Outline

- RAPID PROTOTYPING:
  - Fundamentals of Rapid Prototyping
  - Rapid Prototyping Technologies
  - Applications and Benefits of Rapid Prototyping
- MICROFABRICATION:
  - Microsystem Products
  - Microfabrication processes
  - Nanotechnology

Rapid Prototyping (RP)

What is RP?

A family of unique fabrication processes developed to make engineering prototypes in minimum lead time based on a CAD model of the item

- The traditional method is machining *(time consuming)*
- RP allows a part to be made in hours or days rather than weeks, given that a computer model of the part has been generated on a CAD system

Why Rapid Prototyping?

- Because product designers would like to have a physical model of a new part or product design rather than just a computer model or line drawing
  - Creating a prototype is an integral step in design
  - A *virtual prototype* may not be sufficient for the designer to visualize the part adequately
  - Using RP to make the prototype, the designer can visually examine and physically feel the part and assess its merits and shortcomings.

RP Technologies

Two Basic Categories:

1. *Material removal RP* - machining, primarily milling and drilling, using a dedicated CNC machine that is available to the design department on short notice
   - Starting material is often wax, which is easy to machine and can be melted and resolidified
   - The CNC machines are often small called *desktop milling* or *desktop machining*
2. *Material addition RP* - adds layers of material one at a time to build the solid part from bottom to top

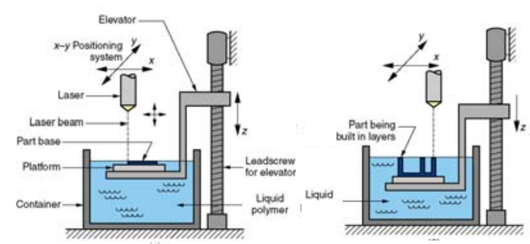
Alternative Names for RP:

- *Layer manufacturing*
- *Direct CAD manufacturing*
- *Solid freeform fabrication*

- RP can be classified according to the starting material:
  1. Liquid-based
  2. Solid-based
  3. Powder-based

Liquid-Based RP Systems

- Starting material is a liquid monomor. Examples of liquid based RP:
  - Stereolithography – Solid ground curing - Droplet deposition mfg



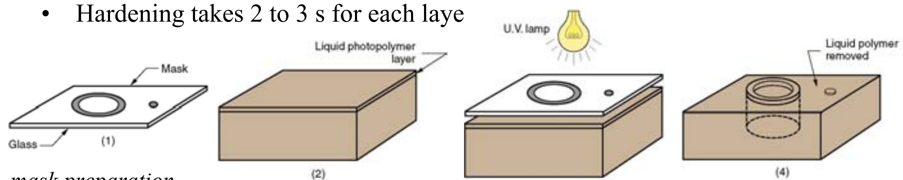
Due to polymerization several layers are added so that the 3-D part geometry gradually takes form

- Stereolithography: RP process for fabricating a solid plastic part out of a photosensitive liquid polymer using a directed laser beam to solidify the polymer *(more popular than other RP methods)*
- The first addition RP technology - introduced 1988 by 3D Systems Inc.

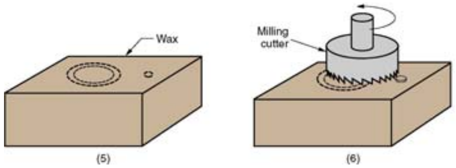
photo courtesy of 3D Systems, Inc

Solid Ground Curing (SGC)

- Like stereolithography, SGC works by curing a photosensitive polymer layer by layer to create a solid model based on CAD geometric data
- Instead of using a scanning laser beam to cure a given layer, the entire layer is exposed to a UV source through a mask above the liquid polymer
- Hardening takes 2 to 3 s for each laye



mask preparation — *applying liquid photopolymer layer* — *mask positioning and exposure of layer* — *uncured polymer removed from surface*

