

# MICROFABRICATION TECHNOLOGIES

- Microsystem Products
- Microfabrication processes
- Nanotechnology

# Trends and Terminology

- Trend: miniaturization of products and parts, with features sizes measured in microns ( $10^{-6}$  m)
- Some of the terms:
  - *Microelectromechanical systems* (MEMS) - miniature systems consisting of both electronic and mechanical components
  - *Microsystem technology* (MST) - refers to the products as well as the fabrication technologies
  - *Nanotechnology* - even smaller devices whose dimensions are measured in nanometers ( $10^{-9}$  m)

# Advantages of Microsystem Products

- Less material usage
- Lower power requirements
- Greater functionality per unit space
- Accessibility to regions that are forbidden to larger products
- In most cases, smaller products should mean lower prices because less material is used

# Types of Microsystem Devices

- Microsensors
- Microactuators
- Microstructures and microcomponents
- Microsystems and micro-instruments

# Microsensors

A sensor is a device that detects or measures some physical phenomenon such as heat or pressure

- Most microsensors are fabricated on a silicon substrate using the same processing technologies as those used for integrated circuits
- Microsensors have been developed for measuring force, pressure, position, speed, acceleration, temperature, flow, and a variety of optical, chemical, environmental, and biological variables

# Microactuators

An actuator converts a physical variable of one type into another type, and the converted variable usually involves some mechanical action

- An actuator causes a change in position or the application of force
- **Examples** of microactuators: valves, positioners, switches, pumps, and rotational and linear motors

# Microstructures and Microcomponents

Micro-sized parts that are not sensors or actuators

- Examples: microscopic lenses, mirrors, nozzles, and beams
- These items must be combined with other components in order to provide a useful function

# Microsystems and micro-instruments

Integration of several of the preceding components with the appropriate electronics package into a miniature system or instrument

- They tend to be very application specific
  - **Examples:** microlasers, optical chemical analyzers, and microspectrometers
- The economics of manufacturing these kinds of systems have tended to make commercialization difficult



# Industrial Applications of Microsystems

- Ink-jet printing heads
- Thin-film magnetic heads
- Compact disks
- Automotive components
- Medical applications
- Chemical and environmental applications
- Other applications

