be patterned	Planar surfaces	Both planar and nonplanar
Some materials that can be patterned directly	Photoresists Monolayers on Au and SiO_2	Photoresists Monolayers on Au, Ag, Cu, GaAs, Al, Pd and SiO_2 Unsensitized polymers Biological macromolecules
Structures that can be patterned	2-D structures	Both 2-D and 3-D structures
Laboratory level limits to resolution	~ 100 nm	~ 1µm
Minimum feature size	~ 100 nm	10 – 100 nm

So these could be overcome by the process known as soft lithography. This essentially uses an elastomeric stamp which is patterned with the patterned relief structure on this and is used to generate multiple number of patterns and structures and using softly lithography, one can make features with sizes ranging from possibly submicrometers as low as 30 nanometer to even 100s or more of micrometers.

It provides an approach, a convenient approach which is a low cost method for fabricating these small structures. Several techniques are available under the umbrella of soft lithography, things such as microcontact printing, replica molding, microtransfer molding, so on, these will be discussed in little details as we go by.

So the basic differences between photolithography and soft lithography are compiled here. In photolithography we use a rigid, hard photo mask kit. In soft lithography, we use an elastomeric stamp usually made of a material called PDMS. Photolithography is applied onto planner surfaces whereas soft lithography can be extended towards a planner as well as non-planner structures. Materials that can be patterned using photolithography include photoresist and some monolayers on gold or silicon I would say.

Where as a large variety of materials could be patterned using soft lithography approaches which can be even used for patterning micro biological molecules. Mostly 2-dimensional structures can be fabricated using photolithography and using soft lithography, we can extend this towards 3-dimensional structures. The lower limit of the structures that can be fabricated using large scale conventional photolithography is of the order of 10s of nanometers.

And these limits keep changing but the limit is much higher in the case of soft lithography and one can only build as low as about a micron or something like that using soft lithography.

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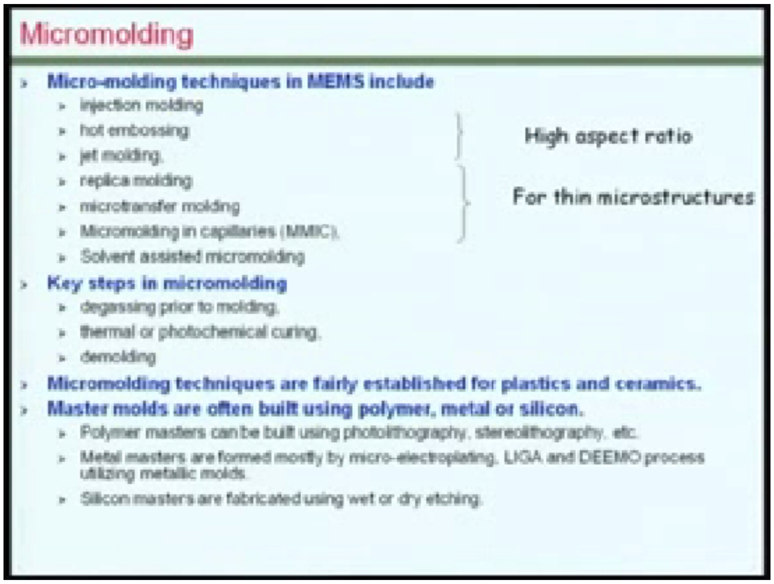

Micromolding

- Micro-molding techniques in MEMS include
  - injection molding
  - hot embossing
  - jet molding.
  - replica molding
  - microtransfer molding
  - Micromolding in capillaries (MMIC).
  - Solvent assisted micromolding
- Key steps in micromolding
  - degassing prior to molding.
  - thermal or photochemical curing.
  - demolding
- Micromolding techniques are fairly established for plastics and ceramics.
- Master molds are often built using polymer, metal or silicon.
  - Polymer masters can be built using photolithography, stereolithography, etc.
  - Metal masters are formed mostly by micro-electroplating, LIGA and DEEMO process utilizing metallic molds.
  - Silicon masters are fabricated using wet or dry etching.

So the minimum features sizes could be even though the minimum feature sizes could be comparable. So, as I mentioned several micro molding techniques including injection molding, hot embossing, jet molding, or replica molding or even microtransfer molding could be used for building relatively high aspect ratio microstructures.

There are some extensions of these which could be used even for thin microstructures, but the key steps in molding such structures would involve making dissolve the material in a solvent and then degass this, essentially remove all the bubbles in the dissolved solution and then deposit or transfer it on to some kind of a mold and then cure it, then remove it from this mold known as demold.

So for many plastic and ceramic materials, such molding techniques are now fairly established. The master molds that we use for this purpose could be made of polymers, metal, or silicon based structures. Polymers as I have mentioned previously, PDMS is one of the example. These masters are made using photolithography or as you will see stereo lithography and other approaches.

Metal masters could be made by electroplating or LIGA we have seen or similar processes. Silicon masters would be made using the etching techniques that we have seen previously.

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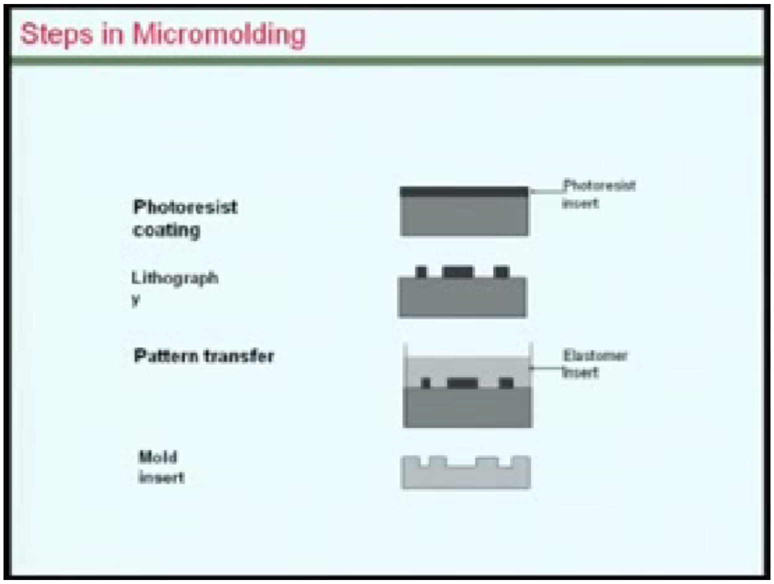

Steps in Micromolding

Photoresist coating

Lithography

Pattern transfer

Mold insert

So in simple terms, the process of micromolding would involve the resist coating and lithography and then using the elastomer, doing this pattern transfer and taking out this mold insert.

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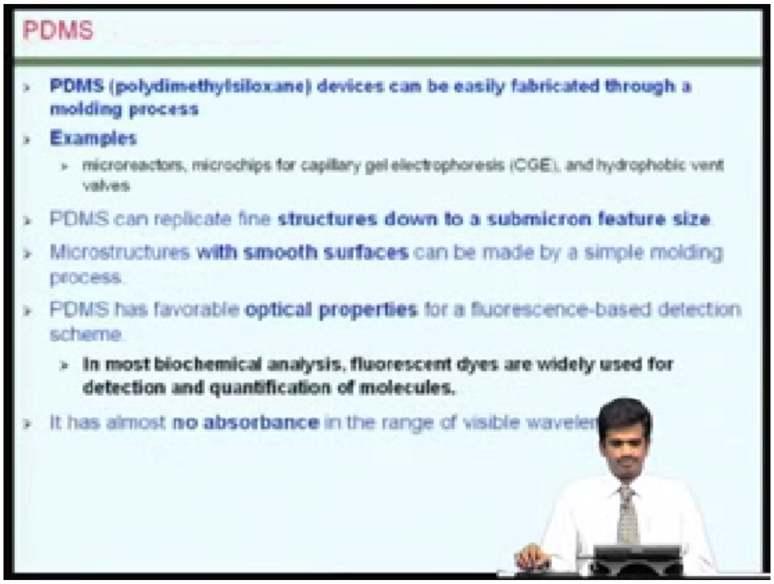

PDMS

- **PDMS (polydimethylsiloxane) devices can be easily fabricated through a molding process**
- **Examples**
  - microreactors, microchips for capillary gel electrophoresis (CGE), and hydrophobic vent valves
- PDMS can replicate fine **structures down to a submicron feature size**
- Microstructures **with smooth surfaces** can be made by a simple molding process.
- PDMS has favorable **optical properties** for a fluorescence-based detection scheme
  - **In most biochemical analysis, fluorescent dyes are widely used for detection and quantification of molecules.**
- It has almost **no absorbance** in the range of visible wavelen

As I mentioned, polydemethylsiloxane known popularly as PDMS can be easily fabricated and can be used for large scale production of polymeric devices as a mold material, can be even used for building microreactors, microchips and various other fluidic systems. This can be used to replicate structures all the way down to micron or smaller insects and it was very good, it can result in geometries with very good surface finish and obviously by molding approaches.

It has very good optical properties and can be extended for various optical detection schemes, sensing schemes while building microsystems and is therefore, widely used in biochemical analysis. It has relatively no absorption of visible light, so it is a transparent material.

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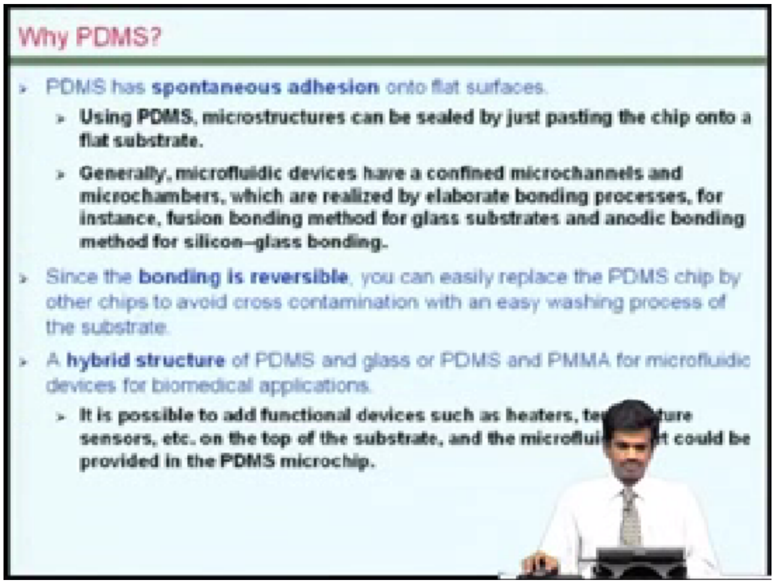

Why PDMS?

- PDMS has **spontaneous adhesion** onto flat surfaces.
  - Using PDMS, microstructures can be sealed by just pasting the chip onto a flat substrate.
  - Generally, microfluidic devices have a confined microchannels and microchambers, which are realized by elaborate bonding processes, for instance, fusion bonding method for glass substrates and anodic bonding method for silicon–glass bonding.
- Since the **bonding is reversible**, you can easily replace the PDMS chip by other chips to avoid cross contamination with an easy washing process of the substrate.
- A **hybrid structure** of PDMS and glass or PDMS and PMMA for microfluidic devices for biomedical applications.
  - It is possible to add functional devices such as heaters, te ture sensors, etc. on the top of the substrate, and the microflui t could be provided in the PDMS microchip.

It has very good adhesion to flat surfaces. So using PDMS, microstructures can be even sealed by just pasting the chip onto the flat surface. In contrast, microfluidic devices which have microchannels or chambers, realized to using the bonding process, would require the extensive high temperatures, silicon-glass bonding approaches for you know capping that. But this bonding of PDMS to this hard flat surface is reversible.