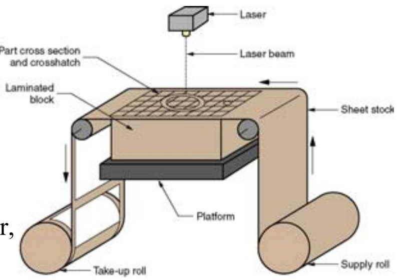


wax filling — *milling for flatness and thickness*

- Time to produce a part by SGC is claimed to be about eight times faster than other RP systems
- The wax provides support for fragile and overhanging features of the part during fabrication

Solid-Based RP Systems

- Starting material is a solid
- Two solid-based RP systems are presented here:
  - Laminated object manufacturing (**LOM**)
  - Fused deposition modeling



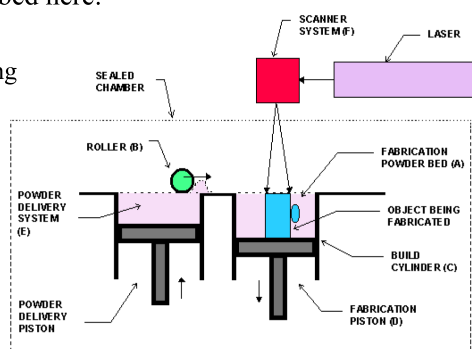
LOM: A solid physical model is made by stacking layers of sheet stock, each an outline of the cross-sectional shape of a CAD model that is sliced into layers

- Starting material = sheet stock, such as paper, plastic, cellulose, metals, or fiber-reinforced materials
- The sheet material is usually supplied with adhesive backing as rolls that are spooled between two reels
- After cutting, excess material in the layer remains in place to support the part during building

Powder-Based RP Systems

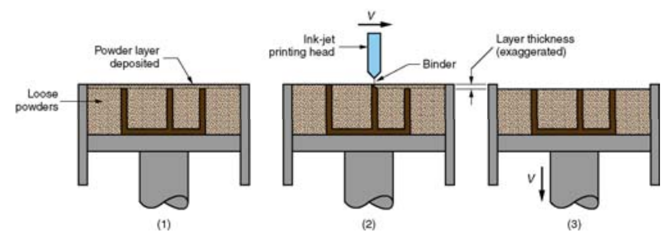
- Starting material is a powder
- Two RP systems are described here:
  - Selective laser sintering
  - Three dimensional printing

In selective laser sintering:



- A moving laser beam sinters heat-fusible powders in areas corresponding to the CAD geometry model one layer at a time to build the solid part
- After each layer is completed, a new layer of loose powders is spread across the surface
- Layer by layer, the powders are gradually bonded into a solid mass that forms the 3-D part geometry
- In areas not sintered by the laser beam, the powders are loose and can be poured out of completed part

Three Dimensional Printing (3DP)



- In 3DP, the part is built in layer-by-layer fashion using an ink-jet printer to eject adhesive bonding material onto successive layers of powders
- The binder is deposited in areas corresponding to the cross-sections of the solid part, as determined by slicing the CAD geometric model into layers
- The binder holds the powders together to form the solid part, while the unbonded powders remain loose to be removed later
- To further strengthen the part, a sintering step can be applied to bond the individual powders

RP Applications

1. Design

Designers are able to confirm their design by building a real physical model in minimum time using RP

- Design benefits :
  - *– Reduced lead times to produce prototype components*
  - *– Improved ability to visualize part geometry*
  - *– Early detection and reduction of design errors*
  - *– Increased capability to compute mass properties*

2. Engineering analysis and planning

Existence of part allows certain engineering analysis and planning activities to be accomplished that would be more difficult without the physical entity

– Comparison of different shapes and styles to determine aesthetic appeal

– Wind tunnel testing of different streamline shapes

– Stress analysis of a physical model

– Fabrication of pre-production parts for process planning and tool design

3. Tooling: Called *rapid tool making* (RTM) when RP is used to fabricate production tooling

RP Applications: Manufacturing

- Small batches of plastic parts that could not be economically injection molded because of the high mold cost
- Parts with intricate internal geometries that could not be made using conventional technologies without assembly
- One-of-a-kind parts such as bone replacements that must be made to correct size for each user