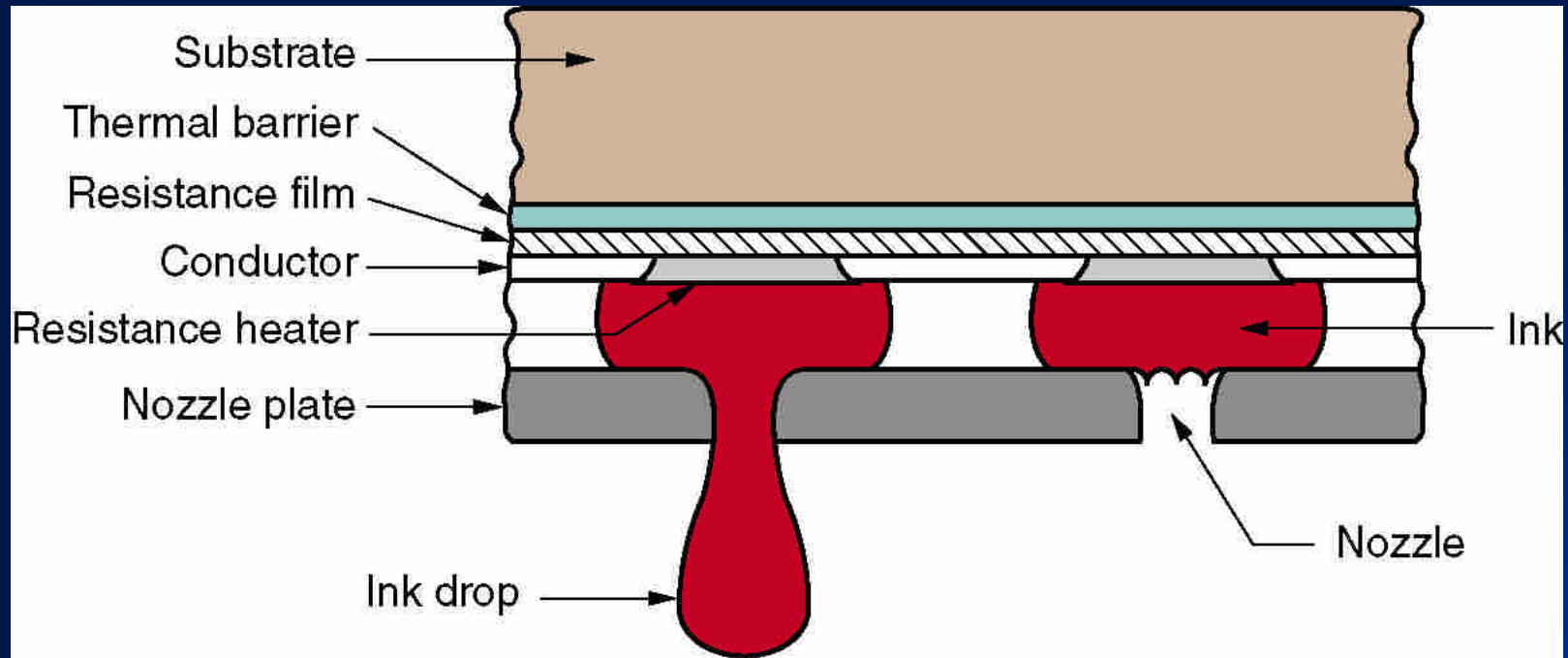


Figure 37.3 - Diagram of an ink-jet printing head

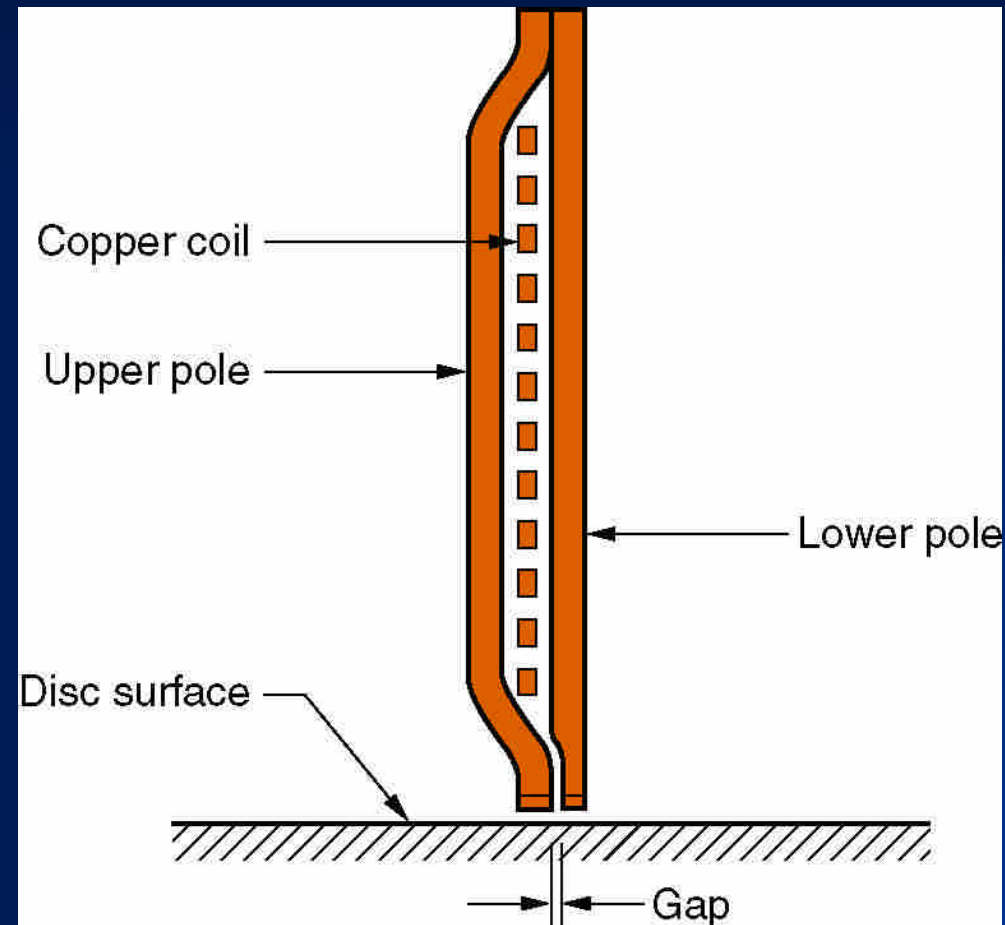


Figure 37.4 - Thin-film magnetic read-write head (simplified)

# Compact Disks

- Important commercial products, as storage media for audio, video, and computer software
  - Mass-produced by plastic molding of polycarbonate
- The molds are made using microsystem technology
  - A master for the mold is made from a smooth thin layer of photosensitive polymer on a glass plate
  - The polymer is exposed to a laser beam that writes the data into the surface
  - The mold is then made by electroforming metal onto this polymer master

# Automotive Components

- Micro-sensors and other micro-devices are widely used in modern automobiles
- There are between 20 and 100 sensors installed in a modern automobile, depending on make and model
  - **Functions** include electronic engine control, cruise control, anti-lock braking systems, air bag deployment, automatic transmission control, power steering, all-wheel drive, automatic stability control, on-board navigation systems, and remote locking and unlocking
  - In 1970 there were virtually no on-board sensors