Therefore, this can be easily replaced and the substrate can be washed and reused which is a very good advantage for PDMS based microstructures. What results is essentially called a hybrid structure of PDMS and glass or even PDMS and PMMA for microfluidic channels and biomedical applications. So it is possible to add functional devices such as heaters, microheaters or temperature sensors on top of the substrate and the fluidic part could be on the PDMS part of this device.

So such hybrid structures are possible even using PDMS.

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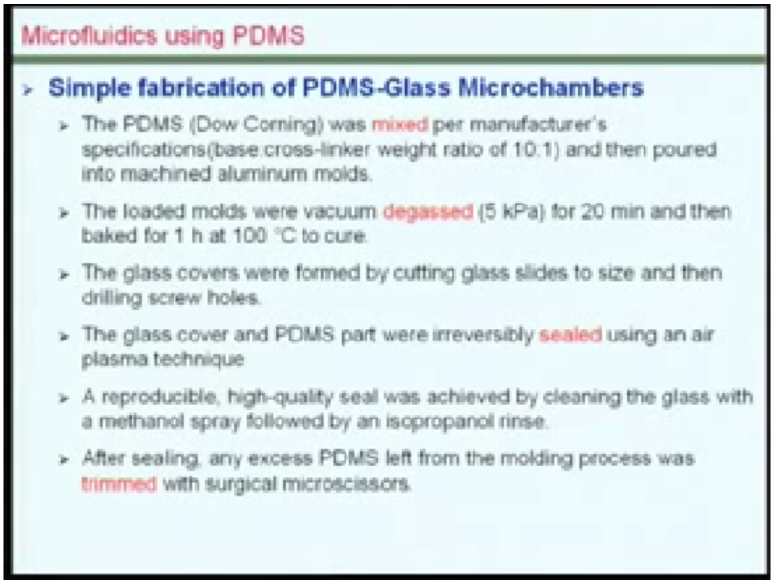

Microfluidics using PDMS

- **Simple fabrication of PDMS-Glass Microchambers**
  - The PDMS (Dow Corning) was mixed per manufacturer's specifications(base:cross-linker weight ratio of 10:1) and then poured into machined aluminum molds.
  - The loaded molds were vacuum degassed (5 kPa) for 20 min and then baked for 1 h at 100 °C to cure.
  - The glass covers were formed by cutting glass slides to size and then drilling screw holes.
  - The glass cover and PDMS part were irreversibly sealed using an air plasma technique
  - A reproducible, high-quality seal was achieved by cleaning the glass with a methanol spray followed by an isopropanol rinse.
  - After sealing, any excess PDMS left from the molding process was trimmed with surgical microscissors.

So it is a relatively simple process to fabricate PDMS-glass microchambers. What we need to do is essentially mix the PDMS commercially available with the solvent and may be put them into aluminium molds and put it in a vacuum oven to degass it at a relatively low temperature for several 10s of minutes that would remove all the bubbles because if the bubbles are there, the fabricated structures would become unreliable sometimes.

Then after it is molded and it is covered with the glass slide and it could be sealed and then we can reproduce the large number of these by cleaning the glass by methanol spray. So after sealing with this glass, this PDMS can be easily trimmed because it is a very flexible material.

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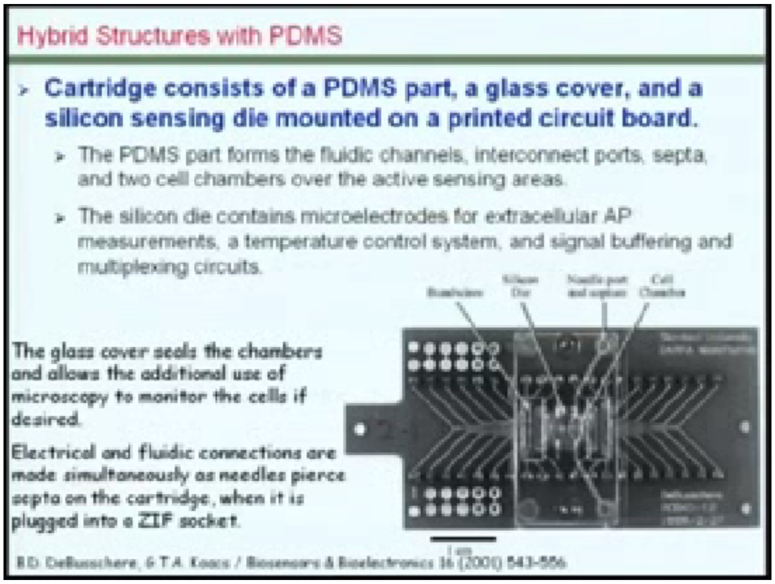

Hybrid Structures with PDMS

- **Cartridge consists of a PDMS part, a glass cover, and a silicon sensing die mounted on a printed circuit board.**
  - The PDMS part forms the fluidic channels, interconnect ports, septa, and two cell chambers over the active sensing areas.
  - The silicon die contains microelectrodes for extracellular AP measurements, a temperature control system, and signal buffering and multiplexing circuits.

The glass cover seals the chambers and allows the additional use of microscopy to monitor the cells if desired.

Electrical and fluidic connections are made simultaneously as needles pierce septa on the cartridge, when it is plugged into a ZIF socket.

B.D. DeBusschere, & T.A. Kovacs / Biosensors & Bioelectronics 16 (2001) 543-556

So for a sample, we can build sensing devices, sensing cartridges with a part on hard material and part on PDMS so that we can even build a biochemical reactor for biosensing applications. So glass cover can be used to seal it and can be used which is transparent and can therefore be used for microscopic to monitor the cells and things like that. So it is a relatively simple and easy process to build such structures.

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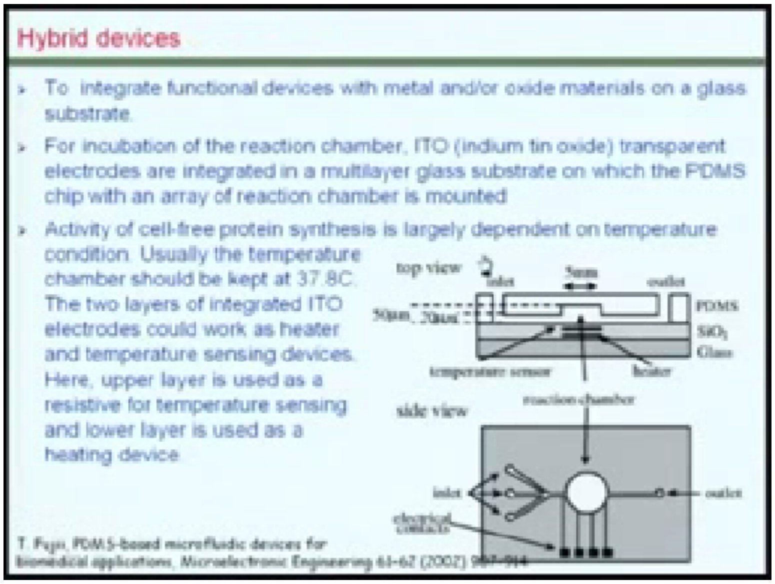

Hybrid devices

- To integrate functional devices with metal and/or oxide materials on a glass substrate
- For incubation of the reaction chamber, ITO (indium tin oxide) transparent electrodes are integrated in a multilayer glass substrate on which the PDMS chip with an array of reaction chamber is mounted
- Activity of cell-free protein synthesis is largely dependent on temperature condition. Usually the temperature chamber should be kept at 37.8C. The two layers of integrated ITO electrodes could work as heater and temperature sensing devices. Here, upper layer is used as a resistive for temperature sensing and lower layer is used as a heating device

T. Fujii, PDMS-based microfluidic devices for biomedical applications, Microelectronic Engineering 61-62 (2002) 907-914

And this has been extended for a number of applications, primarily by bio materials and glass with even transparent electrodes has also been developed which could also be used for similar as electrodes.

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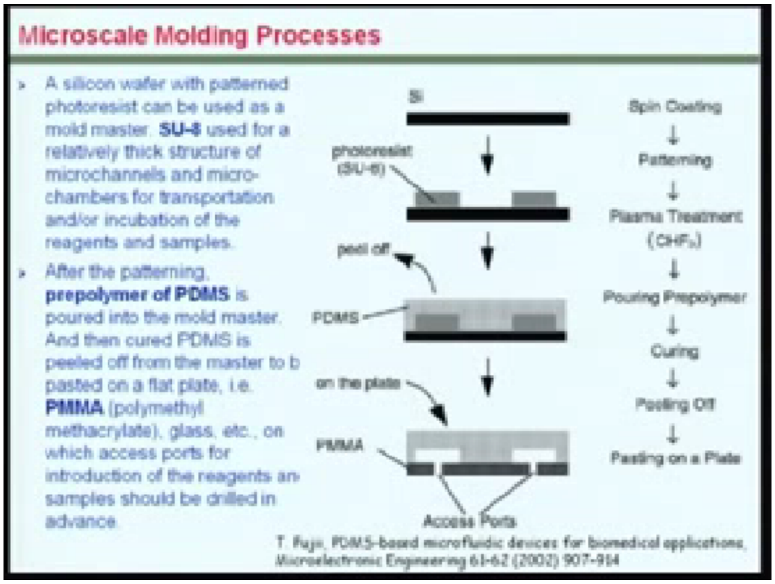

Microscale Molding Processes

- A silicon wafer with patterned photoresist can be used as a mold master. **SU-8** used for a relatively thick structure of microchannels and micro-chambers for transportation and/or incubation of the reagents and samples.
- After the patterning, **prepolymer of PDMS** is poured into the mold master. And then cured PDMS is peeled off from the master to b pasted on a flat plate, i.e. **PMMA** (polymethyl methacrylate), glass, etc., on which access ports for introduction of the reagents an samples should be drilled in advance

T. Fujii, PDMS-based microfluidic devices for biomedical applications, Microelectronic Engineering 61-62 (2002) 907-914

To build molds at micron scale, you can even build a master made of SU-8 as you recall from our earlier discussion. SU-8 is one material which can be made in different thicknesses. So when we want to bring it down to micron scale, appropriate thickness of SU-8 can be exposed to UV light and we can build microstructures using them and then use those to build molds of PDMS or parts and then which can be replicated a number of times.

So the process steps would involve spin coating and patterning and plasma treatment then this prepolymer which is poured on to it and cured and it can be peeled off and pasted on to a substrate and can be used as a seal cavity and the like.

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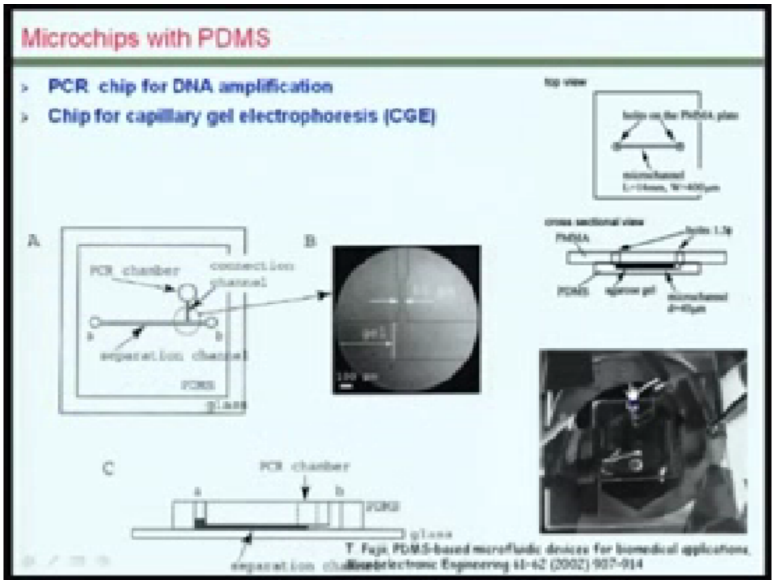

Microchips with PDMS

- PCR chip for DNA amplification
- Chip for capillary gel electrophoresis (CGE)

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There are possibilities extended to build a complete PCR chip for DNA amplification using these approaches.