Problems with Rapid Prototyping

- Part accuracy:
  - Staircase appearance for a sloping part surface due to layering
  - Shrinkage and distortion of RP parts
- Limited variety of materials in RP
  - Mechanical performance of the fabricated parts is limited by the materials that must be used in the RP process

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:

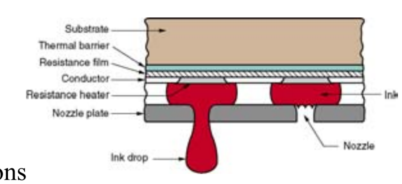
- Less material usage
- Lower power requirements
- Greater functionality per unit space
- Accessibility to regions that are forbidden to larger products
- In most cases, smaller products should mean lower prices because less material is used

Types of Microsystem Devices

- Microsensors *(for measuring force, pressure, position, speed, acceleration, temp., flow, and a variety of optical, chemical, environmental, and biological variables)*
- 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)*
- Microsystems and micro-instruments *(They tend to be very application specific. Examples: microlasers, optical chemical analyzers, and microspectrometers)*

Industrial Applications of Microsystems:

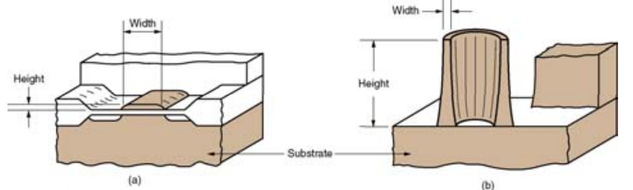
- Ink-jet printing heads
- Thin-film magnetic heads
- Compact disks
- Automotive components
- Medical applications
- Chemical and environmental applications
- Other applications



ink-jet printing head

Silicon Layer Processes

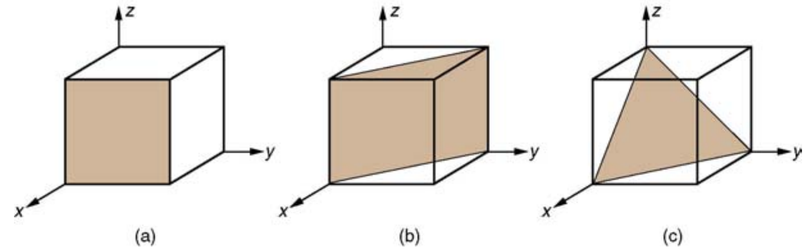
- First application of silicon in MST was in the fabrication of piezoresistive sensors to measure stress, strain, and pressure in the early 1960s.
- Silicon is now widely used in MST to produce sensors, actuators, and other microdevices.
- The basic processing technologies are those used to produce integrated circuits. However, there are certain differences between the processing of ICs and the fabrication of microdevices:
  - *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*



fabrication of integrated circuits　　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

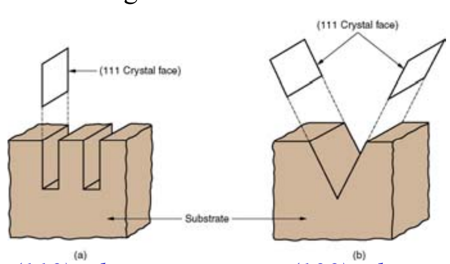


(100)　(110)　(111)

Bulk Micromachining

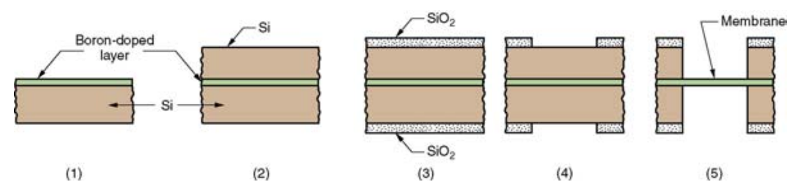
- Certain etching solutions, such as potassium hydroxide (KOH), have a very low etching rate in the direction of the (111) crystal face
- This permits formation of distinct geometric structures with sharp edges in single-crystal Si if the lattice is oriented favorably
- *Bulk micromachining* - relatively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

Several structures that can be formed in single-crystal silicon substrate by bulk micromachining