# Medical Applications

- A driving force for **microscopic devices** is the principle of minimal-invasive therapy, which means using very small incisions or even available body orifices to access the medical problem of concern
- Standard medical practice today is to use endoscopic examination accompanied by laparoscopic surgery for hernia repair and removal of organs such as gall bladder and appendix
- Growing use of similar procedures is expected in brain surgery, operating through one or more small holes drilled through the skull

# Microfabrication Processes

- Many MST products are based on silicon
- Reasons why silicon is a desirable material in MST:
  - Microdevices often include electronic circuits, so both the circuit and the device can be made on the same substrate
  - **Silicon has good mechanical properties:** high strength & elasticity, good hardness, and relatively low density
  - **Techniques to process silicon are well-established**

## Other Materials and MST Processing

- MST often requires other materials in addition to silicon to obtain a particular microdevice
  - Example: microactuators often consist of several components made of different materials
- Thus, **microfabrication techniques consist of more than just silicon processing**:
  - LIGA process (Lithographie Galvanoformung Abformtechnik, German words)
  - Other conventional and nontraditional processes accomplished on a microscopic scale



## Differences between Microfabrication and IC Fabrication

- Aspect ratios (height-to-width ratio of the features) in microfabrication are generally much greater than in IC fabrication
- The device sizes in microfabrication are often much larger than in IC processing
- The structures produced in microfabrication often include cantilevers and bridges and other shapes requiring gaps between layers

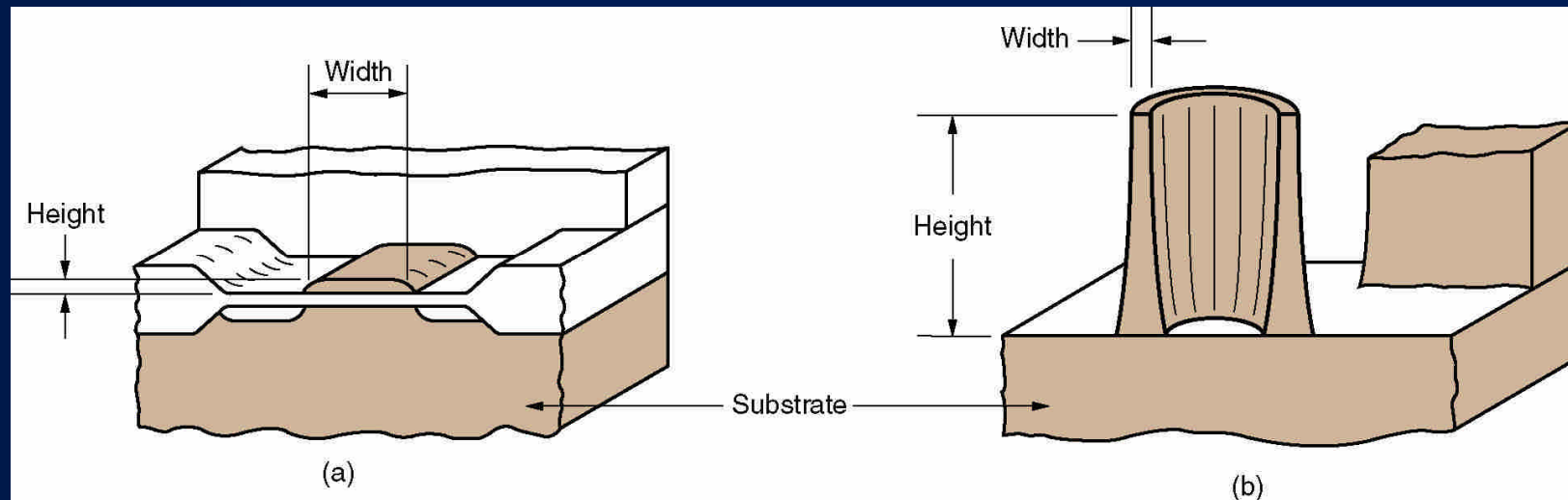


Figure 37.5 - Aspect ratio (height-to-width ratio) typical in (a) fabrication of integrated circuits and (b) microfabricated components

## 3D Features in Microfabrication

- Chemical wet etching of polycrystalline silicon is isotropic, with the formation of cavities under the edges of the resist
- However, in single-crystal Si, etching rate depends on the orientation of the lattice structure
- 3-D features can be produced in single-crystal silicon by wet etching, provided the crystal structure is oriented to allow the etching process to proceed anisotropically