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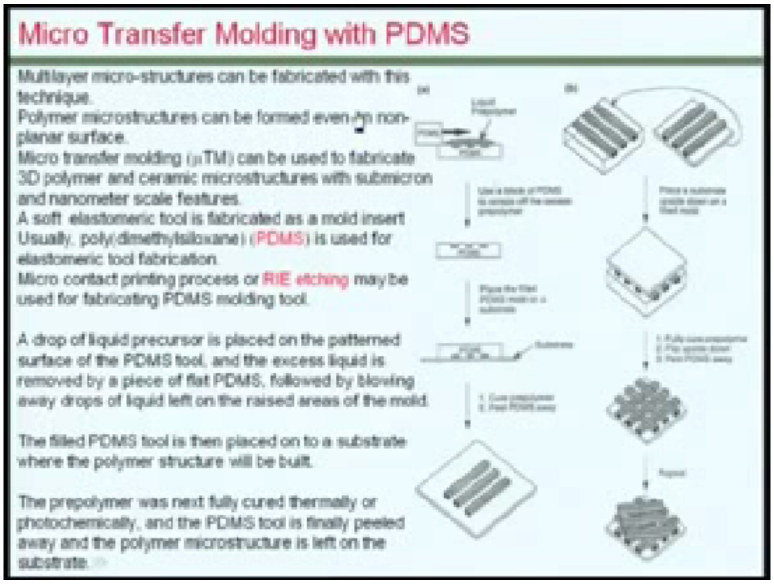

Micro Transfer Molding with PDMS

Multilayer micro-structures can be fabricated with this technique.
Polymer microstructures can be formed even on non-planar surface.
Micro transfer molding (μTM) can be used to fabricate 3D polymer and ceramic microstructures with submicron and nanometer scale features.
A soft elastomeric tool is fabricated as a mold insert
Usually, poly(dimethylsiloxane) (PDMS) is used for elastomeric tool fabrication.
Micro contact printing process or RIE etching may be used for fabricating PDMS molding tool.

A drop of liquid precursor is placed on the patterned surface of the PDMS tool, and the excess liquid is removed by a piece of flat PDMS, followed by blowing away drops of liquid left on the raised areas of the mold.

The filled PDMS tool is then placed on to a substrate where the polymer structure will be built.

The prepolymer was next fully cured thermally or photochemically, and the PDMS tool is finally peeled away and the polymer microstructure is left on the substrate.

A somewhat similar approach is known as micro transfer molding. In this case multilayer microstructures can be fabricated, once again polymeric materials formed on even nonplanar surfaces. This can be used as when talking about 3-dimensional structures and even extended for ceramic microstructures at micro scales. PDMS could be used one again and it works similar to what we have seen previously.

So we first make this mold and then use the mold to create the PDMS based structure and then use this for repetitive production.

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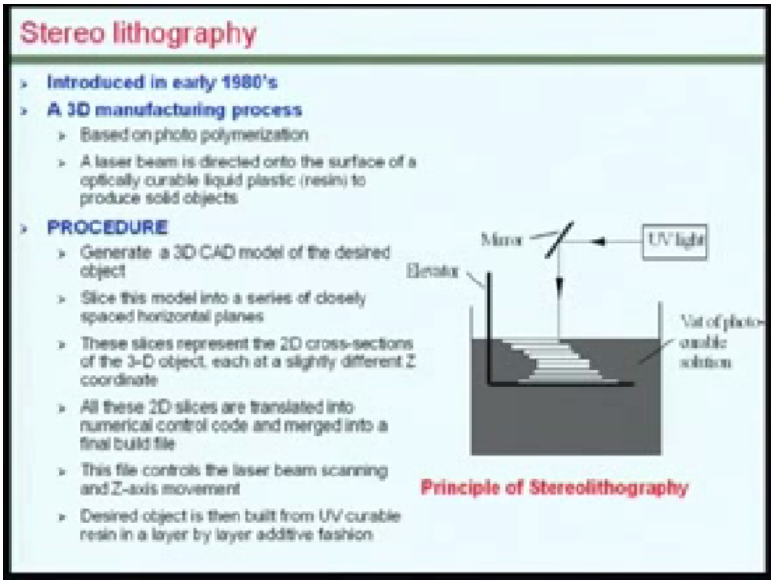

Stereo lithography

- Introduced in early 1980's
- A 3D manufacturing process
  - Based on photo polymerization
  - A laser beam is directed onto the surface of a optically curable liquid plastic (resin) to produce solid objects
- PROCEDURE
  - Generate a 3D CAD model of the desired object
  - Slice this model into a series of closely spaced horizontal planes
  - These slices represent the 2D cross-sections of the 3-D object, each at a slightly different Z coordinate
  - All these 2D slices are translated into numerical control code and merged into a final build file
  - This file controls the laser beam scanning and Z-axis movement
  - Desired object is then built from UV curable resin in a layer by layer additive fashion

Principle of Stereolithography

Slightly different approach of fabricating 3-dimensional structures using polymers is known as stereo lithography. This is developed about 20-30 years ago and has been initially used for building meso-scale structures on polymers. What is done is to use a beam of curing UV light as a substrate and when this is inserted into a vat of photocurable solution and it is cured one layer at a time.

So what is done is that this substrate that is there will be lowered by the thickness of a layer and then the solution will cover this surface and after that you will cure this surface for the part that we want to build. So after each step, we will move this substrate by the thickness of each layer. So a layer by layer fabrication of 3-dimensional structures are possible. With today's tools, it is a relatively easy to make such layer by layer slices of any complicated 3-dimensional structure.

So with these 2-dimensional slices, patterns are transferred on to this liquid that forms over the substrate. So the Z-axis movement essentially controls the thickness whereas the scant UV beam would control the 2-dimensional shape of each layer. So the decided object can eventually be build out of this solution. This has been extended to microparts by better control of all this movement and the scanning of the beam.

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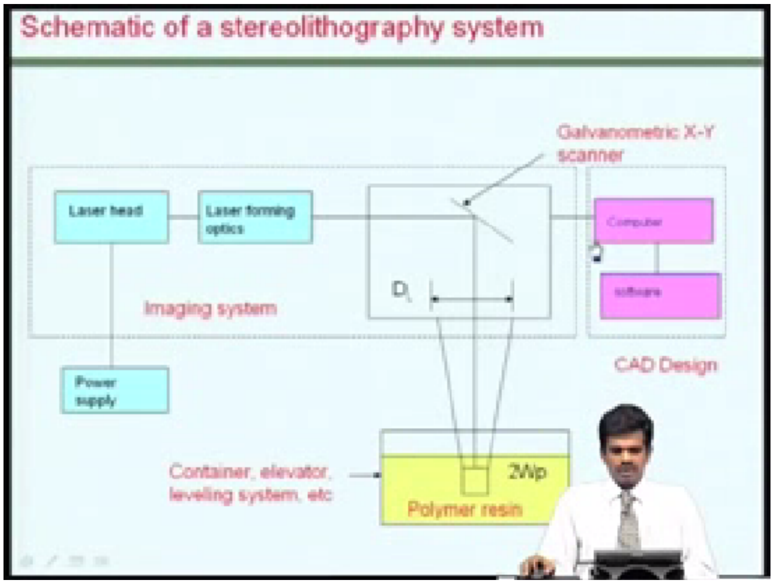

Schematic of a stereolithography system

Once again the system would consist of this polymeric resin and this laser focussing arrangement and kind of movement arrangement which would be computer-controlled based on the CAD design. The beam is basically allowed to fall on the top layer of this resin in a controlled fashion so that the shapes could be formed based on that.

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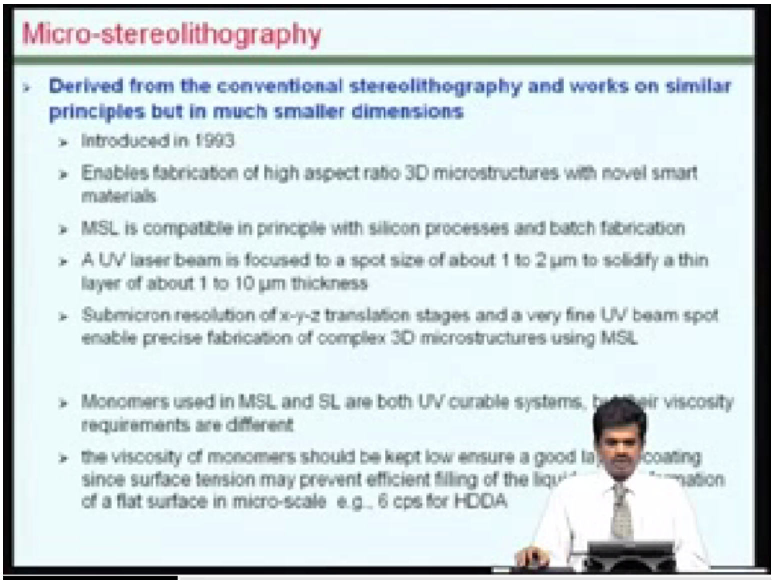

Micro-stereolithography

- **Derived from the conventional stereolithography and works on similar principles but in much smaller dimensions**
  - Introduced in 1993
  - Enables fabrication of high aspect ratio 3D microstructures with novel smart materials
  - MSL is compatible in principle with silicon processes and batch fabrication
  - A UV laser beam is focused to a spot size of about 1 to 2 µm to solidify a thin layer of about 1 to 10 µm thickness
  - Submicron resolution of x-y-z translation stages and a very fine UV beam spot enable precise fabrication of complex 3D microstructures using MSL
  - Monomers used in MSL and SL are both UV curable systems, b[illegible]ir viscosity requirements are different
  - the viscosity of monomers should be kept low ensure a good la[illegible]coating since surface tension may prevent efficient filling of the liqu[illegible]mation of a flat surface in micro-scale e.g., 6 cps for HDDA

So in micro-stereolithography which is a relatively newer technique, one can build 3-dimensional structures primary made of polymers in processes which are very similar to those used in silicon fabrication and in an approach which is also a layer by layer approach, 3-dimensional structures are possible. So in some cases, one may need to use sacrificial layers to build the structure layers above that but in many cases, it is possible to do without.

So we need to control the viscosity of the solution so that it covers uniformly over this surface so that continuous coverage would be possible.