(110) silicon　*(100) silicon*

Examples: Bulk Micromachining of Thin Membranes



Formation of a thin membrane in a silicon substrate:

(1) silicon substrate is doped with boron,

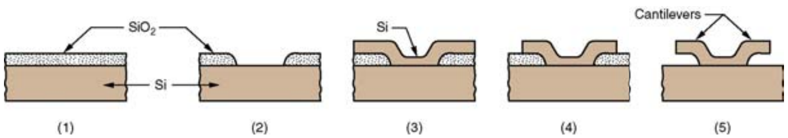
(2) a thick layer of silicon is applied on top of the doped layer by deposition,

(3) both sides are thermally oxidized to form a SiO_2 resist on the surfaces,

(4) the resist is patterned by lithography

(5) anisotropic etching is used to remove the silicon except in the boron doped layer

Examples: Cantilevers, Overhangs, and Similar Structures



Surface micromachining to form a cantilever:

(1) on the silicon substrate a silicon dioxide layer is formed, whose thickness will determine the gap size for the cantilevered member;

(2) portions of the SiO_2 layer are etched using lithography;

(3) a polysilicon layer is applied;

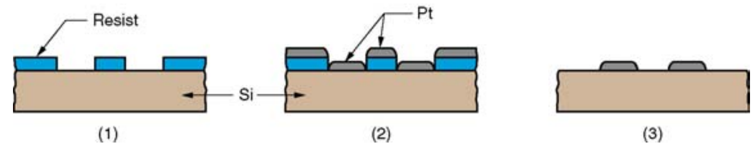
(4) portions of the polysilicon layer are etched using lithography; and

(5) the 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



The lift-off technique:

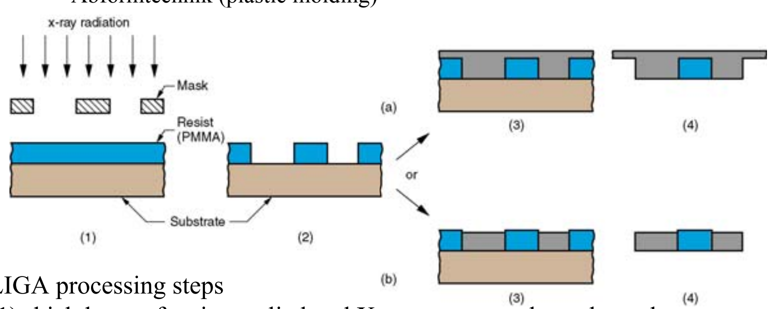
(1) resist is applied to substrate and structured by lithography,

(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)



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
- 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

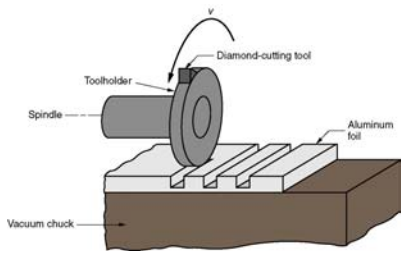
Ultra-High Precision Machining

- 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 µm
- Applications: computer hard discs, photocopier drums, mold inserts for compact disk reader heads, high-definition TV projection lenses, and VCR scanning heads

• Example: milling of grooves in aluminum foil using a single-point diamond fly-cutter

–The aluminum foil is 100 µm thick

–The grooves are 85 µm wide and 70 µm deep



Microstereolithography (MSTL)

- Layer thickness in conventional STL = 75 µm to 500 µm, MSTL layer thickness = 10 to 20 µm typically, with even thinner layers possible
- Laser spot size diameter in STL is around 250 µm, MSTL spot size is as small as 1 or 2 µm
- 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 nm = 10^{-9} 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

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
- A significant difference is the lithography technologies that must be used at the smaller scales in nanofabrication
  - Ultraviolet photolithography **cannot** be used effectively, owing to the relatively long wavelengths of UV radiation
  - Instead, the preferred technique is high-resolution electron beam lithography, whose shorter wavelength virtually eliminates diffraction during exposure

Next Topic:

Friction in Manufacturing