

Module 10 : Futuristic topics in robots

Lecture 37 : Introductions to MEMS-I (micro electro-mechanical systems)

Objectives

In this course you will learn the following

- MEMS(Micro Electro-Mechanical system)
- Gross level robotic system
- MEMS Robotic Systems in Reality
- Fabrication Processes
- Material Removal Processes
- Miniature robotic system
- Lithography: (Patterning)
- Chemical Etching
- Anisotropic etching
- Sputtering
- Chemical Vapor Deposition (CVD)
- Plasma Etching
- Surface Micromachining
- Electroplating
- LIGA

MEMS(Micro Electro-Mechanical system) :

MEMS refer to *miniature mechatronic systems which are bulk fabricated using VLSI (very large scale integration) technology* .

VLSI technology was traditionally used for fabrication of chips. Using this technology if we can manufacture tiny electronic components then why not to use it for manufacturing of tiny mechanical components. This is the driving factor for evolution of MEMS. Some people refer the techniques & processes used for fabrication of micro components as MEMS while some refer the conventional traditional 2-D Silicon based fabrication processes as MEMS. Using it we can manufacture micro electrical & mechanical components on

same substrate or on different substrate & then we can integrate them.

Advantages :

- Manufacturing of Micro size sensors and actuators using MEMS & Integration with electronics on single chip (system or lab on chip). This will have large scope in Robotic systems.
- MEMS has better quality at decreased cost of production due to bulk processing .
- Many new features and products previously unthought can be possible. e.g. Capsule Camera . a small camera in capsule. after taking capsule it will travel through all intestinal canals & send 2 images per second to a pager like device which is located outside human body on a belt. It will remove the necessity of bulky endoscopy.
- Combination of MEMS with other branches: Example optical MEMS, Bio-MEMS a futuristic devices.
- We will see its combination with Robotic system in today's lecture.

Gross level robotic system:

- **Sensors**

Example: sensors for mobile robots, aerial robots, MEMS based accelerometers, MEMS based gyroscope etc.

- **Actuators**

Example: Piezo based miniature actuator which are basically used for micro manipulation.

Miniature robotic system

Sensors, actuators, plant or structure of robot at micro level. Use of such miniature robotic system in surgery applications.

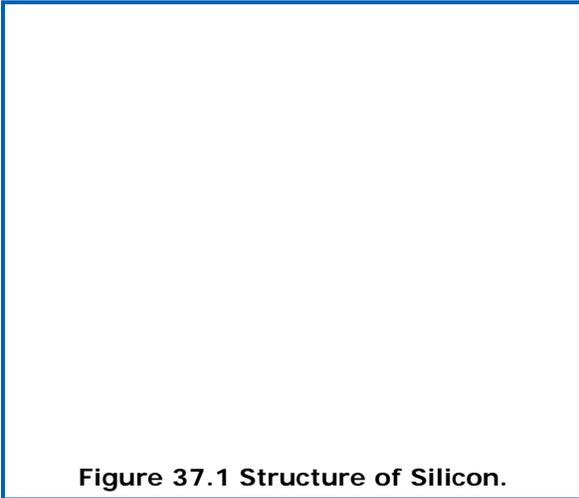
MEMS Robotic Systems in Reality:

- Millibots (CMU): means Very small Robots & if n no. of such robots are working in co-ordination with each other then that set of Robot is referred as Millibot fleet .
- Gyrover: Single wheeled robot uses gyroscope for stabilization .
- Surgical robotic systems.
- Robots handling genes cells.
- Micromanipulators, microgrippers using comb actuators for Bio-medical applications.
- Walking microrobots.

Material for MEMS :

Primary material is Silicon as VLSI technology is used for manufacturing .

Properties of Silicon:



- Stronger than steel.
- Light as Aluminium.
- Can be coated with varieties of materials.
- Available in form of Wafers of 2", 4", 8", 12" dia.