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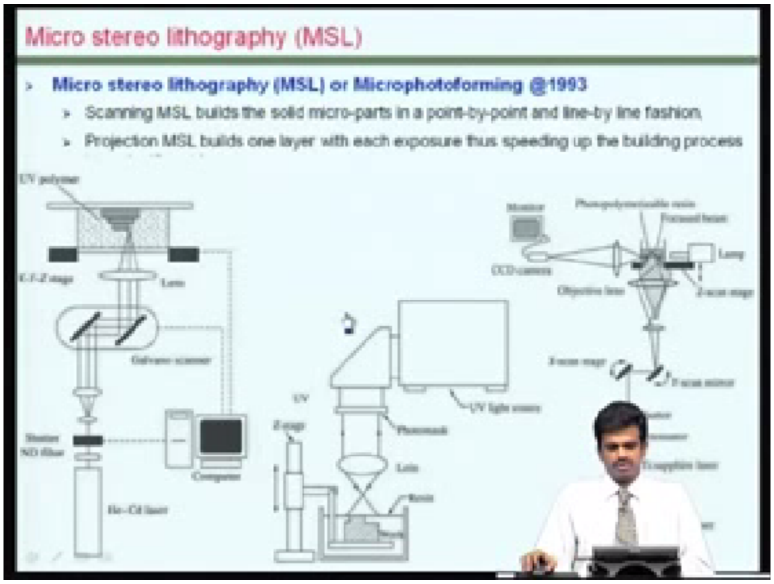

Micro stereo lithography (MSL)

- **Micro stereo lithography (MSL) or Microphotoforming @1993**
  - Scanning MSL builds the solid micro-parts in a point-by-point and line-by line fashion,
  - Projection MSL builds one layer with each exposure thus speeding up the building process

Several variants of sterolithography approaches are possible. As you know, the scanning based approach would be relatively slow because you are essentially exposing 1 pixel at a time. LCD based projection methods are also being experimented with for building the volume production using micro stereolithography. These are some of the variants of the micro sterolithography approaches for building microstructures.

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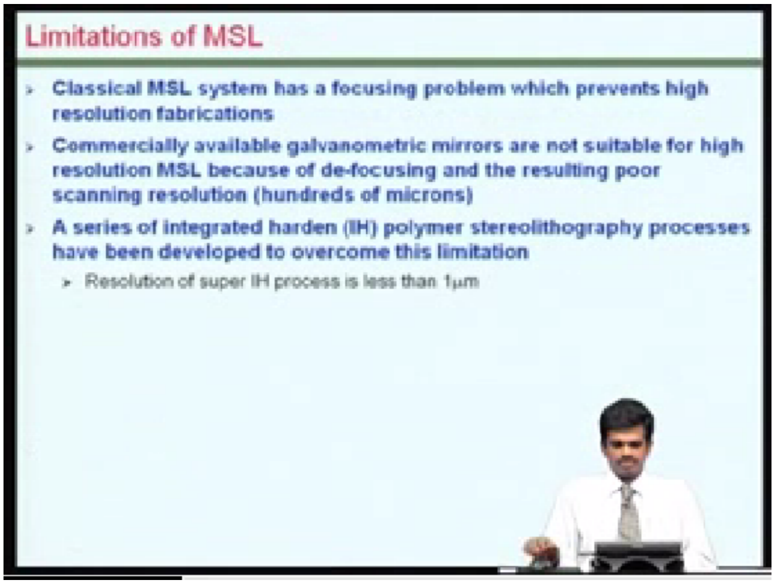

Limitations of MSL

- **Classical MSL system has a focusing problem which prevents high resolution fabrications**
- **Commercially available galvanometric mirrors are not suitable for high resolution MSL because of de-focusing and the resulting poor scanning resolution (hundreds of microns)**
- **A series of integrated harden (IH) polymer stereolithography processes have been developed to overcome this limitation**
  - Resolution of super IH process is less than 1μm

Some of the problems include limitations in focusing these beams into the solution and the thickness that one can get and the kind of controls that one can have on the mirror movement as well as on the stage movement. There are several modifications are being made on some of these things to improve the characteristics of the structures.

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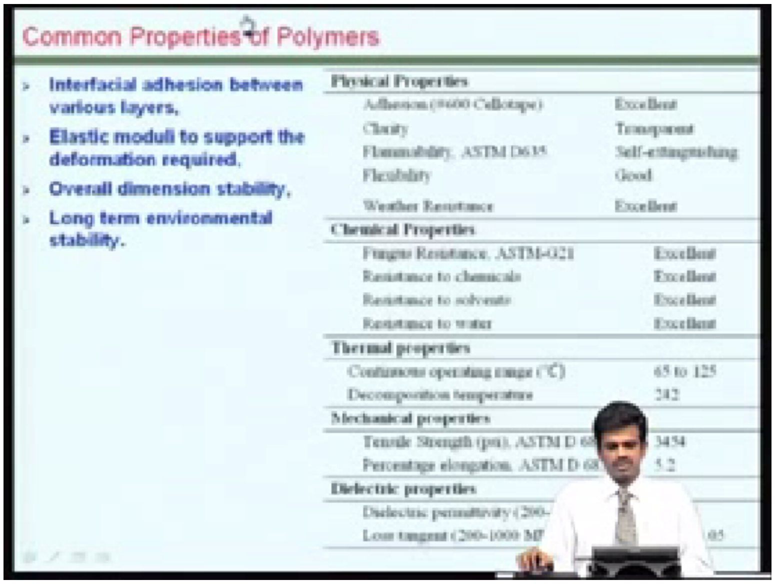

Common Properties of Polymers

- Interfacial adhesion between various layers,
- Elastic moduli to support the deformation required,
- Overall dimension stability,
- Long term environmental stability.

Physical Properties	
Adhesion (#600 Cellotape)	Excellent
Clarity	Transparent
Flammability, ASTM D635	Self-extinguishing
Flexibility	Good
Weather Resistance	Excellent
Chemical Properties	
Fungus Resistance, ASTM-G21	Excellent
Resistance to chemicals	Excellent
Resistance to solvents	Excellent
Resistance to water	Excellent
Thermal properties	
Continuous operating range (°C)	65 to 125
Decomposition temperature	242
Mechanical properties	
Tensile Strength (psi), ASTM D 68	3454
Percentage elongation, ASTM D 68	5.2
Dielectric properties	
Dielectric permittivity (200-	
Loss tangent (200-1000 MF	05

To summarize, the polymers have several interesting characteristics which could be exploited to build functional microsystems. They have very good elastic moduli so that larger deformation could be realized. Good dimensional stability and long term environmental stability are other characteristics. Usually have good electric and chemical characteristics for most polymers. So polymer microsystems are very likely to become highly popular in the near future.

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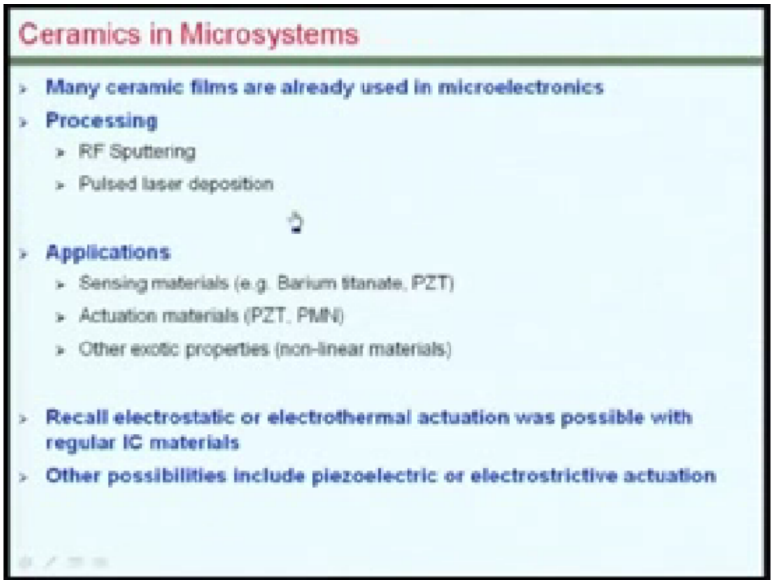

Ceramics in Microsystems

- Many ceramic films are already used in microelectronics
- Processing
  - RF Sputtering
  - Pulsed laser deposition
- Applications
  - Sensing materials (e.g. Barium titanate, PZT)
  - Actuation materials (PZT, PMN)
  - Other exotic properties (non-linear materials)
- Recall electrostatic or electrothermal actuation was possible with regular IC materials
- Other possibilities include piezoelectric or electrostrictive actuation

Many ceramic materials have already been discussed in the context of microsystems. We have also talked about various ways of depositing the electric materials such as RF sputtering or pulsed laser deposition in the context of silicon-based thin films. These could be extended for depositing ceramic materials. You will see that some ceramic materials could also be fabricated based on the polymeric approaches that we have seen earlier today.

This have wide range of sensing and actuation applications and in rare cases, they have peculiar characteristics that are not there most of the other materials that you have seen previously. For example, barium titanate and other materials have no linear characteristics which could be exploited in many microsystems with specialized applications. To recall electrostatic actuators are very popular in microsystems.

Because it only requires electrodes of silicon-based materials which could therefore be fabricated with approaches that are common with silicon foundries. With ceramic materials included, we have new possibilities of actuation including piezoelectric or electrostrictive methods of actuation.

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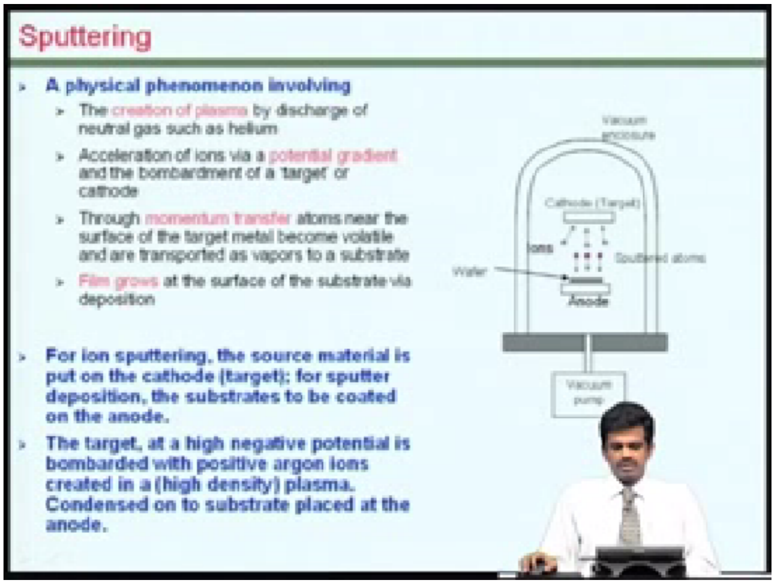

Sputtering

- A physical phenomenon involving
  - The creation of plasma by discharge of neutral gas such as helium
  - Acceleration of ions via a potential gradient and the bombardment of a 'target' or cathode
  - Through momentum transfer atoms near the surface of the target metal become volatile and are transported as vapors to a substrate
  - Film grows at the surface of the substrate via deposition
- For ion sputtering, the source material is put on the cathode (target); for sputter deposition, the substrates to be coated on the anode.
- The target, at a high negative potential is bombarded with positive argon ions created in a (high density) plasma. Condensed on to substrate placed at the anode.

The deposition schemes as I have mentioned, we have seen sputtering in another context. It involves creation of a plasma and these ions will hit the target and replace atoms from the target material or molecules which could be transferred on to the substrate or wafer which is kept in the anode to facilitate, we need a vacuum so that we can create the plasma inside this chamber.

