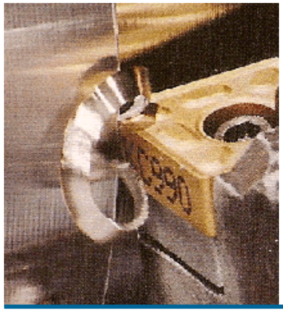
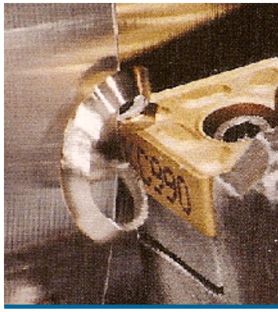
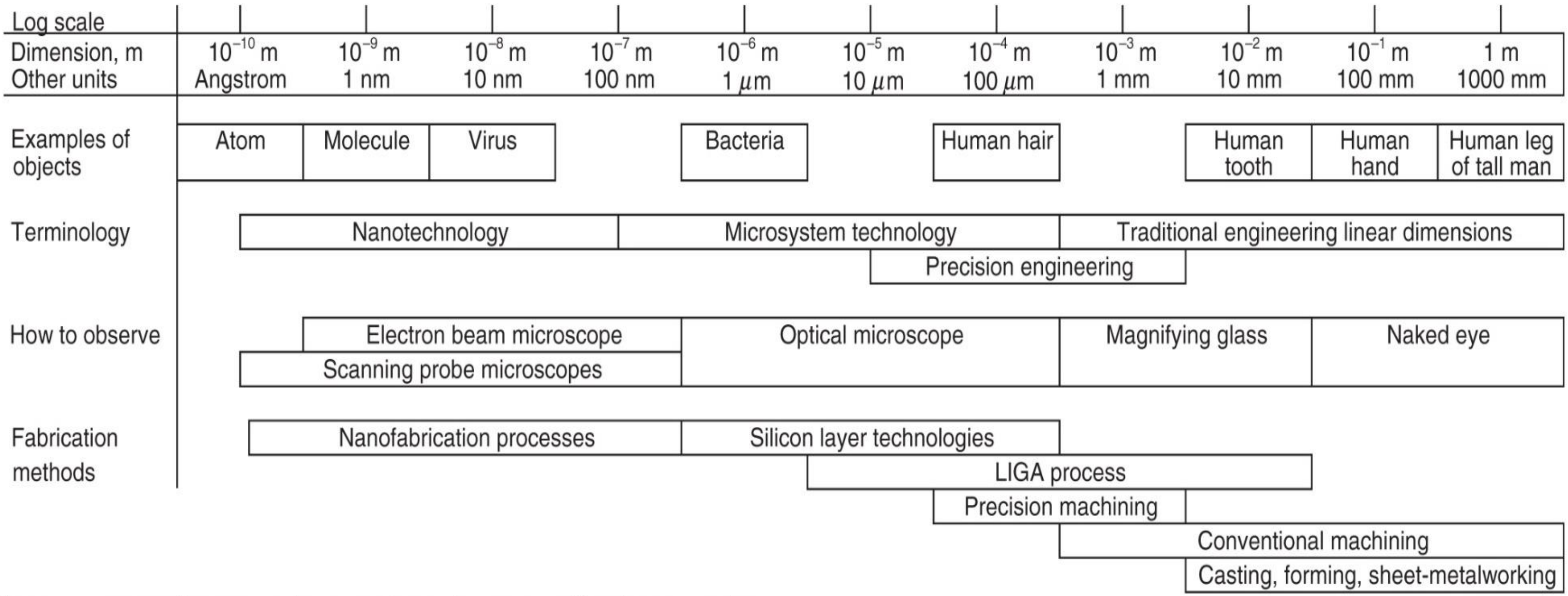


MICROFABRICATION TECHNOLOGIES

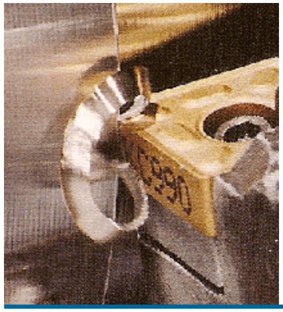
1. Microsystem Products
2. Microfabrication Processes



Relative Sizes in Microtechnology and Nanotechnology

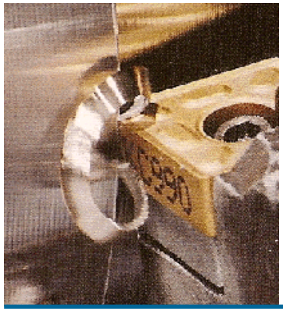


Key: nm = nanometer, μm = micron or micrometer, mm = millimeter, m = meter



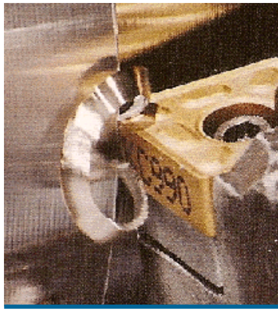
Design Trend and Terminology

- Miniaturization of products and parts, with features sizes measured in microns (10^{-6} m) or smaller
  - *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 entities whose dimensions are measured in nanometers (10^{-9} m)