Other materials

- Polycrystalline silicon (polysilicon) .
- Silicon dioxide (SiO_2), Silicon nitride (Si_3N_4) .
- Aluminum (thin film) .
- Gold (thin film) .
- Doping of silicon . This particularly used for stopping the chemical etching process.

Fabrication Processes :

- Various fabrication processes are enlisted below. One may use combination of these processes to manufacture the required component.
- Lithography : It is used for forming some pattern on wafer which will be further used for Selective etching .

Material Removal Processes :

- Chemical etching.
 - Isotropic
 - Anisotropic
- Plasma etching: RIE.

Material Deposition Processes :

- Oxidation
- Sputtering
- Chemical vapor deposition (CVD)
- Electroplating
- Surface micromachining (Combination of Lithography alongwith Material removal or Material deposition process)
- LIGA .

Lithography: (Patterning)

Basic idea is to form a pattern of Photoresist on Wafer. Then subject it to selective etching.

Positive Photoresist: [\(animation\)](#)

Negative Photoresist: [\(animation\)](#)

E-Beam lithography:

- Features are written by scanning (usually vector scan) electron beam.
- No necessity of mask.
- Can be used for preparation of mask.
- Very fine size (sub-micron or <1 micron) features can be produced easily.
- Not suitable for higher length features(e.g 1 mm feature).
- Preferred in research

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Chemical Etching :

Isotropic etching :

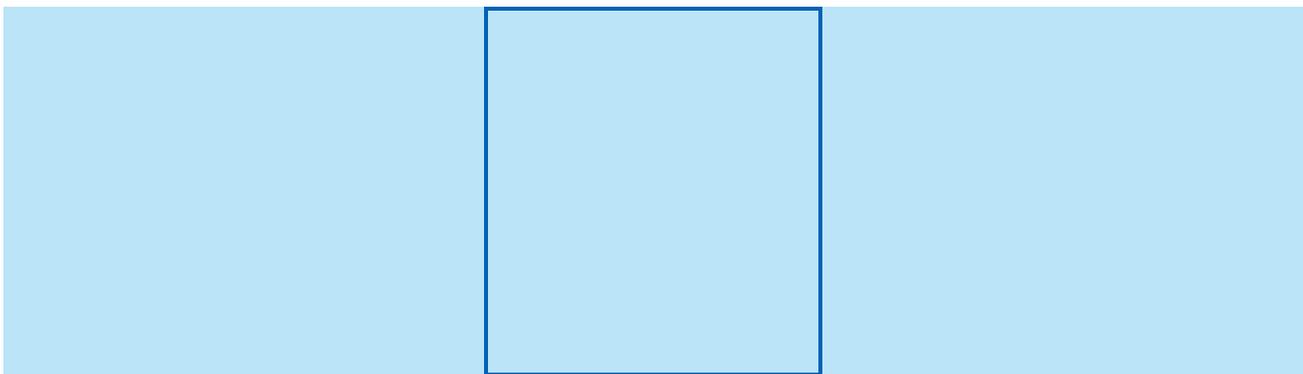
- Etchant : HNA mixture (Mixture of Nitric acid & Acetic acid).
- HNA can dissolve 550 mm thick silicon wafer in about 20 min.
- HNA mixture removes silicon equally in all directions. SiO₂ etch: 10-30nm/min.

- By varying concentration of acids in mixture we can control etching time.
- There is unavoidable undercutting which need to be considered while designing.



Anisotropic etching:

- Along different planes silicon has different density.
- Etchant: KOH, EDP are sensitive to densities.
- $\langle 111 \rangle$ direction has lower etching rates than $\langle 100 \rangle$.
- Can produce grooves, slanted/vertical walls.
- Wafers are available with same direction of all crystals perpendicular to its surface.



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Plasma Etching :



Figure 37.2 Plasma Etching

- Gas is exposed to electric and magnetic fields.
- Ionized gas hits the target surface to remove material.
- (Plasma + Chemical) → Reactive ion etching (RIE) – very efficient process.

Oxidation :

Oxidation of Si : keep in air at high temp (1000-1200°C) Well understood and controlled process means to have this much thickness how much time we should keep it in furnace?