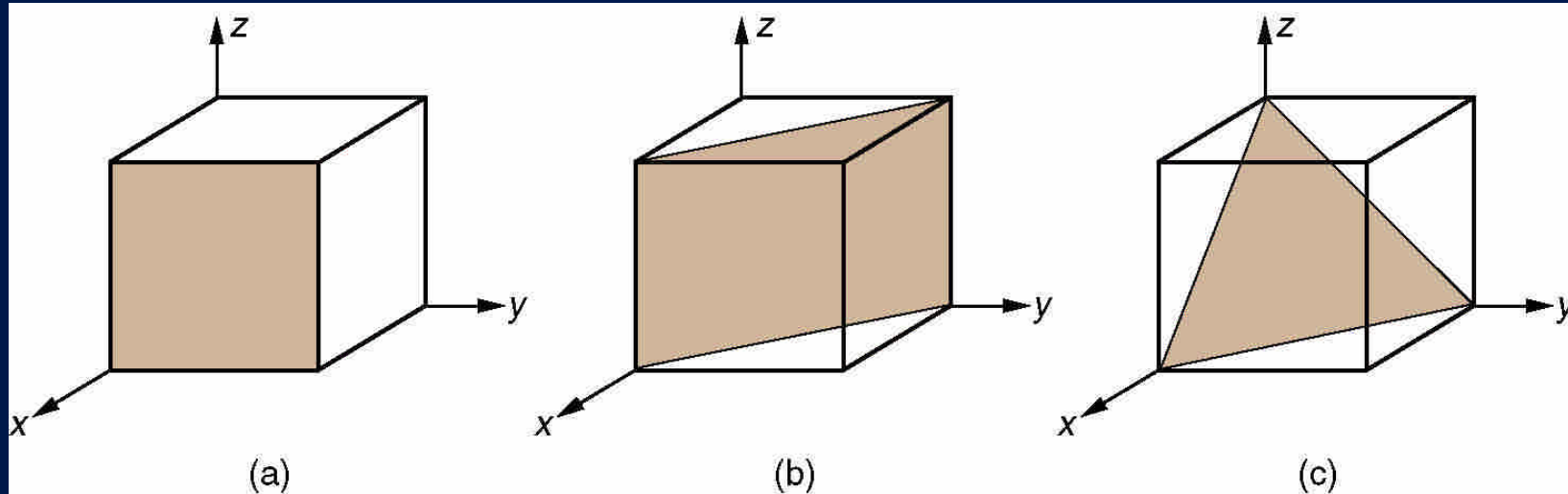


Figure 37.6 - Three crystal faces in the silicon cubic lattice structure:  
(a) (100) crystal face, (b) (110) crystal face, and  
(c) (111) crystal face

## Bulk Micromachining to Achieve Large Aspect Ratios

- Certain etching solutions, such as potassium hydroxide (KOH), have a very low etching rate in the direction of the (111) crystal face
- This permits formation of distinct geometric structures with sharp edges in single-crystal Si if the lattice is oriented favorably
- *Bulk micromachining* - relatively deep wet etching process on single-crystal silicon substrate
- *Surface micromachining* - planar structuring of the substrate surface, using much more shallow etching