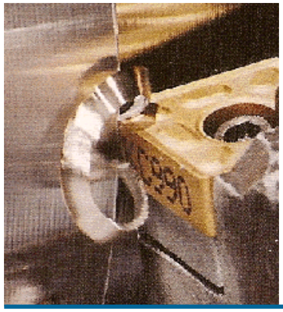
Advantages of Microsystem Products

- 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

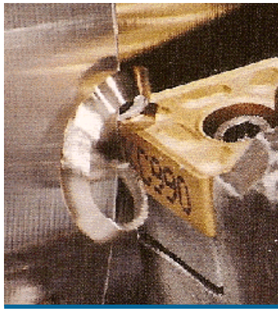
- Microsensors
- Microactuators
- Microstructures and microcomponents
- Microsystems and micro-instruments



Microsensors

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

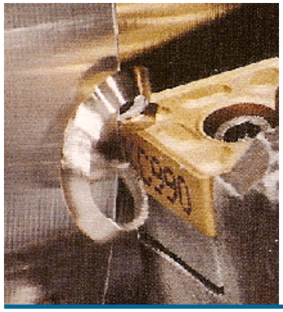
- Most microsensors are fabricated on a silicon substrate using the same processing technologies as those used for integrated circuits
- Microsensors have been developed to measure force, pressure, position, speed, acceleration, temperature, flow, and various optical, chemical, environmental, and biological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



Microactuators

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

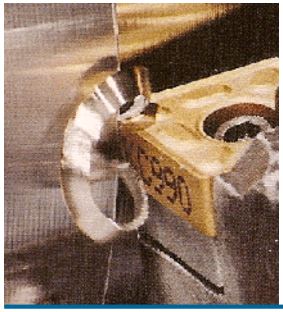
- An actuator causes a change in position or the application of force
- Examples of microactuators: valves, positioners, switches, pumps, and rotational and linear motors



Microstructures and Microcomponents

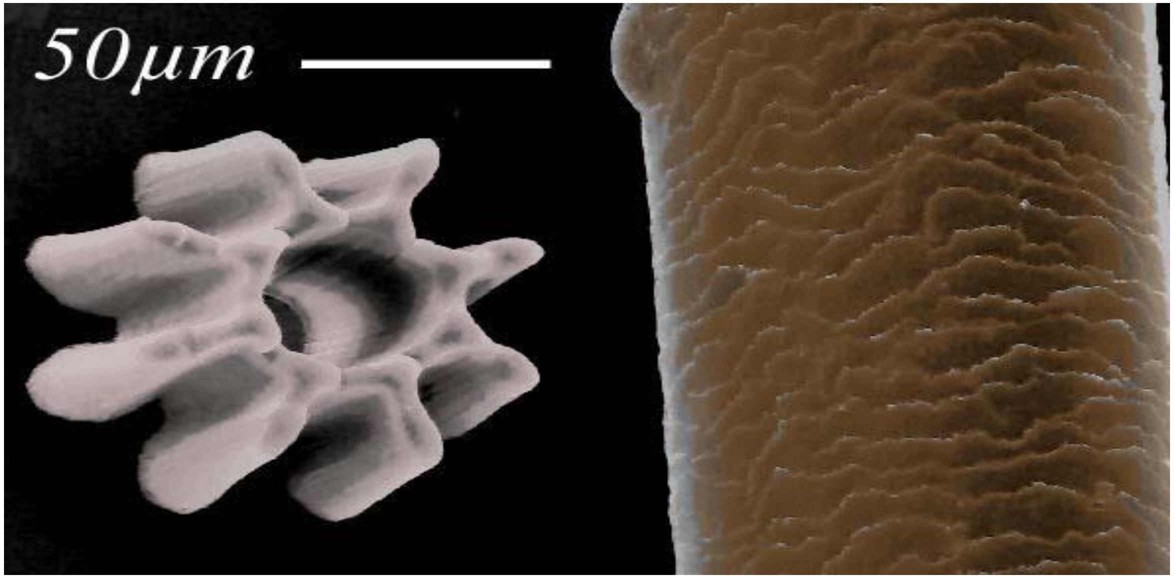
Micro-sized parts that are not sensors or actuators

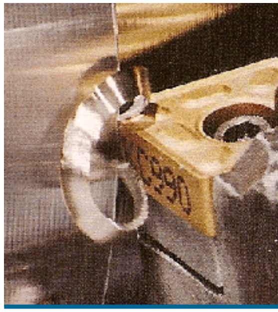
- Examples: microscopic lenses, mirrors, nozzles, gears, and beams
- These items must be combined with other components in order to provide a useful function



Microscopic Gear and Human Hair

Image by scanning electron microscope - gear is high-density polyethylene molded by a process similar to LIGA (photo courtesy of W. Hung, Texas A&M U., and M. Ali, Nanyang Tech. U).