Parameters

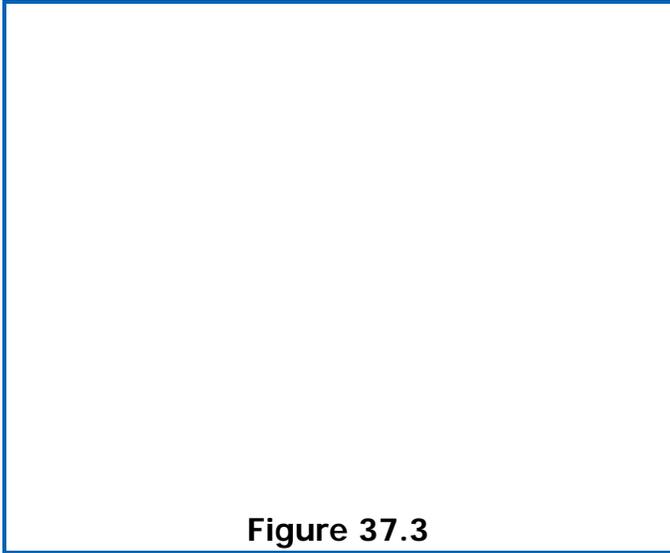
- Temperature Environment
- Time

Oxide:

Important patterning material. It is not affected by many chemicals. Chemical which does not affect Silicon oxide but can affect Silicon are used.

Major problem in using oxide as a patterning material is thermal stresses.

Sputtering :



It is done in Vacuum chamber. Between electrodes there is Ar/ He (inert gases) plasma. There is heating of target by these high velocity plasma ions. Because of heating it will release ions which will be deposited on wafers.

- Target surface bombarded with a flux of *inert* ions (Ar, He)
- DC fields or RF for accelerating.
- Deposition rates 1 μm/min for Al
- Granular deposited film under stress

Use of Low temperature is major advantage of this process. Generally in MEMS low temperature processes are preferred. Because at microscale these thermal stresses are very dominant.

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Chemical Vapor Deposition (CVD):



Chemical reaction is taking place in vacuum chamber. Generally Higher temperatures (>300°C) are employed.

Chemically active gases are passed in the chamber. They will react with each other & form the molecules required to be deposited.

Polysilicon, SiO₂, Si₃N₄, tungsten, titanium, copper etc. can be deposited. But it has one advantage that molecules formed will be deposited on surface of chambers also.

Parameters:

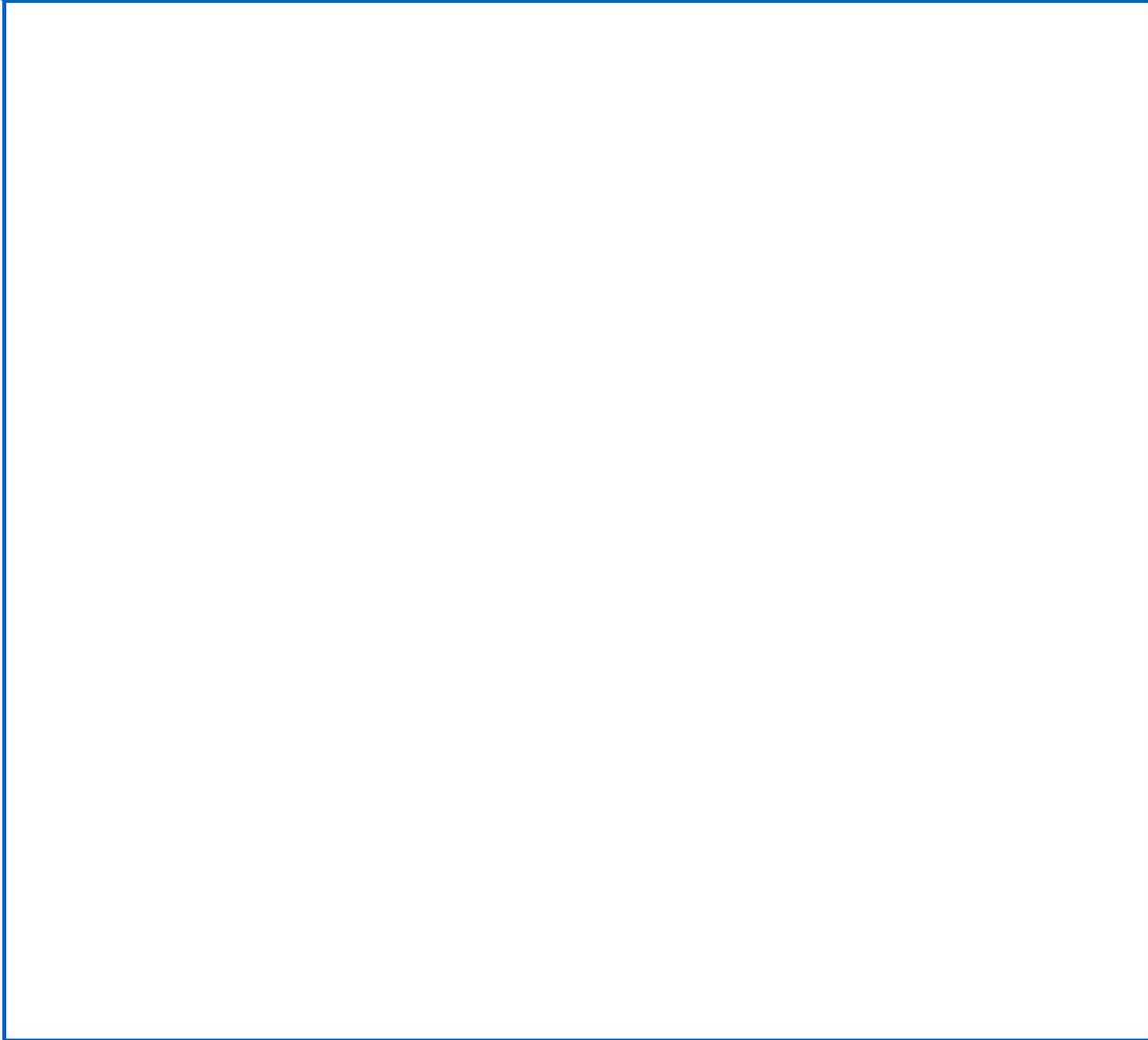
- Pressure
- Temp
- Gas flow

Surface Micromachining :