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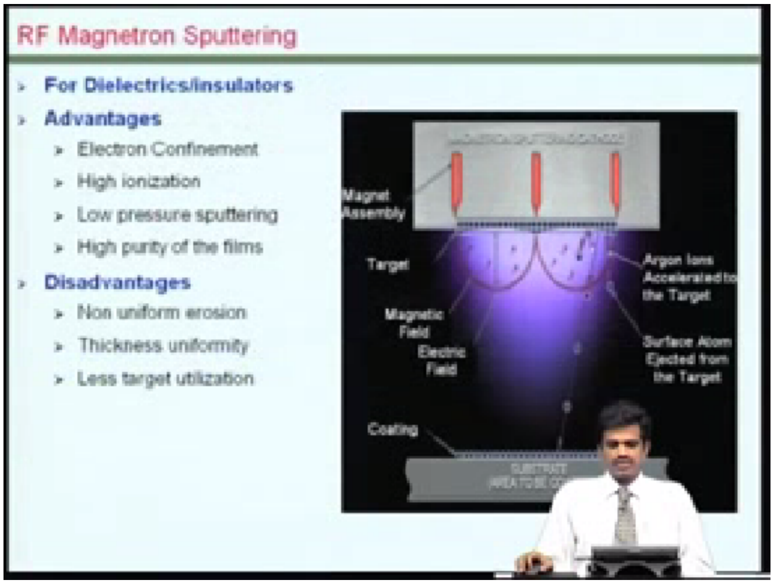

RF Magnetron Sputtering

- For Dielectrics/insulators
- Advantages
  - Electron Confinement
  - High ionization
  - Low pressure sputtering
  - High purity of the films
- Disadvantages
  - Non uniform erosion
  - Thickness uniformity
  - Less target utilization

This obviously the DC plasma is useful for metal material whereas for dielectrics, we typically use RF magnetron based sputtering schemes. We can therefore have very good high purity films in this approach.

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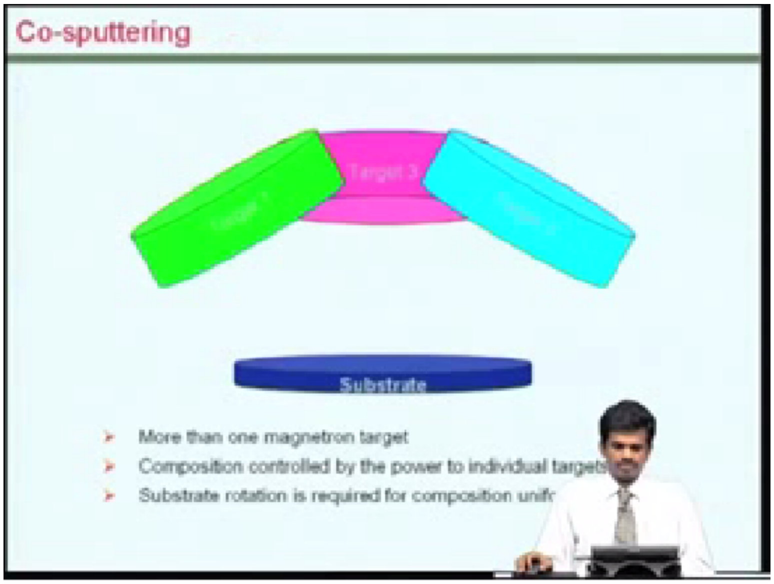

Co-sputtering

- More than one magnetron target
- Composition controlled by the power to individual targets
- Substrate rotation is required for composition unif

It is also possible to deposit multiple compositions using multiple targets on to the same wafer and by arranging the angles or locations of these targets, one can even control the deposition rate as well as the composition.

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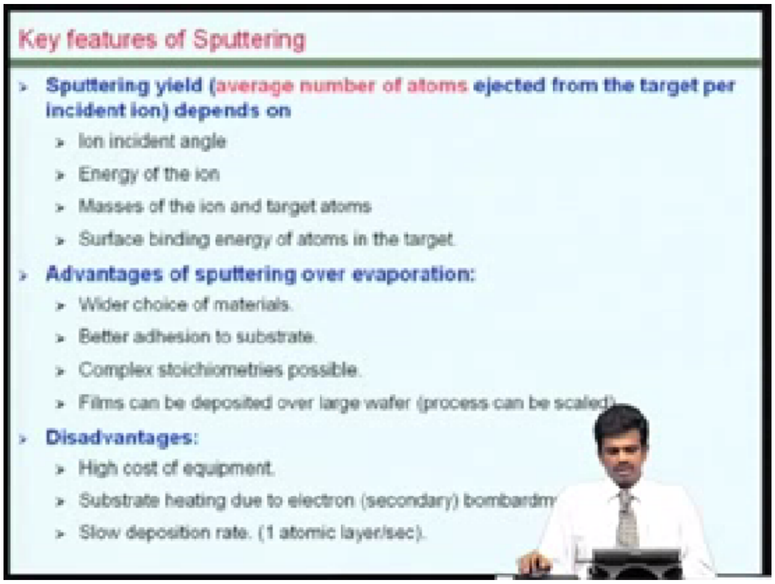

Key features of Sputtering

- Sputtering yield (average number of atoms ejected from the target per incident ion) depends on
  - Ion incident angle
  - Energy of the ion
  - Masses of the ion and target atoms
  - Surface binding energy of atoms in the target
- Advantages of sputtering over evaporation:
  - Wider choice of materials.
  - Better adhesion to substrate.
  - Complex stoichiometries possible.
  - Films can be deposited over large wafer (process can be scaled).
- Disadvantages:
  - High cost of equipment.
  - Substrate heating due to electron (secondary) bombardm
  - Slow deposition rate. (1 atomic layer/sec).

The sputtering yield would depend on a number of factors including the angle of incidence of this ions, the energy of the ion and the mass of the ion and surface bonding energy of the atoms of the target. Wide range of materials can be deposited using this approach. These have very good adhesion characteristics and it is possible to make films of complex structured forms.

Films can be deposited over a relatively large wafer areas. They compared to some of the other methods of deposition, it is probably little more costly and things like that.

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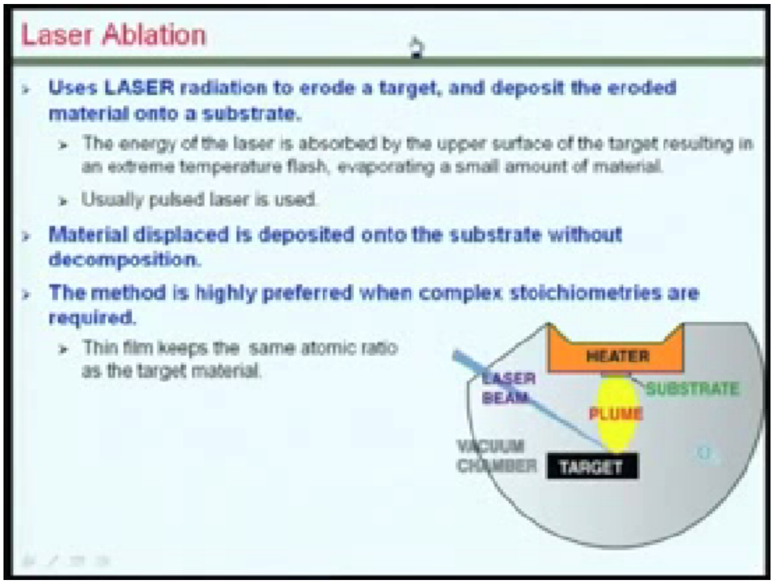

Laser Ablation

- Uses LASER radiation to erode a target, and deposit the eroded material onto a substrate.
  - The energy of the laser is absorbed by the upper surface of the target resulting in an extreme temperature flash, evaporating a small amount of material.
  - Usually pulsed laser is used.
- Material displaced is deposited onto the substrate without decomposition.
- The method is highly preferred when complex stoichiometries are required.
  - Thin film keeps the same atomic ratio as the target material.

Another approach that we have seen in the context of silicon is based on laser ablation in this case. Rather than using this ionic bombardment, we use a laser beam to displace the molecules which essentially goes and hits the substrate.

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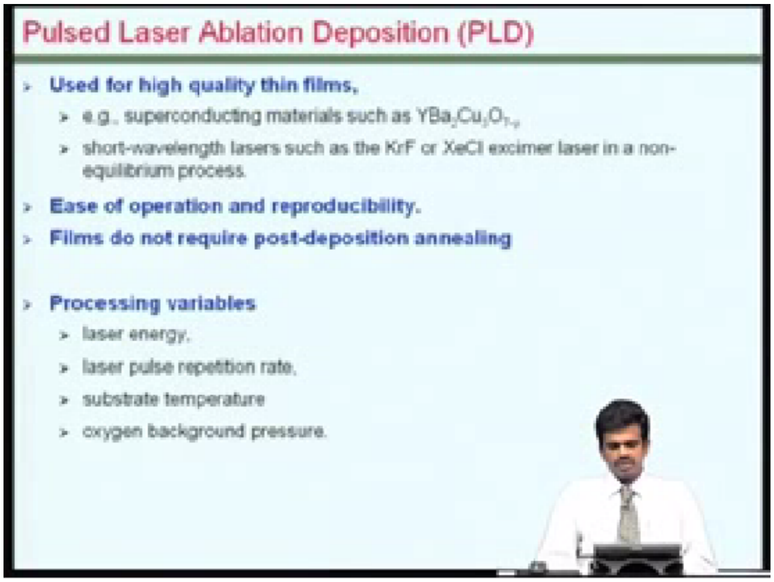

Pulsed Laser Ablation Deposition (PLD)

- **Used for high quality thin films,**
  - e.g., superconducting materials such as $YBa_2Cu_3O_{7-y}$
  - short-wavelength lasers such as the KrF or XeCl excimer laser in a non-equilibrium process.
- **Ease of operation and reproducibility.**
- **Films do not require post-deposition annealing**

- **Processing variables**
  - laser energy,
  - laser pulse repetition rate,
  - substrate temperature
  - oxygen background pressure.

In the case of many ceramic materials, we use the technique known as Pulsed Laser Ablation Deposition which can result in high purity thin films of ceramic materials and can be used for high reproducibility and as in the case of sputtering, the processing variables include the laser energy and laser pulse repetition rate because it is a pulsed approach, the temperature of the substrate and the background pressure.

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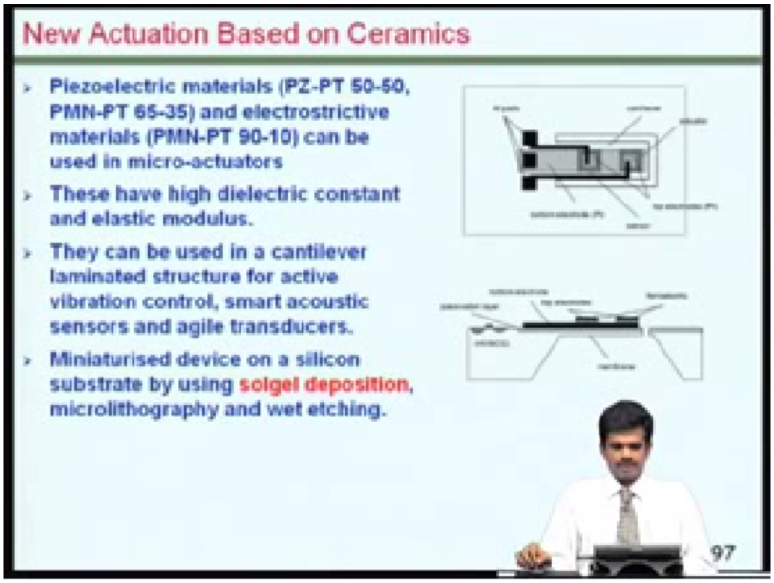

New Actuation Based on Ceramics

- **Piezoelectric materials (PZ-PT 50-50, PMN-PT 65-35) and electrostrictive materials (PMN-PT 90-10) can be used in micro-actuators**
- **These have high dielectric constant and elastic modulus.**
- **They can be used in a cantilever laminated structure for active vibration control, smart acoustic sensors and agile transducers.**
- **Miniaturised device on a silicon substrate by using solgel deposition, microlithography and wet etching.**

For ceramics thin films, there are several other approaches are also pursued. One of them is known as the solgel approach. This is useful for depositing materials such as lead-zirconium titanate and PMN which has electrostatic properties. In this example, it is shown that this is deposited over a cantilever structure on micromachines silica and the electrodes are patterned on both sides of this material.