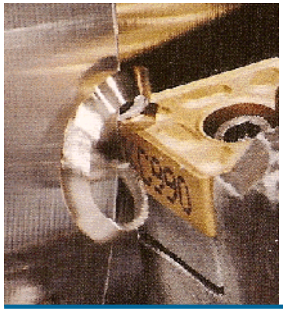




Microsystems and micro-instruments

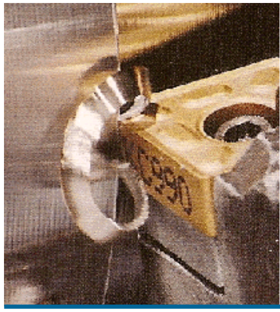
Integration of several of the preceding components with the appropriate electronics package into a miniature system or instrument

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



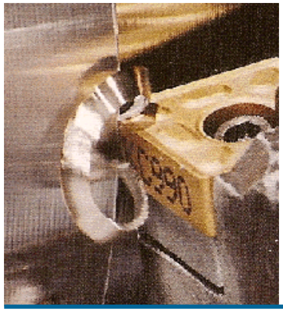
Industrial Applications of Microsystems

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



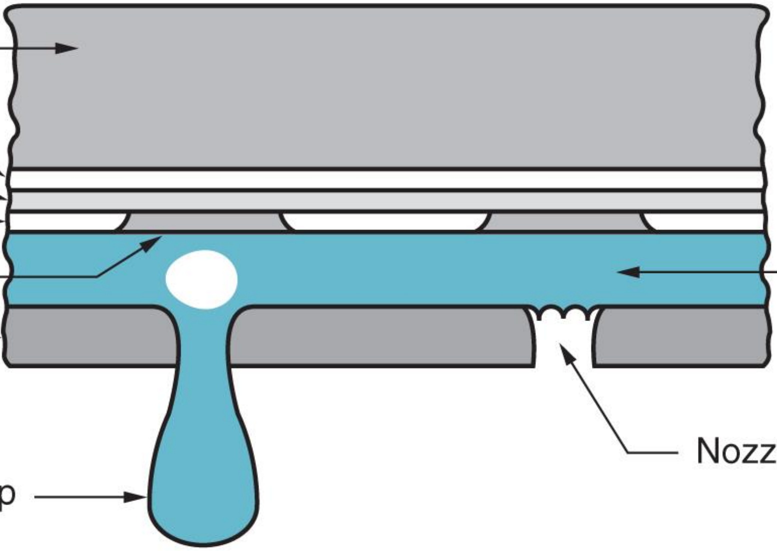
Ink-Jet Printing Heads

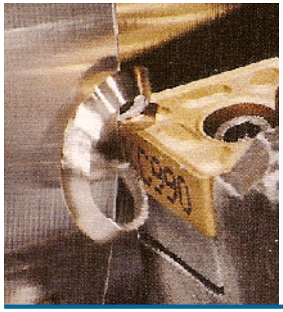
- Currently one of the largest applications of microsystems
- A typical ink-jet printer uses up several cartridges each year
- Today's ink-jet printers have resolutions of 1200 dots per inch (dpi)
  - This resolution converts to a nozzle separation of only about 21 μm
    - Certainly in the microsystem range



Ink-Jet Printer Head

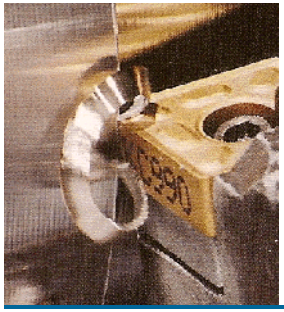
- Resistance heater boils ink to create plume that forces drop to be expelled onto paper