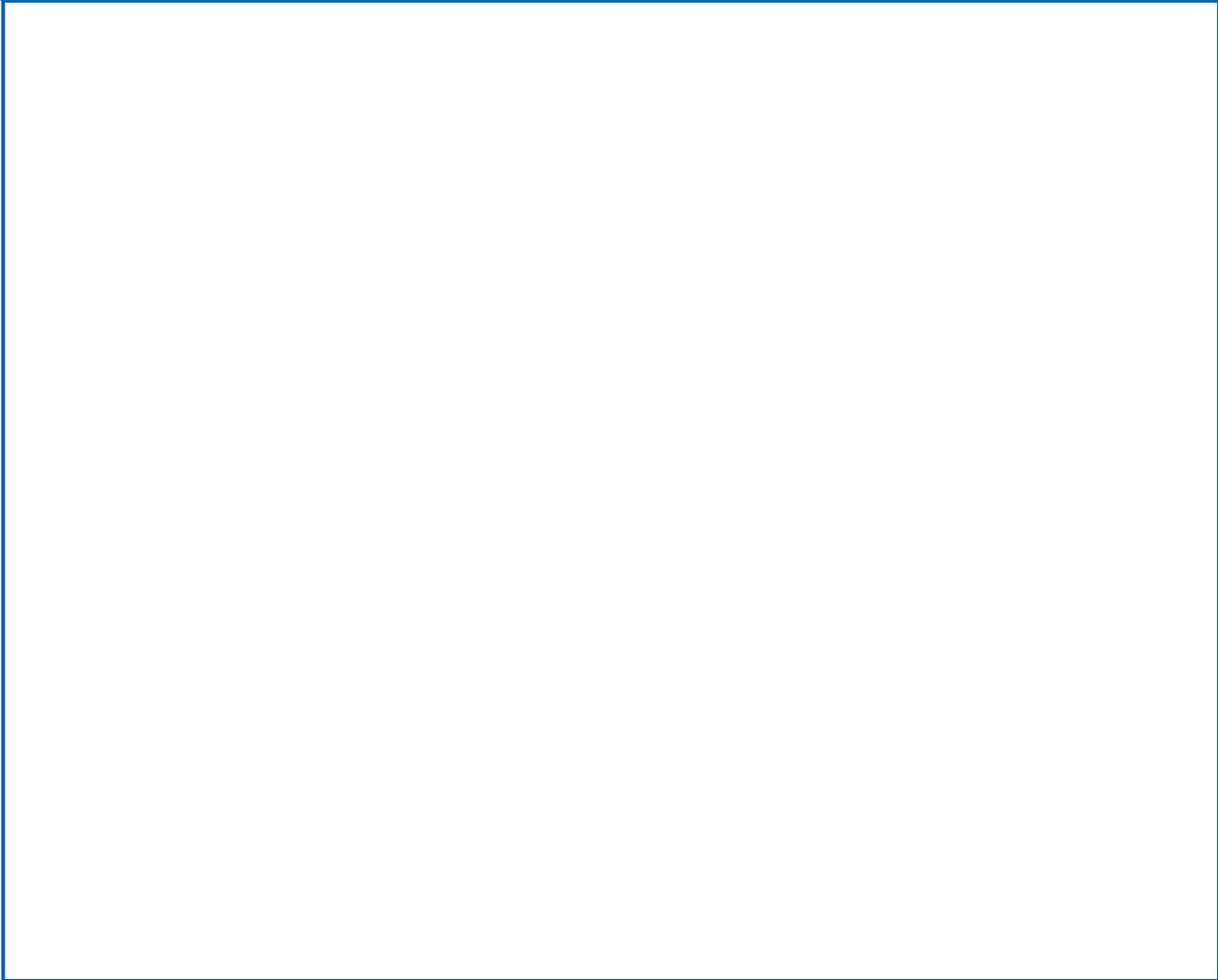
It can be regarded as combination of lithography and etching. It is Defined with respect to deposited films instead of Si substrate

Electroplating :



As the name suggests it is plating of one material on another material. Using lithography patterning is done on surface of substrate & then it is selectively plated. in this there is a adhesive layer on substrate on which copper & chromium layers are there. Then there is a thick layer of PMMA photoresist. Basically it is polymer. This thick layer will be selectively exposed to light. Deep cavities will be formed which will be filled by electroplating. Then rest of things are removed by using chemical

LIGA :



Combined Lithography, electroplating and molding process for high aspect ratio (depth/width) structures. Very high aspect ratio are obtained due to X-rays as X-rays are having high penetrating ability. But it is dangerous. Hence not used in industry.

Fabrication of Accelerometer :



Design Considerations :

Design considerations are totally different than the one which deals with gross level design .

- Design for fabrication

e.g. Manufacturing of long shaft is not possible .

- Fabrication

It is series of selective deposition and etching processes. These processes alongwith patterning should be used very effectively.

- Array of devices can be fabricated

At a time components of same shape but different sizes can be manufactured from which the one useful can be found out.

- Cost

No. of lithography steps should be minimum for cost effective design as the cost of mask used in this process is very high..

Other consideration:

- Thermal expansion of devices.

- Air damping:

When we are dealing with gross level system air damping has negligible effect but while dealing with MEMS it has significant effect. If we carry out an experiment with MEMS in vacuum & in ambient air there will be deviation in results obtained because of air damping effect.

- Integration of electronics along with mechanical device.

Due to some limitations mechanical & electronic components are fabricated separately which we have to integrate on same chip.

- Packaging and safety

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