So with this one can actually build a vibrating cantilever and even the vibration can be sensed using these.

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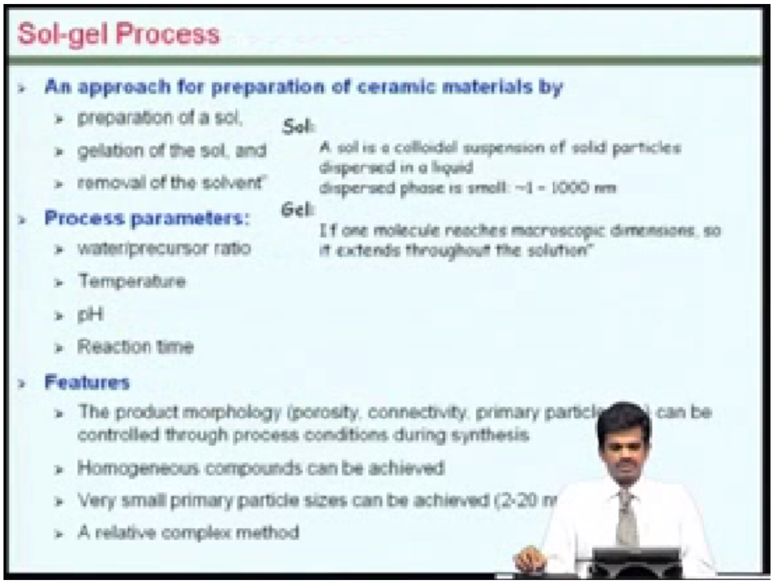

Sol-gel Process

- **An approach for preparation of ceramic materials by**
  - preparation of a sol,
  - gelation of the sol, and
  - removal of the solvent"
- **Process parameters:**
  - water/precursor ratio
  - Temperature
  - pH
  - Reaction time
- **Features**
  - The product morphology (porosity, connectivity, primary particl can be controlled through process conditions during synthesis
  - Homogeneous compounds can be achieved
  - Very small primary particle sizes can be achieved (2-20 n
  - A relative complex method

Sol:

A sol is a colloidal suspension of solid particles dispersed in a liquid

dispersed phase is small: ~1 - 1000 nm

Gel:

If one molecule reaches macroscopic dimensions, so it extends throughout the solution"

So in Sol-gel process, what we essentially have is a sol which is a colloidal suspension of solid particles in a polymeric liquid form. So this is essentially formed by a series of process steps of solid state reactions and then forming fine powders of this material of very low dimensions and then we may disperse this in a polymer and create a gel and this would be deposited on to the substrate and will be used.

So the process parameters could therefore be based on the ratio of the powder to the liquid and the temperatures of curing and pH of the solution and the reaction time.

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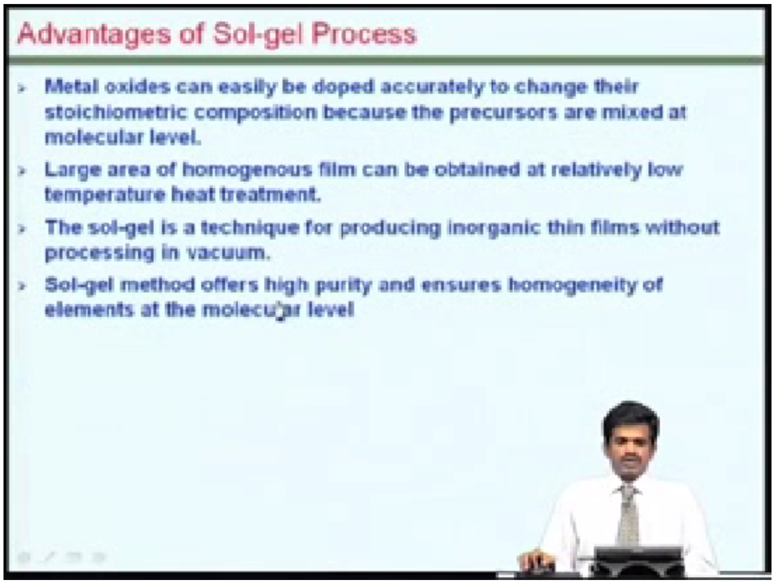

Advantages of Sol-gel Process

- Metal oxides can easily be doped accurately to change their stoichiometric composition because the precursors are mixed at molecular level.
- Large area of homogenous film can be obtained at relatively low temperature heat treatment.
- The sol-gel is a technique for producing inorganic thin films without processing in vacuum.
- Sol-gel method offers high purity and ensures homogeneity of elements at the molecular level

Advantages of Sol-gel process include that it can be used for metal oxides very easily which can be actually doped with additional compounds because you are starting with a solid state reaction, so this powders could be mixed and then these could be used. So a large area of homogenous film can be obtained with this and this can be used for without using vacuum. So the sol-gel method offers high purity and it ensures homogeneity of elements even at the molecular level.

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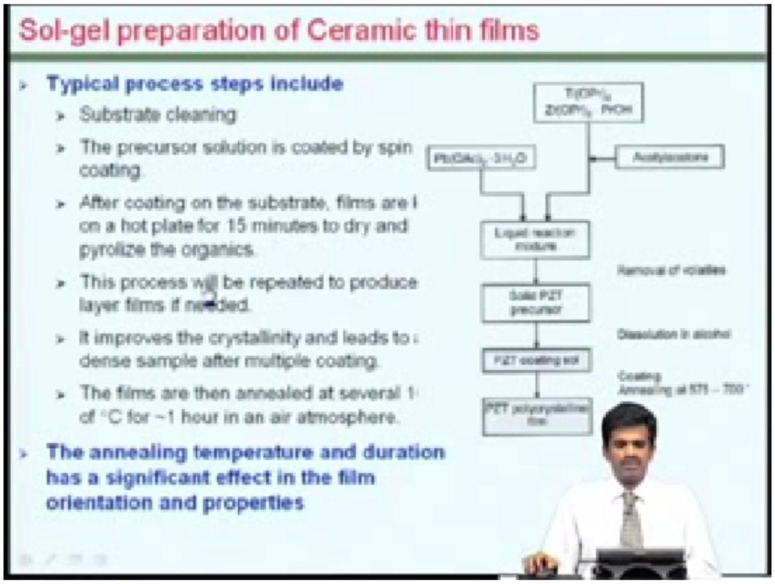

Sol-gel preparation of Ceramic thin films

- **Typical process steps include**
  - Substrate cleaning
  - The precursor solution is coated by spin coating.
  - After coating on the substrate, films are l on a hot plate for 15 minutes to dry and pyrolize the organics.
  - This process will be repeated to produce layer films if needed.
  - It improves the crystallinity and leads to dense sample after multiple coating.
  - The films are then annealed at several 1 of °C for ~1 hour in an air atmosphere.
- **The annealing temperature and duration has a significant effect in the film orientation and properties**

So the typical process steps would therefore involve substrate cleaning and then spin coating this precursor solution on to the substrate and coating it. Then just as other process, we keep it on the hot plate for 15 minutes and then you put it in a furnace for several 100s of degree centigrade and then keep it there for what is called a process known as centric. In some cases, we can also do annealing to create this ceramic film.

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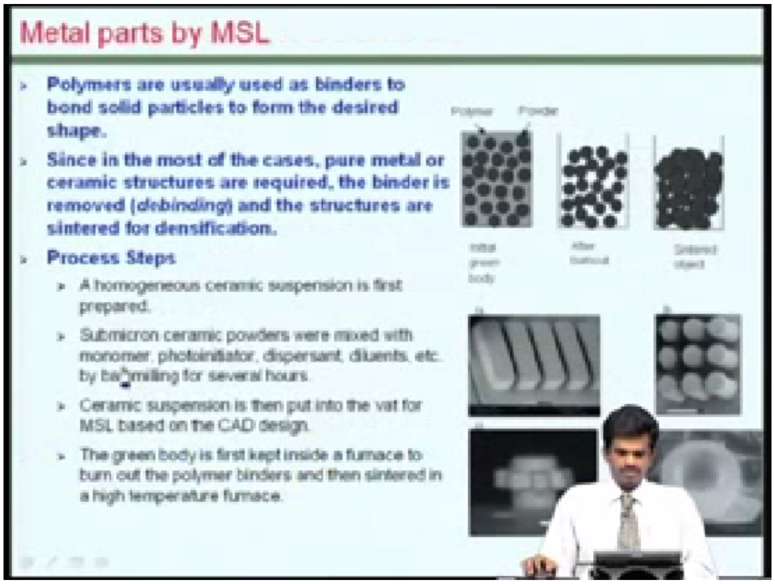

Metal parts by MSL

- **Polymers are usually used as binders to bond solid particles to form the desired shape.**
- **Since in the most of the cases, pure metal or ceramic structures are required, the binder is removed (debinding) and the structures are sintered for densification.**
- **Process Steps**
  - A homogeneous ceramic suspension is first prepared.
  - Submicron ceramic powders were mixed with monomer, photoinitiator, dispersant, diluents, etc. by ball milling for several hours.
  - Ceramic suspension is then put into the vat for MSL based on the CAD design.
  - The green body is first kept inside a furnace to burn out the polymer binders and then sintered in a high temperature furnace.

So when it is mixed with this polymer, the powder particles are dispersed like this and when we actually do a polymer burnout, these powders will actually be lose particles in some sense. So this could actually be gelled together to form stable products by the process known as centric. This approach can even be used along with micro stereolithography. Recall, in micro stereolithography, we have this polymeric resin which is cured.

So we disperse these ceramic particles in it and then we fire this, cinder this and it has been shown that in our 3-dimensional parts could be made by this approach.

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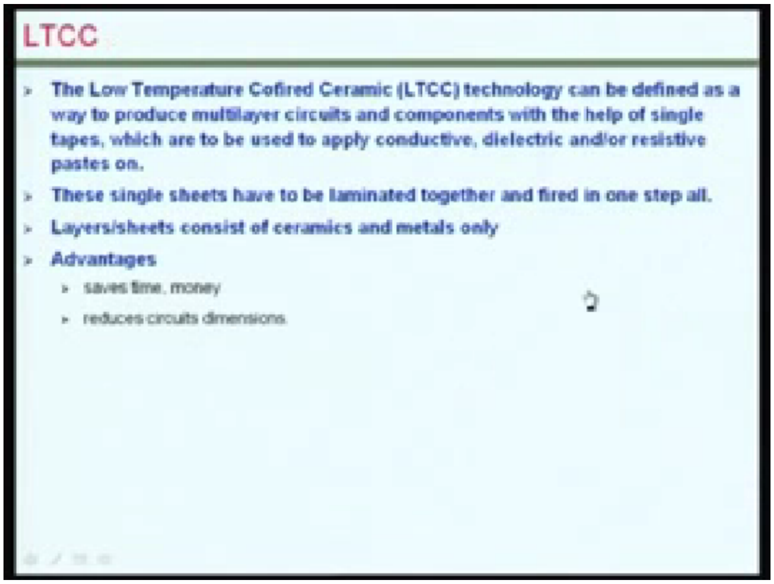

LTCC

- The Low Temperature Cofired Ceramic (LTCC) technology can be defined as a way to produce multilayer circuits and components with the help of single tapes, which are to be used to apply conductive, dielectric and/or resistive pastes on.
- These single sheets have to be laminated together and fired in one step all.
- Layers/sheets consist of ceramics and metals only
- Advantages
  - saves time, money
  - reduces circuits dimensions

Another interesting approach for building ceramic parts is known as LTCC, Low Temperature Cofired Ceramics. Single sheets are available commercially which are essentially stacked together and cindered, fired at a relatively lower temperature than conventional ceramics and hence this name Low Temperature Cofired Ceramics.