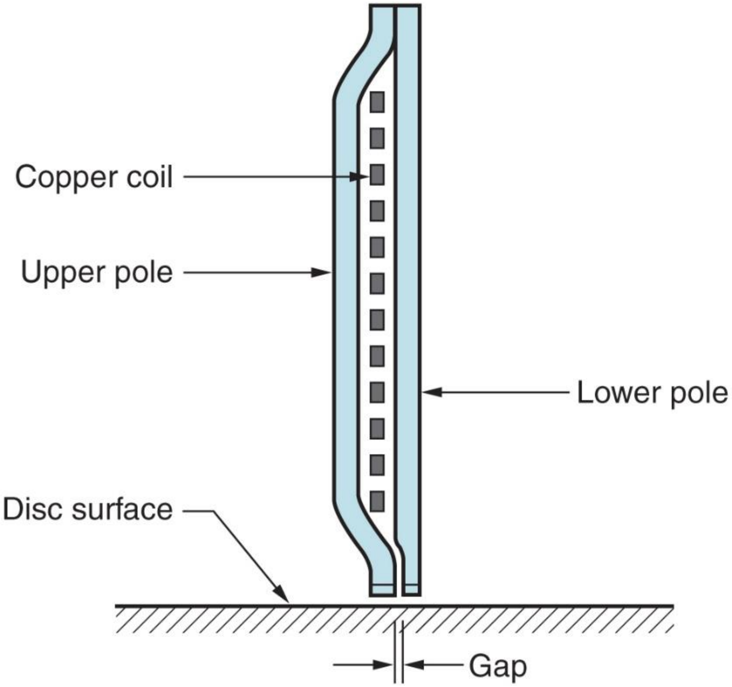


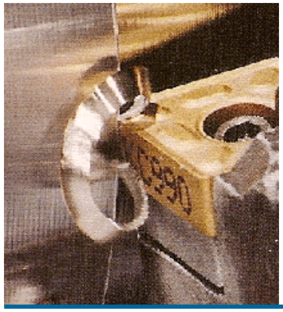
Thin-Film Magnetic Heads

- Read-write heads are key components in magnetic storage devices
- Reading and writing of magnetic media with higher bit densities limited by the size of the read-write head
- Development of thin-film magnetic heads was an important breakthrough not only in digital storage technology but microfabrication technologies as well
- Thin-film read-write heads are produced annually in hundreds of millions of units.



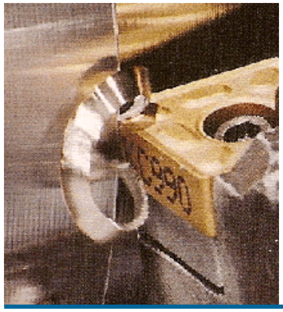
Thin-Film Magnetic Read-Write Head





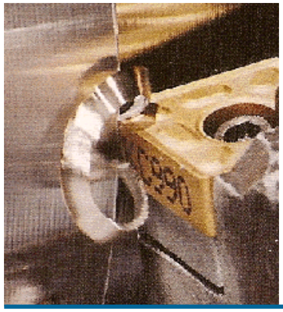
Automotive Components

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



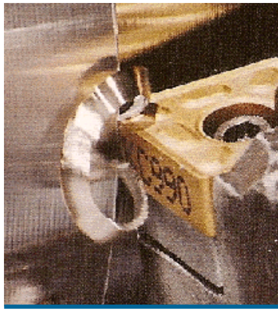
Medical Applications

- A driving force for microscopic devices is the principle of minimal-invasive therapy
  - Small incisions or even available body orifices to access the medical problem
- Standard medical practice today is to use endoscopic examination accompanied by laparoscopic surgery for hernia repair and removal of gall bladder and appendix
- Similar procedures are used in brain surgery, operating through small holes drilled in skull



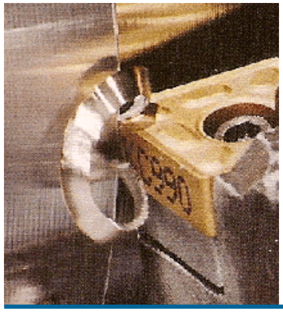
Microfabrication Processes

- Many MST products are based on silicon - Why?
  - 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 and elasticity, good hardness, and relatively low density
    - Techniques to process silicon are well established from processing of ICs



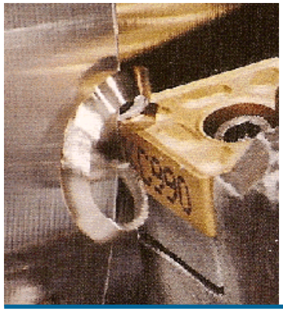
Other Materials and MST Processing

- 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
  - Other conventional and nontraditional processes performed on microscopic scale



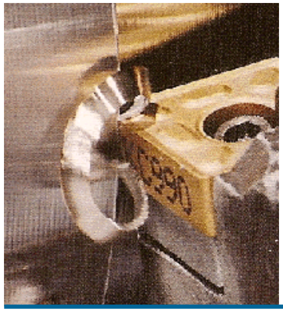
Silicon Layer Processes

- 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 processing of ICs and fabrication of microdevices