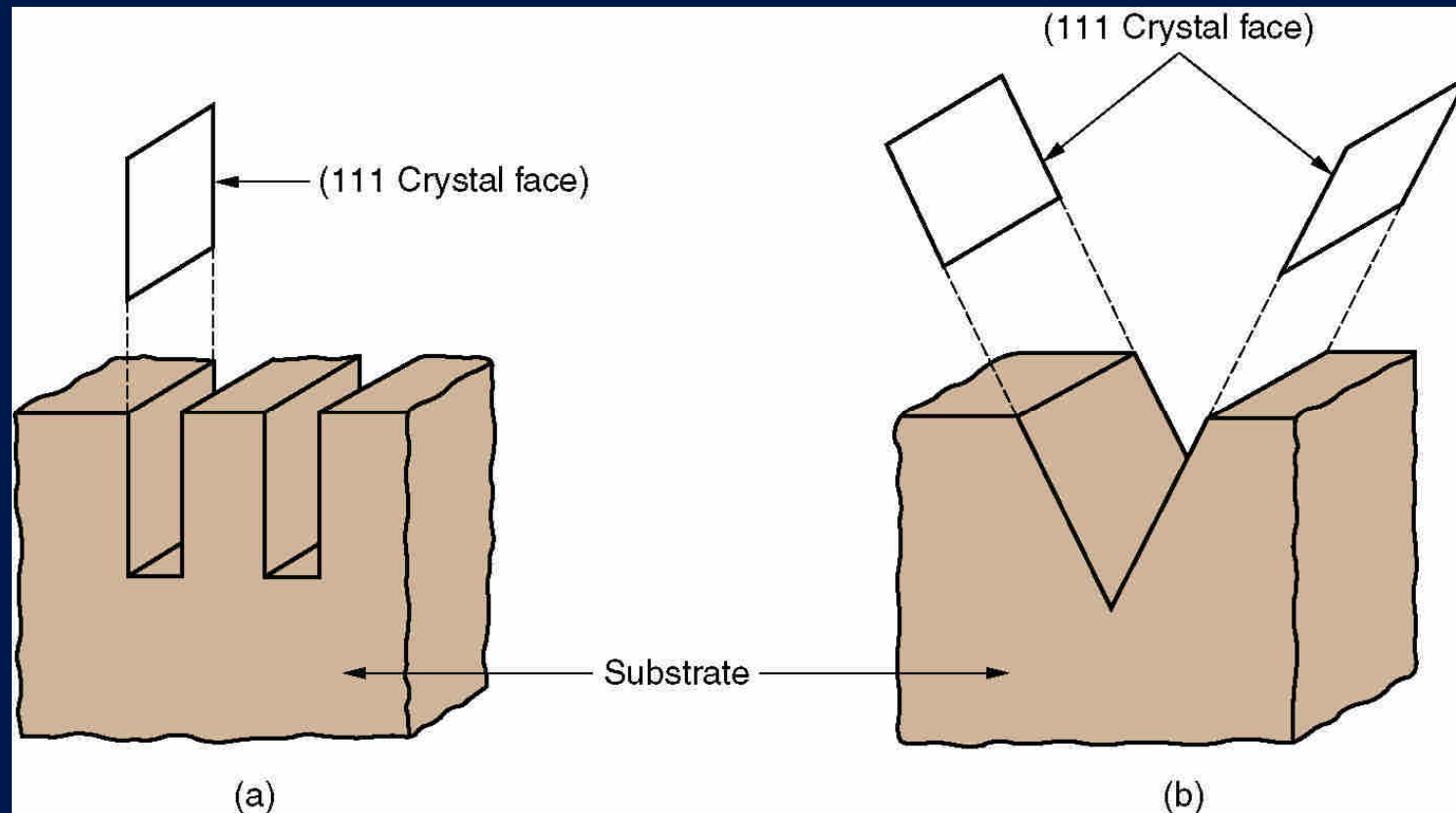


Figure 37.7 - Several structures that can be formed in single-crystal silicon substrate by bulk micromachining:  
(a) (110) silicon and (b) (100) silicon

## Bulk Micromachining to Create Thin Membranes in a Microstructure

- A method is needed to control the etching penetration into the silicon, so as to leave a membrane layer
- A common method is to dope the Si substrate with boron atoms, which reduces the etching rate of Si
- Epitaxial deposition is then used to apply an upper layer of silicon so it will have the same single-crystal structure and lattice orientation as the substrate
- Boron doping to establish the etch resistant layer of silicon is called the “p+ etch-stop technique”

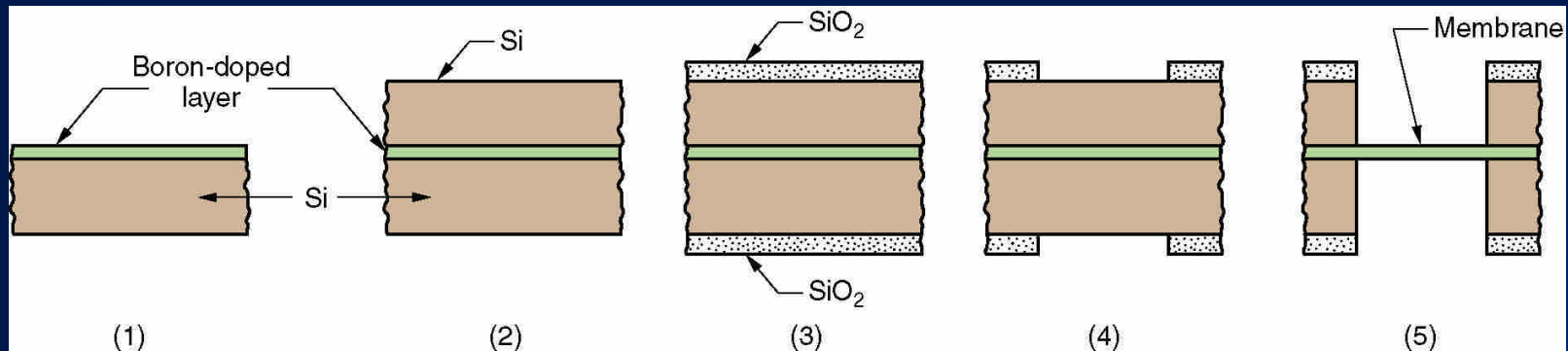


Figure 37.7 - Formation of a thin membrane in a silicon substrate:  
 (1) silicon substrate is doped with boron, (2) a thick layer of silicon is applied on top of the doped layer by epitaxial deposition, (3) both sides are thermally oxidized to form a SiO<sub>2</sub> resist on the surfaces, (4) the resist is patterned by lithography, and (5) anisotropic etching is used to remove the silicon except in the boron doped layer