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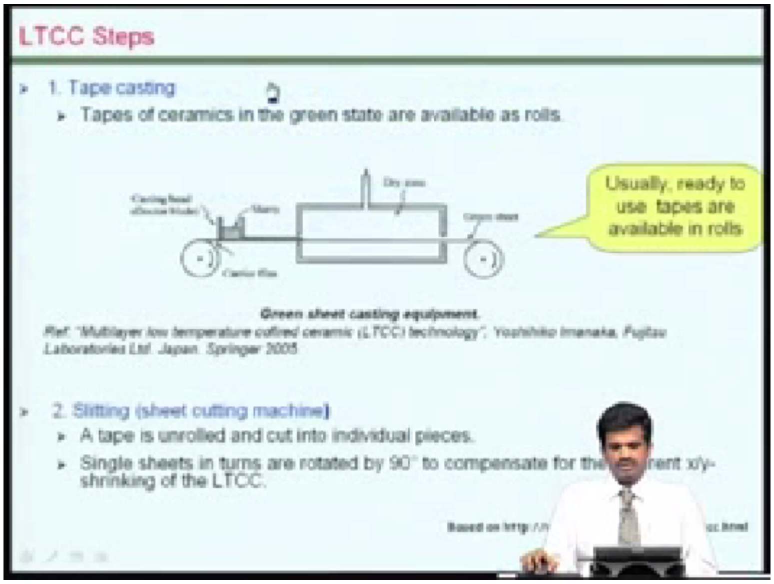

LTCC Steps

- 1. Tape casting
  - Tapes of ceramics in the green state are available as rolls

Green sheet casting equipment.

Ref: "Multilayer low temperature cofired ceramic (LTCC) technology", Yoshihiko Imanaka, Fujitsu Laboratories Ltd. Japan. Springer 2005

- 2. Slitting (sheet cutting machine)
  - A tape is unrolled and cut into individual pieces.
  - Single sheets in turns are rotated by 90° to compensate for the rent x/y-shrinking of the LTCC.

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It starts with making this tapes which are called the green tapes of the ceramics which are slit into pieces.

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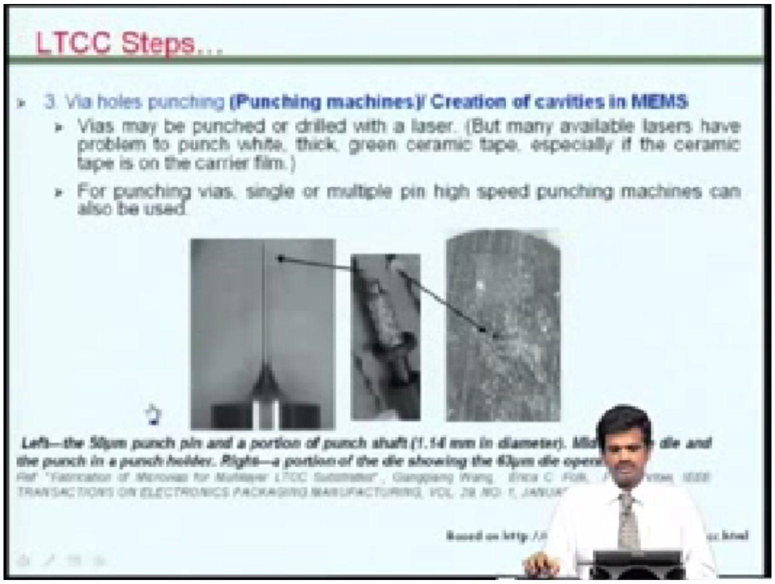

LTCC Steps…

- 3. Via holes punching **(Punching machines)/ Creation of cavities in MEMS**
  - Vias may be punched or drilled with a laser. (But many available lasers have problem to punch white, thick, green ceramic tape, especially if the ceramic tape is on the carrier film.)
  - For punching vias, single or multiple pin high speed punching machines can also be used.

Left—the 50μm punch pin and a portion of punch shaft (1.14 mm in diameter). Mid die and the punch in a punch holder. Right—a portion of the die showing the 63μm die opera

Ref: "Fabrication of Microvias for Multilayer LTCC Substrates", Gangqiang Wang, Erica C. Folk, F IEEE TRANSACTIONS ON ELECTRONICS PACKAGING MANUFACTURING, VOL. 29, NO. 1, JANUA

Based on http://

And then via holes are punched on to the sheets.

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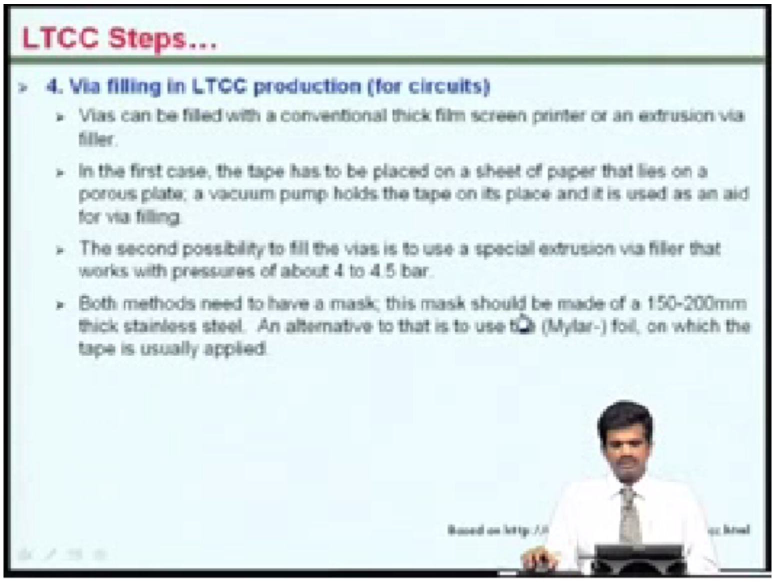

LTCC Steps…

- **4. Via filling in LTCC production (for circuits)**
  - Vias can be filled with a conventional thick film screen printer or an extrusion via filler.
  - In the first case, the tape has to be placed on a sheet of paper that lies on a porous plate; a vacuum pump holds the tape on its place and it is used as an aid for via filling.
  - The second possibility to fill the vias is to use a special extrusion via filler that works with pressures of about 4 to 4.5 bar.
  - Both methods need to have a mask; this mask should be made of a 150-200mm thick stainless steel. An alternative to that is to use the (Mylar-) foil, on which the tape is usually applied.

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and then these could be filled if required by metal conductors.

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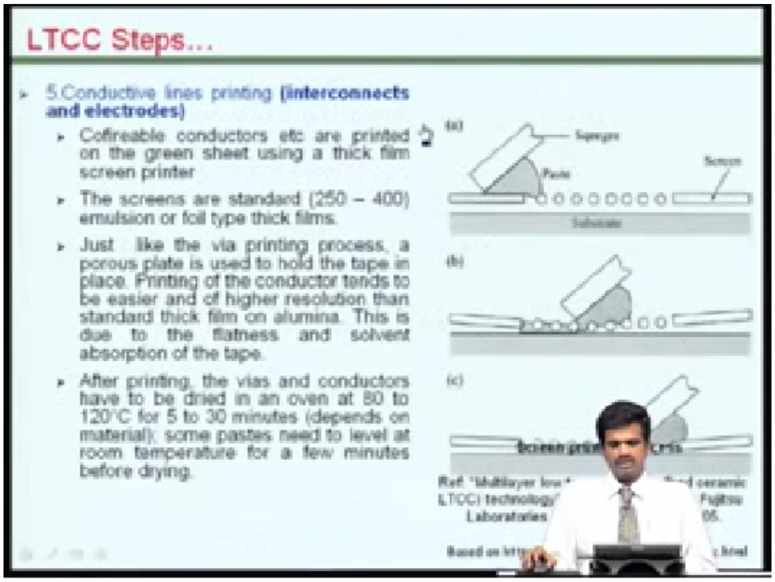

LTCC Steps…

- 5.Conductive lines printing **(interconnects and electrodes)**
  - Cofireable conductors etc are printed on the green sheet using a thick film screen printer
  - The screens are standard (250 – 400) emulsion or foil type thick films.
  - Just like the via printing process, a porous plate is used to hold the tape in place. Printing of the conductor tends to be easier and of higher resolution than standard thick film on alumina. This is due to the flatness and solvent absorption of the tape.
  - After printing, the vias and conductors have to be dried in an oven at 80 to 120°C for 5 to 30 minutes (depends on material); some pastes need to level at room temperature for a few minutes before drying.

Screen prin… …rs

Ref. "Multilayer low… …ed ceramic LTCC) technology"… …Fujitsu Laboratories … …05.

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so that multilayer contacts could be made and then we use screen printing to transfer patterns on to the top layer.

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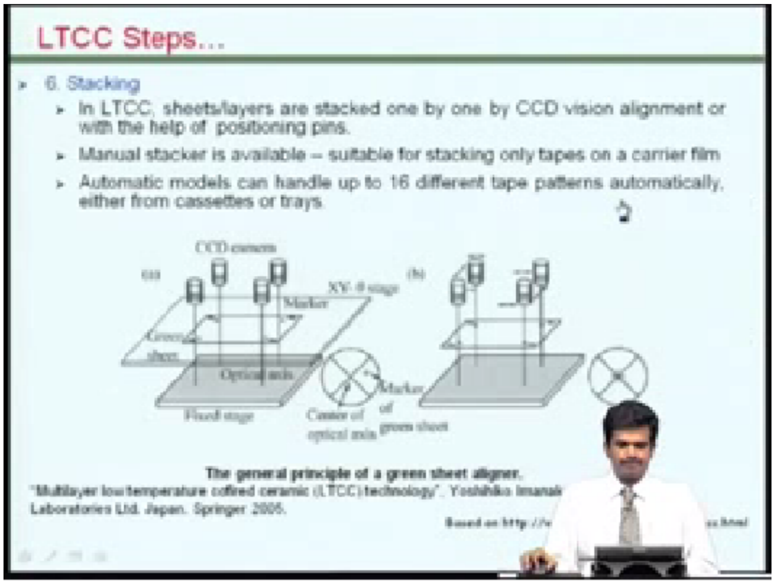

LTCC Steps…

- 6. Stacking
  - In LTCC, sheets/layers are stacked one by one by CCD vision alignment or with the help of positioning pins.
  - Manual stacker is available – suitable for stacking only tapes on a carrier film
  - Automatic models can handle up to 16 different tape patterns automatically, either from cassettes or trays.

The general principle of a green sheet aligner.

"Multilayer low temperature cofired ceramic (LTCC) technology", Yoshihiko Imanak… Laboratories Ltd. Japan. Springer 2005.

Based on http://… …html

And these are then stacked together by registering properly and with good alignment.