Microfabrication vs. 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
  - These features are not found in integrated circuits

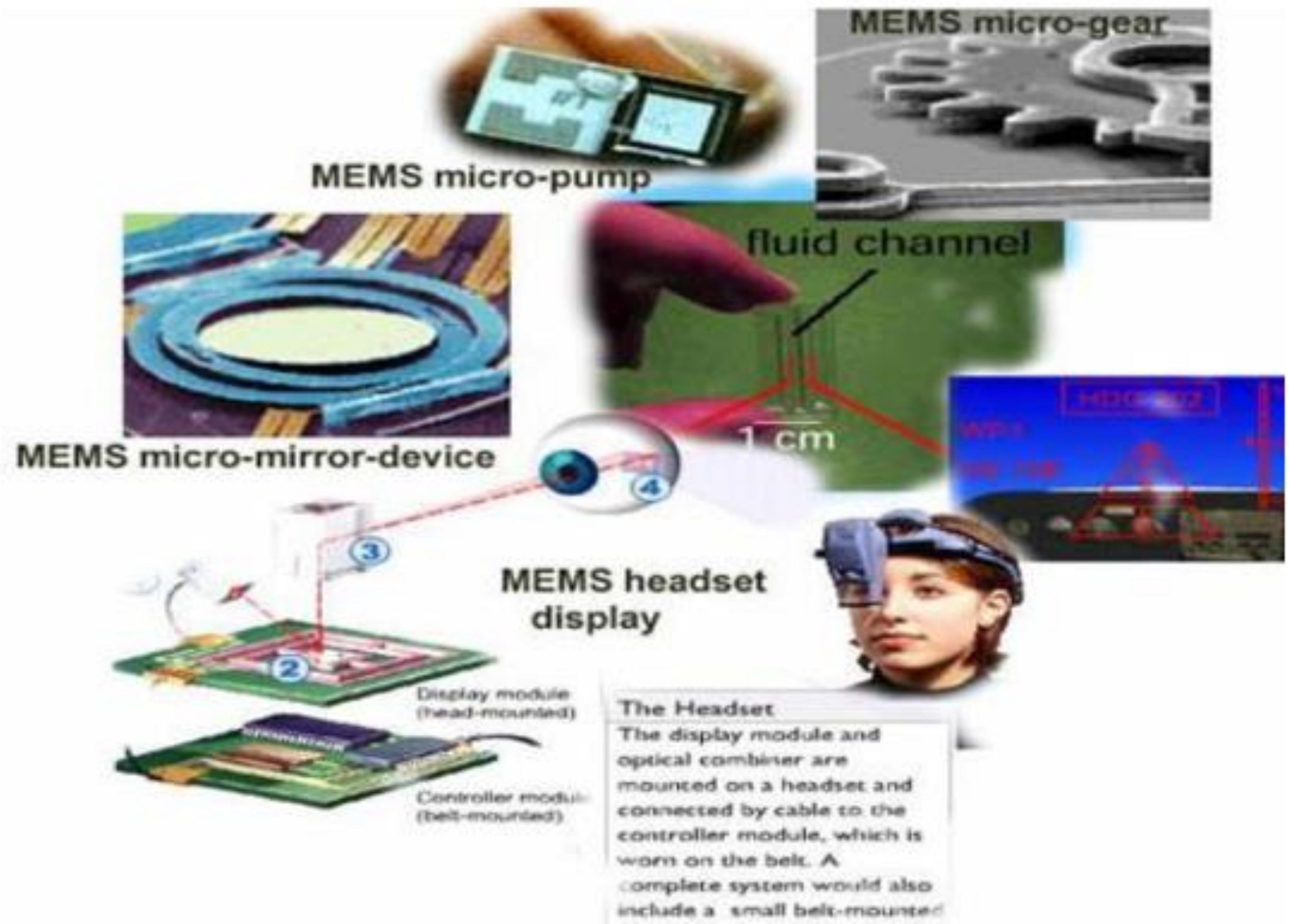


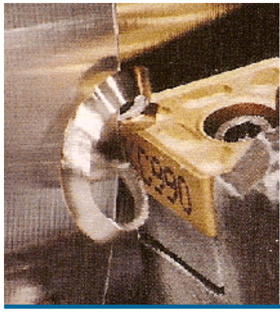
Introduction/Outline

- What Are MEMS?
- Components of MEMS
- Applications
- Summary

What are MEMS?

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.