# Cantilevers, Overhangs, and Similar Structures

- Surface micromachining can be used to construct cantilevers, overhangs, and similar structures on a silicon substrate
  - The cantilevered beams are parallel to but separated by a gap from the silicon surface
  - Gap size and beam thickness are in the micron range

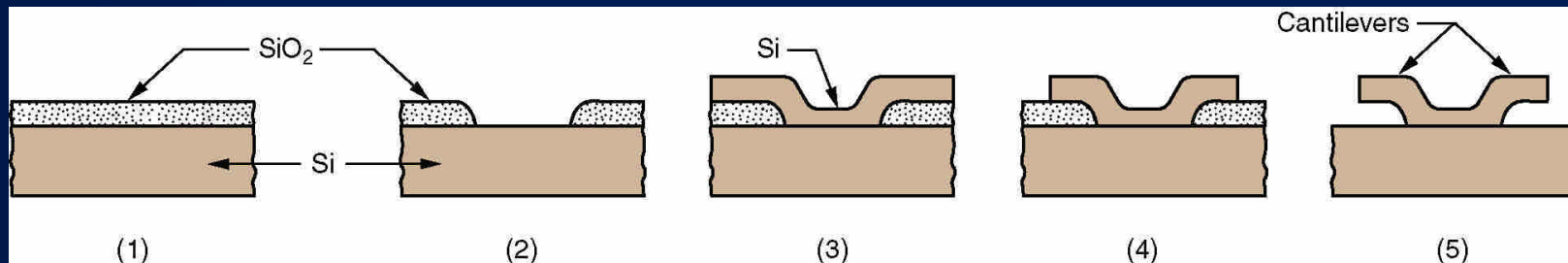


Figure 37.9 - Surface micromachining to form a cantilever: (1) on the silicon substrate is formed a silicon dioxide layer, whose thickness will determine the gap size for the cantilevered member; (2) portions of the  $\text{SiO}_2$  layer are etched using lithography; (3) a polysilicon layer is applied; (4) portions of the polysilicon layer are etched using lithography; and (5) the  $\text{SiO}_2$  layer beneath the cantilevers is selectively etched

# Lift-Off Technique in Microfabrication

A procedure to pattern metals such as platinum on a substrate

- These structures are used in certain chemical sensors, but are difficult to produce by wet etching
- Dry etching provides anisotropic etching in almost any material
- Dry etching - material removal by the physical and/or chemical interaction between an ionized gas and the atoms of a surface exposed to the gas

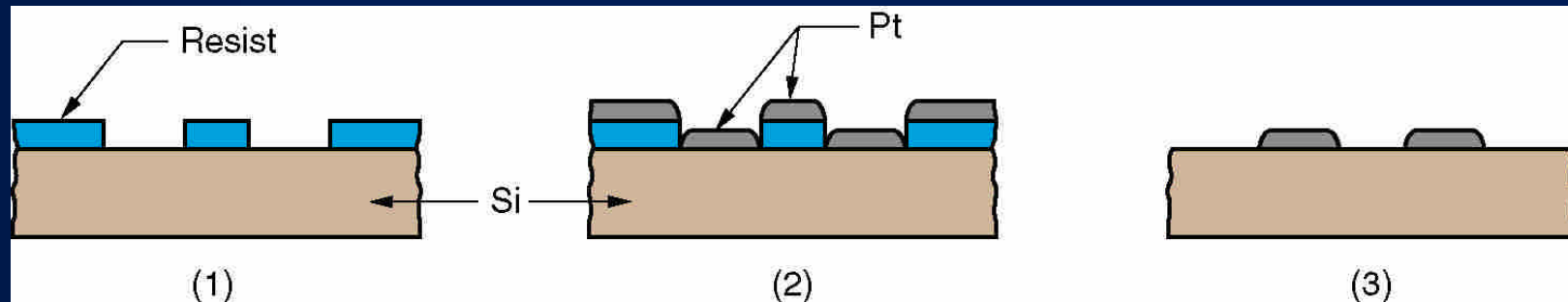


Figure 37.10 - The lift-off technique: (1) resist is applied to substrate and structured by lithography, (2) platinum is deposited onto surfaces, and (3) resist is removed, taking with it the platinum on its surface but leaving the desired platinum microstructure

# LIGA Process

- An important technology of MST
- **Developed in Germany** in the early 1980s
- The letters LIGA stand for the German words
  - Lithographie (in particular X-ray lithography)
  - Galvanoformung (translated electrodeposition or electroforming)
  - Abformtechnik (plastic molding)
- The letters also indicate the LIGA process sequence