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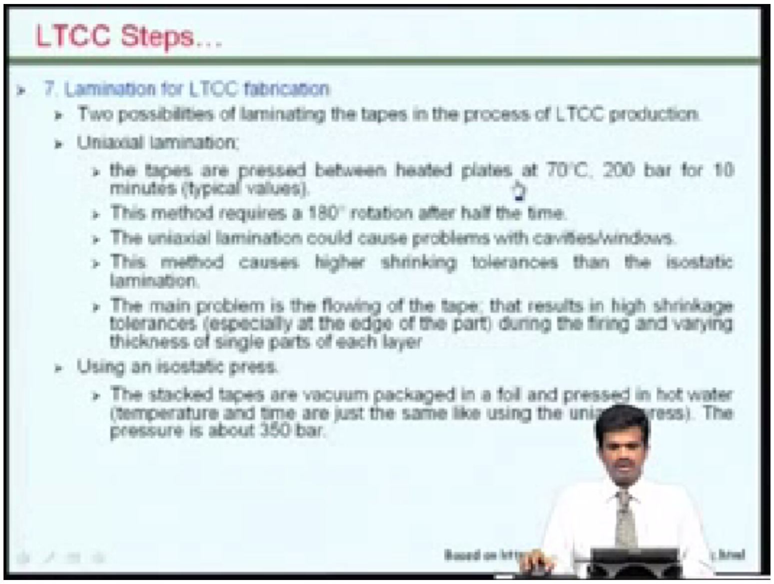

LTCC Steps…

- 7. Lamination for LTCC fabrication
  - Two possibilities of laminating the tapes in the process of LTCC production.
  - Uniaxial lamination;
    - the tapes are pressed between heated plates at 70°C, 200 bar for 10 minutes (typical values).
    - This method requires a 180° rotation after half the time.
    - The uniaxial lamination could cause problems with cavities/windows.
    - This method causes higher shrinking tolerances than the isostatic lamination.
    - The main problem is the flowing of the tape; that results in high shrinkage tolerances (especially at the edge of the part) during the firing and varying thickness of single parts of each layer
  - Using an isostatic press.
    - The stacked tapes are vacuum packaged in a foil and pressed in hot water (temperature and time are just the same like using the uni ress). The pressure is about 350 bar.

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And these are laminated and paste together using an isostatic press.

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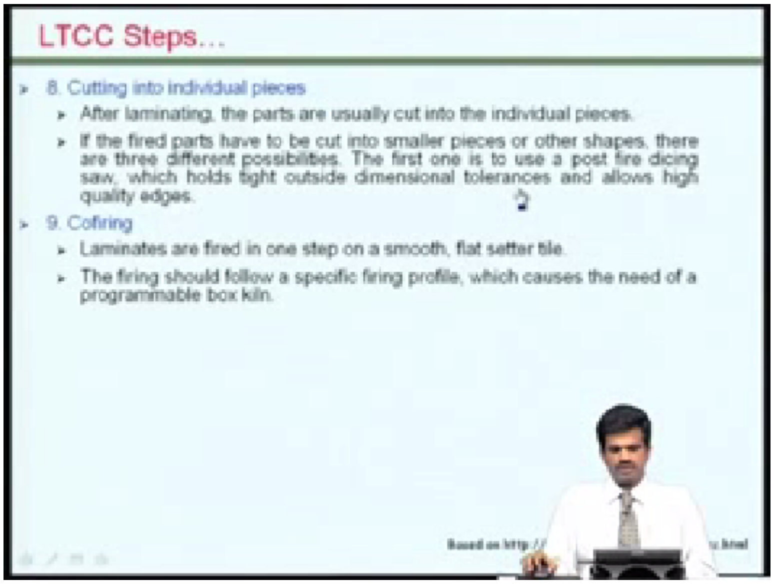

LTCC Steps…

- 8. Cutting into individual pieces
  - After laminating, the parts are usually cut into the individual pieces.
  - If the fired parts have to be cut into smaller pieces or other shapes, there are three different possibilities. The first one is to use a post fire dicing saw, which holds tight outside dimensional tolerances and allows high quality edges.
- 9. Cofiring
  - Laminates are fired in one step on a smooth, flat setter tile.
  - The firing should follow a specific firing profile, which causes the need of a programmable box kiln.

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And then cutting into individual devices.

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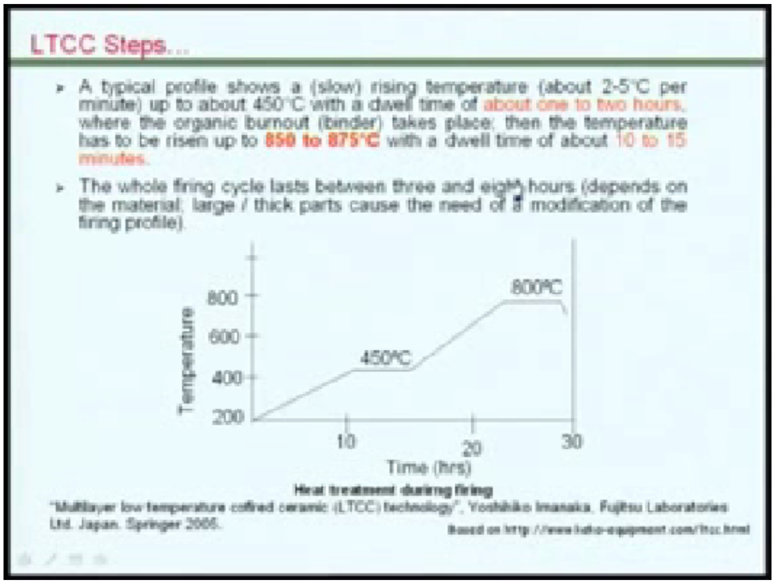

LTCC Steps...

- A typical profile shows a (slow) rising temperature (about 2-5°C per minute) up to about 450°C with a dwell time of about one to two hours, where the organic burnout (binder) takes place; then the temperature has to be risen up to **850 to 875°C** with a dwell time of about 10 to 15 minutes.
- The whole firing cycle lasts between three and eight hours (depends on the material; large / thick parts cause the need of a modification of the firing profile).

Heat treatment during firing

"Multilayer low temperature cofired ceramic (LTCC) technology", Yoshihiko Imanaka, Fujitsu Laboratories Ltd. Japan. Springer 2005.

Based on http://www.keko-equipment.com/ltcc.html

And fired with a predetermined temperature cycle.

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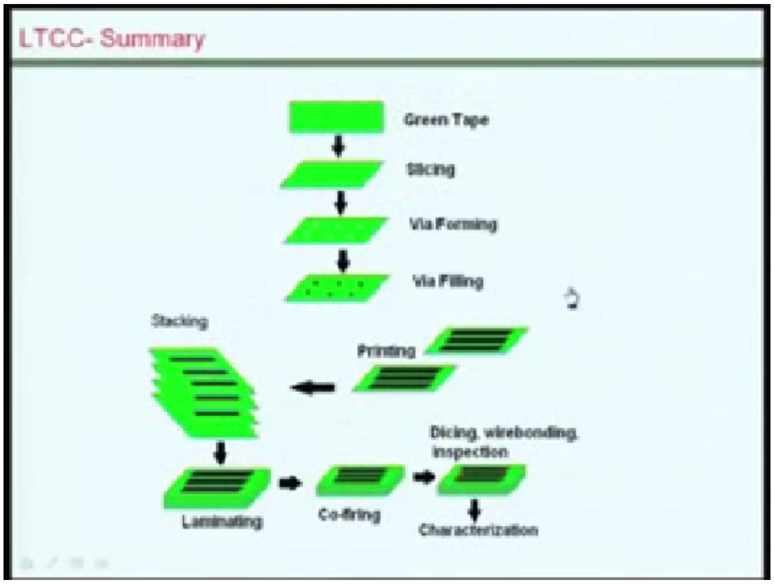

LTCC- Summary

So with this approach, one can actually start from this individual layers of green tapes and build a multilayer structures.

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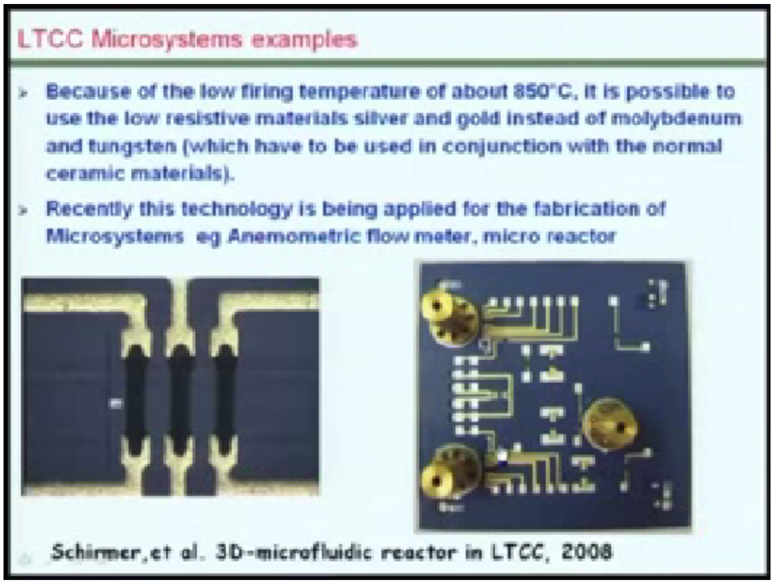

LTCC Microsystems examples

- Because of the low firing temperature of about 850°C, it is possible to use the low resistive materials silver and gold instead of molybdenum and tungsten (which have to be used in conjunction with the normal ceramic materials).
- Recently this technology is being applied for the fabrication of Microsystems eg Anemometric flow meter, micro reactor

Schirmer, et al. 3D-microfluidic reactor in LTCC, 2008

This has been shown to be useful in building micro reactors or flow meters with LTCC-based approach. Conductor materials are possible, resistive materials are possible using these approaches but the key is that one can get self-packaged devices indicated even with electrical interconnects by this approach.

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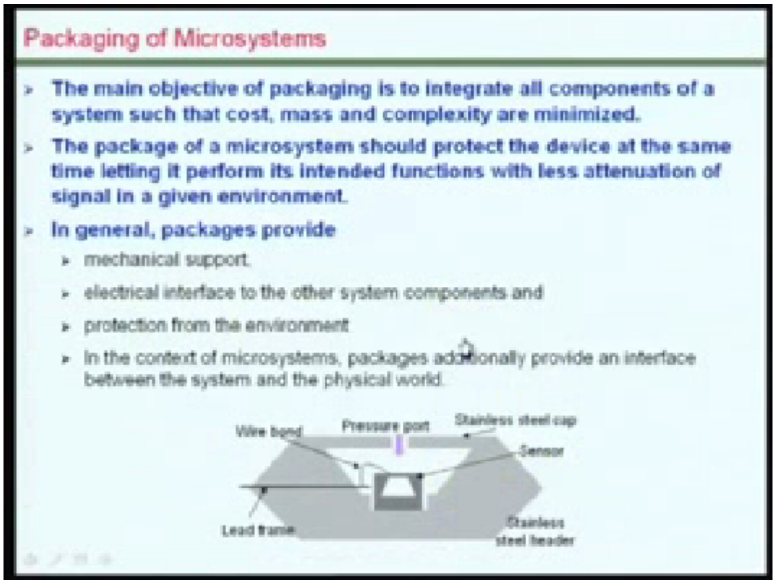

Packaging of Microsystems

- The main objective of packaging is to integrate all components of a system such that cost, mass and complexity are minimized.
- The package of a microsystem should protect the device at the same time letting it perform its intended functions with less attenuation of signal in a given environment.
- In general, packages provide
  - mechanical support
  - electrical interface to the other system components and
  - protection from the environment
  - In the context of microsystems, packages additionally provide an interface between the system and the physical world.

So what we have seen so far is various approaches of building microsystems and what we have see towards the end is that with some of these non-conventional approaches, it is in fact possible to build packaged microsystems. One aspect that we have not yet discussed is how we actually package and what are the issues in packaging microsystems when you build them using silicon. So we will talk about that in another lecture and I thank you for listening.