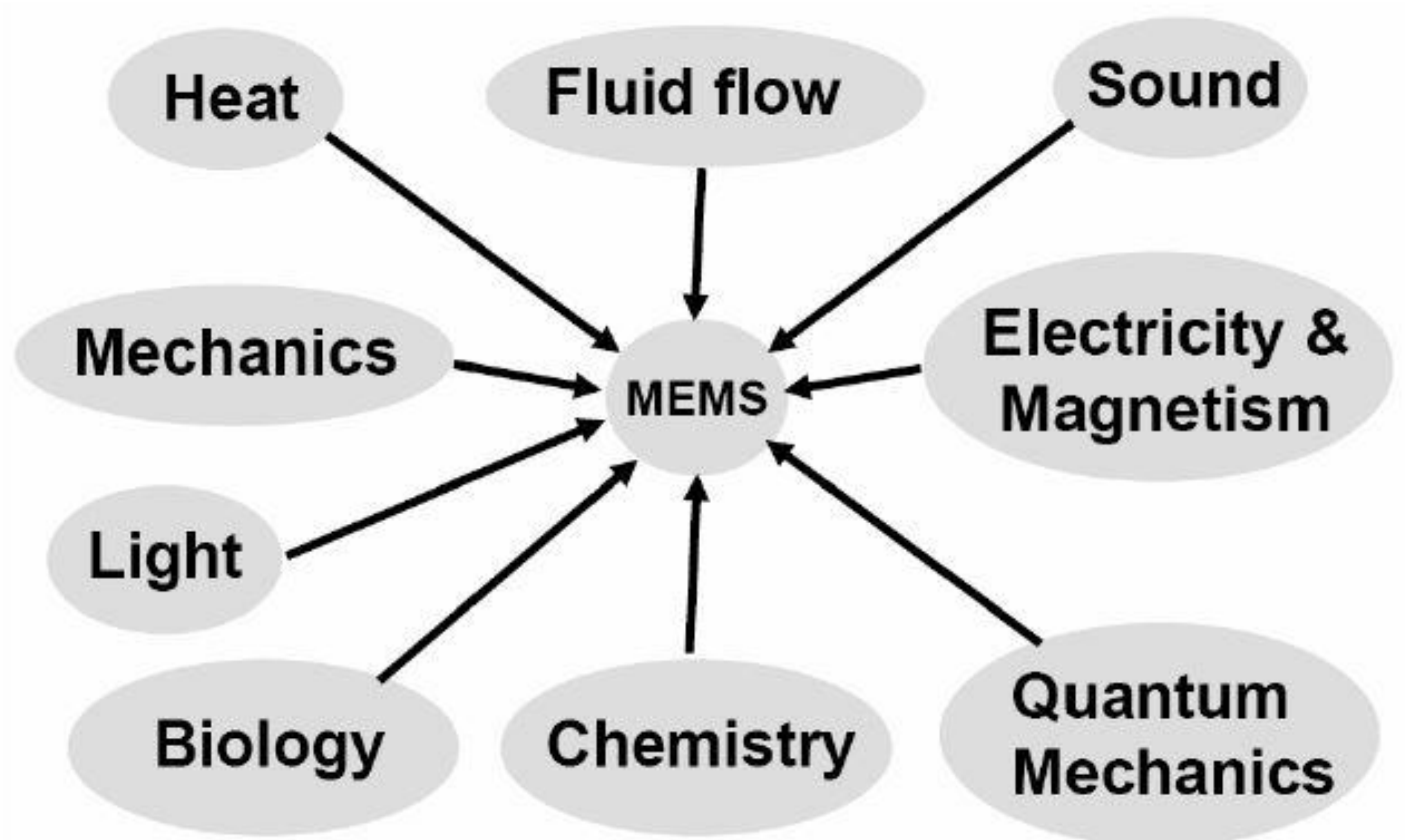


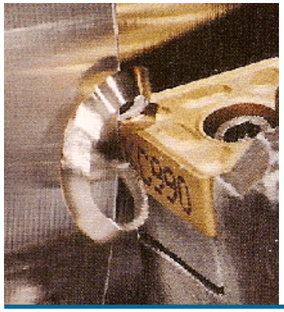


What are MEMS?

- **Micro** - Small size, microfabricated structures
- **Electro** - Electrical signal /control (In / Out)
- **Mechanical** - Mechanical functionality (In / Out)
- **Systems** - Structures, Devices, Systems