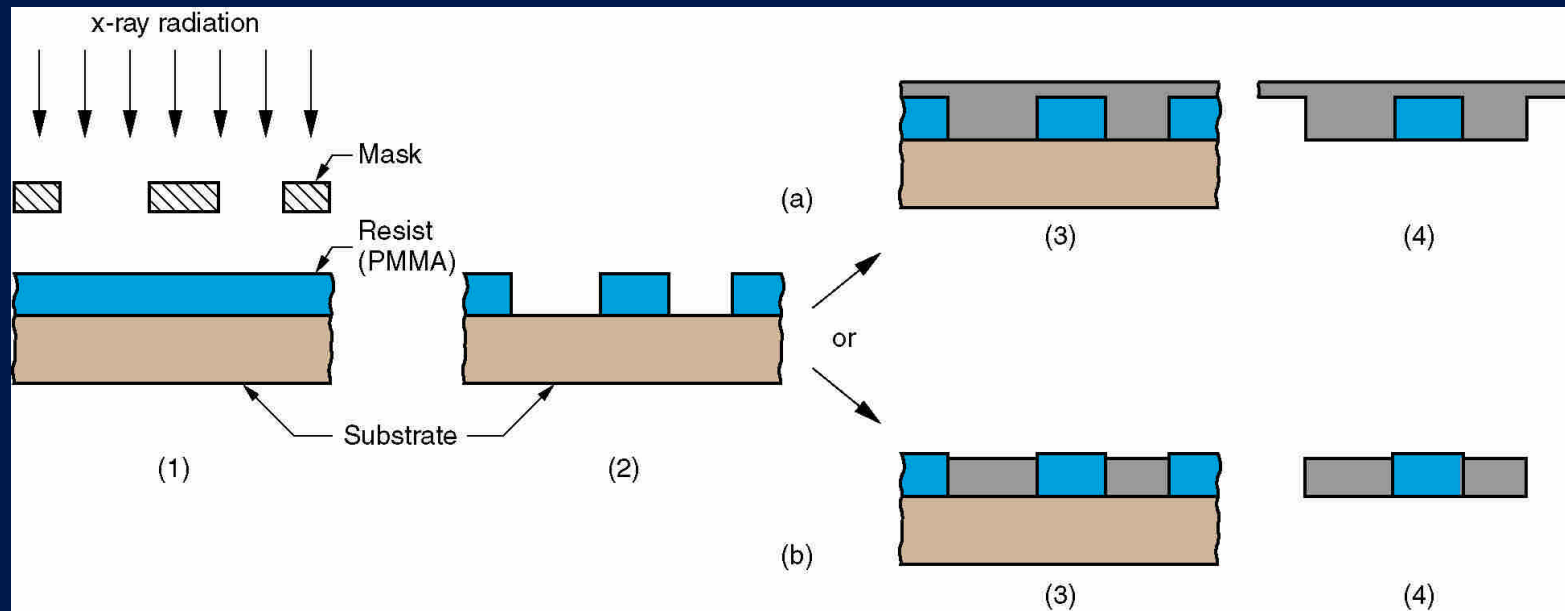


Figure 37.10 - LIGA processing steps: (1) thick layer of resist applied and X-ray exposure through mask, (2) exposed portions of resist removed, (3) electrodeposition to fill openings in resist, (4) resist stripped to provide (a) a mold or (b) a metal part

# Advantages and Disadvantages of LIGA

- LIGA is a versatile process – it can produce parts by several different methods
- **High aspect ratios are possible** (large height-to-width ratios in the fabricated part)
- A wide range of part sizes are feasible, with heights ranging from micrometers to centimeters
- Close tolerances are possible
- Disadvantage: LIGA is a very expensive process, so large quantities of parts are usually required to justify its application

# Ultra-High Precision Machining

- Trends in conventional machining include taking smaller and smaller cut sizes
- Enabling technologies include:
  - Single-crystal diamond cutting tools
  - Position control systems with resolutions as fine as 0.01  $\mu\text{m}$
- Applications: computer hard discs, photocopier drums, mold inserts for compact disk reader heads, high-definition TV projection lenses, and VCR scanning heads



## Ultra-High Precision Machining – An Example

- One reported application: milling of grooves in aluminum foil using a single-point diamond fly-cutter
  - The aluminum foil is 100  $\mu\text{m}$  thick
  - The grooves are 85  $\mu\text{m}$  wide and 70  $\mu\text{m}$  deep