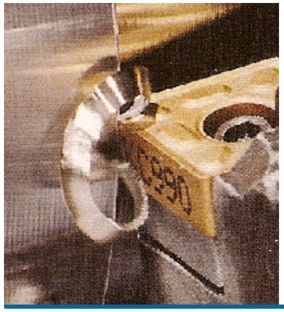
Multidisciplinary



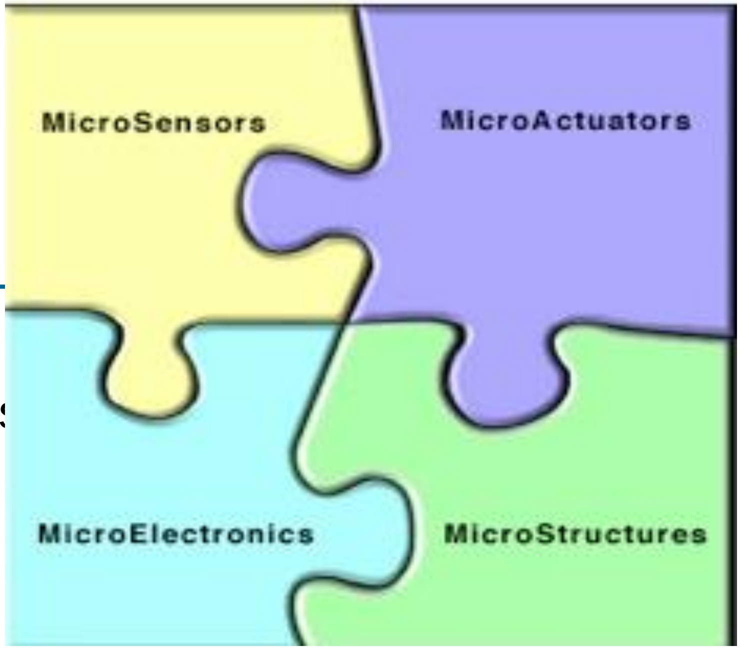


What are MEMS?

- **Made up of components between 1-100 micrometers in size**
- **Devices vary from below one micron up to several mm**
- **Functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics**
- **One main criterion of MEMS is that there are at least some elements that have mechanical functionality, whether or not they can move**



Components



Microelectronics:

- “brain” that receives, processes, and makes deci
- data comes from microsensors

Microsensors:

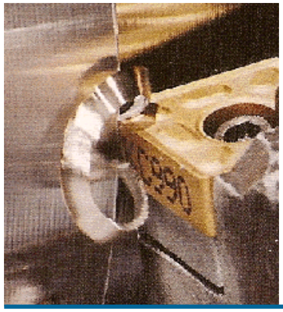
- constantly gather data from environment
- pass data to microelectronics for processing
- can monitor mechanical, thermal, biological, chemical optical, and magnetic readings

Microactuator:

- acts as trigger to activate external device
- microelectronics will tell microactuator to activate device

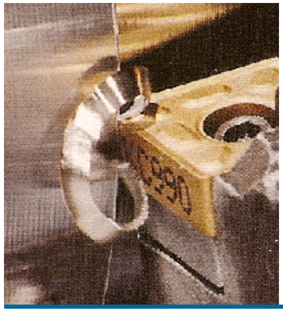
Microstructures:

- extremely small structures built onto surface of chip
- built right into silicon of MEMS



Why Micro machine?

- Minimize energy and materials use in manufacturing
- • Redundancy and arrays
- • Integration with electronics
- • Reduction of power budget
- • Faster devices
- • Increased selectivity and sensitivity
- • Cost/performance advantages
- • Improved reproducibility (batch fabrication)
- • Improved accuracy and reliability
- • Minimally invasive (e.g. pill camera)



Factors to Consider

Establish need in light of conventional approaches (faster, smaller, cheaper)

– Does the MEMS solution provide a significant cost reduction?

– Does it enable a new function or level of performance that cannot be achieved otherwise?

– Does the market justify the development of a MEMS approach? Can conventional machining or plastic molding techniques be used?

– Does the cost analysis include package & test?

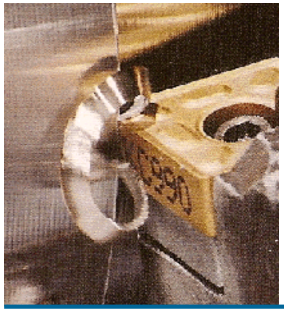
Understand the basic physics and operating principles, including scaling laws