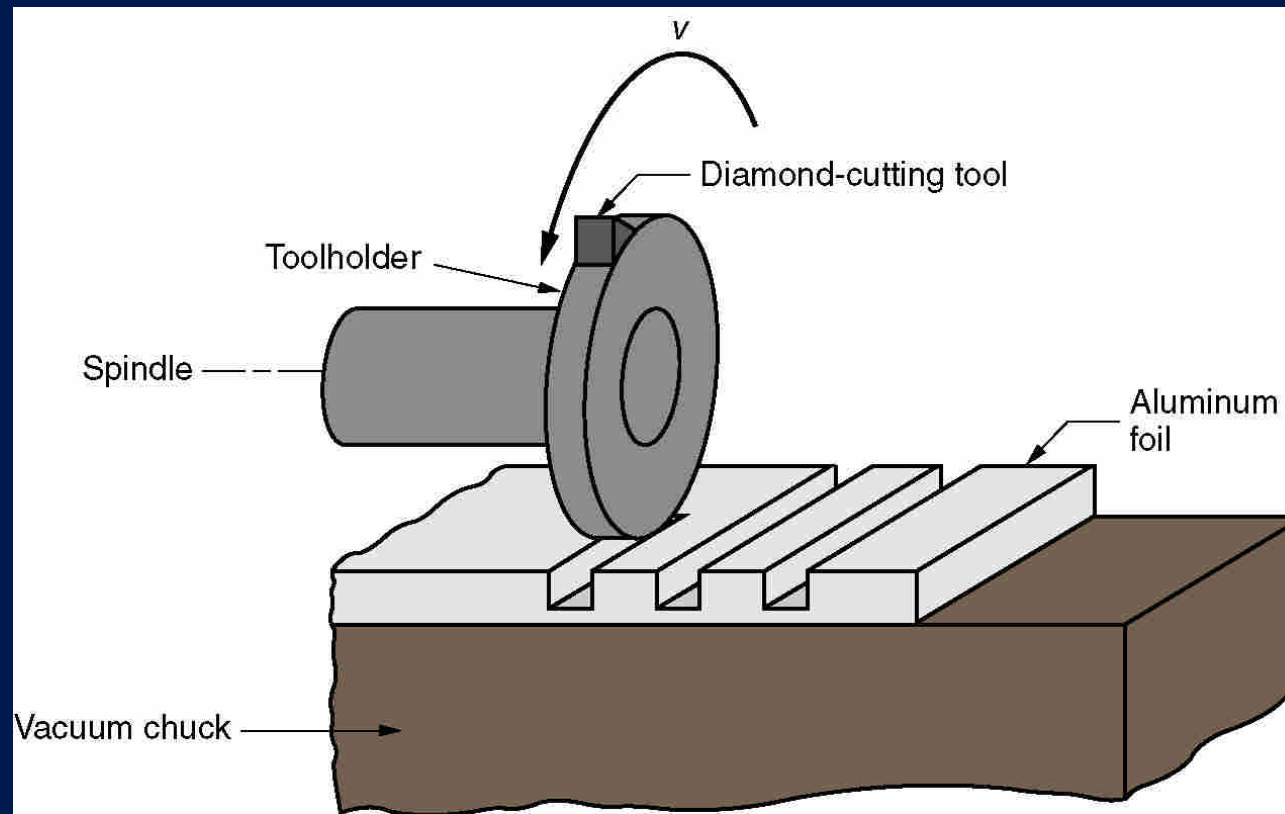


Figure 37.11 - Ultra-high precision milling of grooves in aluminum foil

## Microstereolithography (MSTL)

- Layer thickness in conventional STL = 75  $\mu\text{m}$  to 500  $\mu\text{m}$ , MSTL layer thickness = 10 to 20  $\mu\text{m}$  typically, with even thinner layers possible
- Laser spot size diameter in STL is around 250  $\mu\text{m}$ , MSTL spot size is as small as 1 or 2  $\mu\text{m}$
- Another difference: work material in MSTL is not limited to a photosensitive polymer
- Researchers report success in fabricating 3-D microstructures from ceramic and metallic materials
- The difference is that the starting material is a powder rather than a liquid

# Nanotechnology

Next generation of even smaller devices and their fabrication processes to make structures with feature sizes measured in nanometers ( $1 \text{ nm} = 10^{-9} \text{ m}$ )

- Structures of this size can almost be thought of as purposely arranged collections of individual atoms and molecules
- Two processing technologies expected to be used:
  - Molecular engineering
  - Nanofabrication - similar to microfabrication only performed on a smaller scale

# Molecular Engineering

Additive processes that build the nanostructure from its molecular components

- Nature provides a guide for the kinds of fabrication techniques that might be used
- In molecular engineering and in nature, entities at the atomic and molecular level are combined into larger entities, proceeding in a constructive manner toward the creation of some deliberate thing

# Nanofabrication Technologies

Processes similar to those used in the fabrication of ICs and microsystems, but carried out on a scale several orders of magnitude smaller than in microfabrication

- The processes involve the addition, alteration, and subtraction of thin layers using lithography to determine the shapes in the layers
- Applications: transistors for satellite microwave receivers, lasers used in communications systems, compact disc players