– Increased surface-to-volume ratio

– Actuation forces

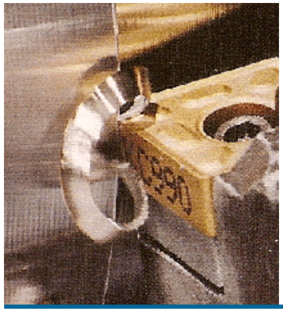
– Thermal transport

• Understand the important issues in designing



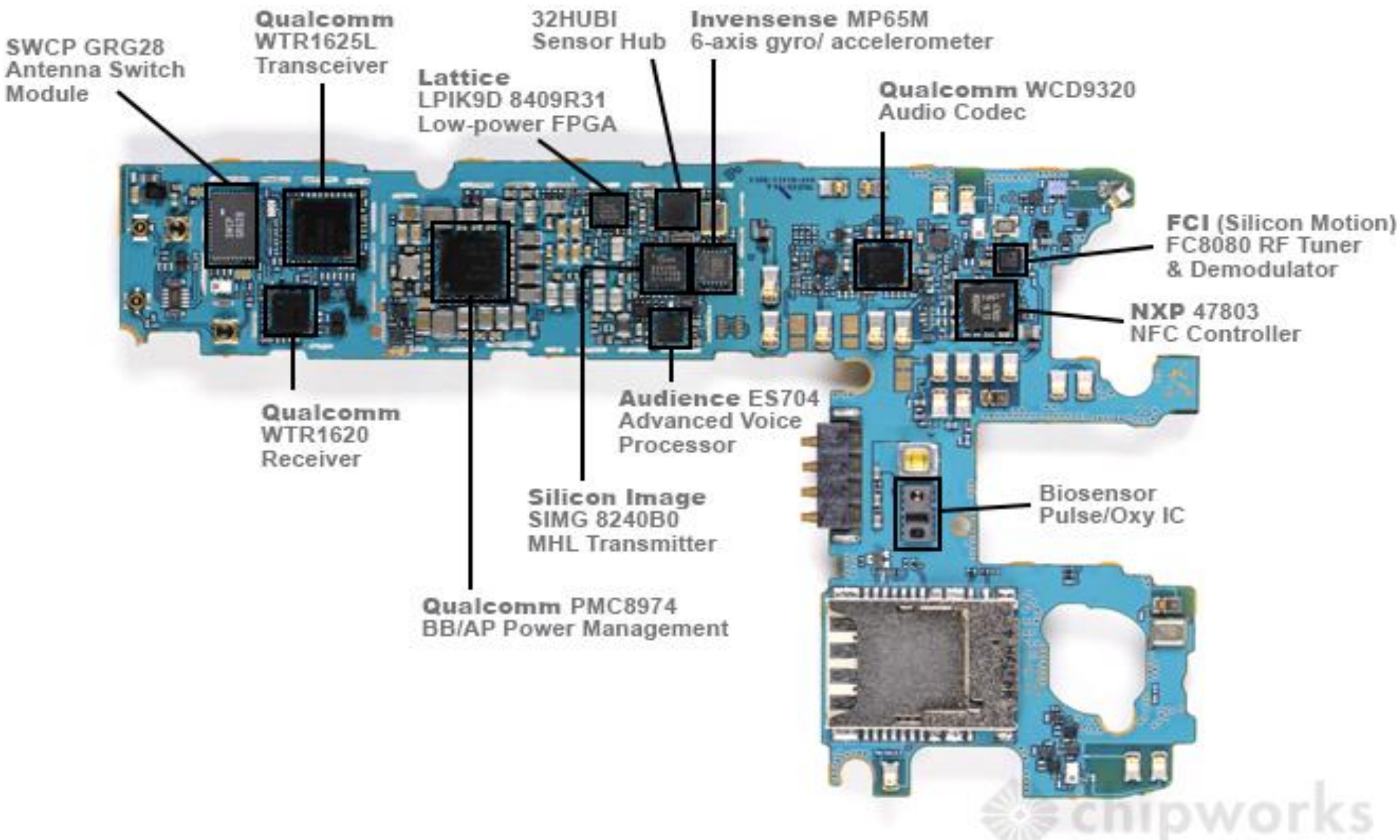
Factors to Consider

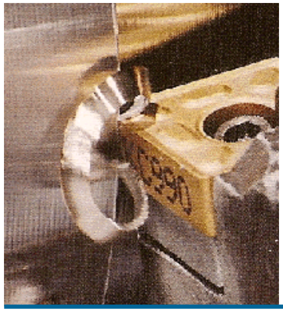
Can you use an existing “standard” process?
– If not, can you design a simple and reasonably priced fabrication process?
Consider the issues of packaging at the outset:
– Can existing packages be used or adapted?
– Reliability issues (e.g. hermetically sealed)?
Estimate the final cost of the ready-to-use device
– Difficult to get cost data out of foundry for custom process. Will depend sensitively on volume and yield. This is really difficult to access!
– Include the cost of packaging
– Include the cost of testing



Where Are MEMS?

Smartphones, tablets, cameras, gaming devices, and many other electronics have MEMS technology inside of them

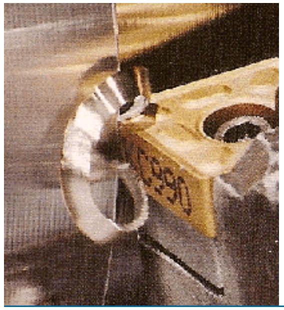




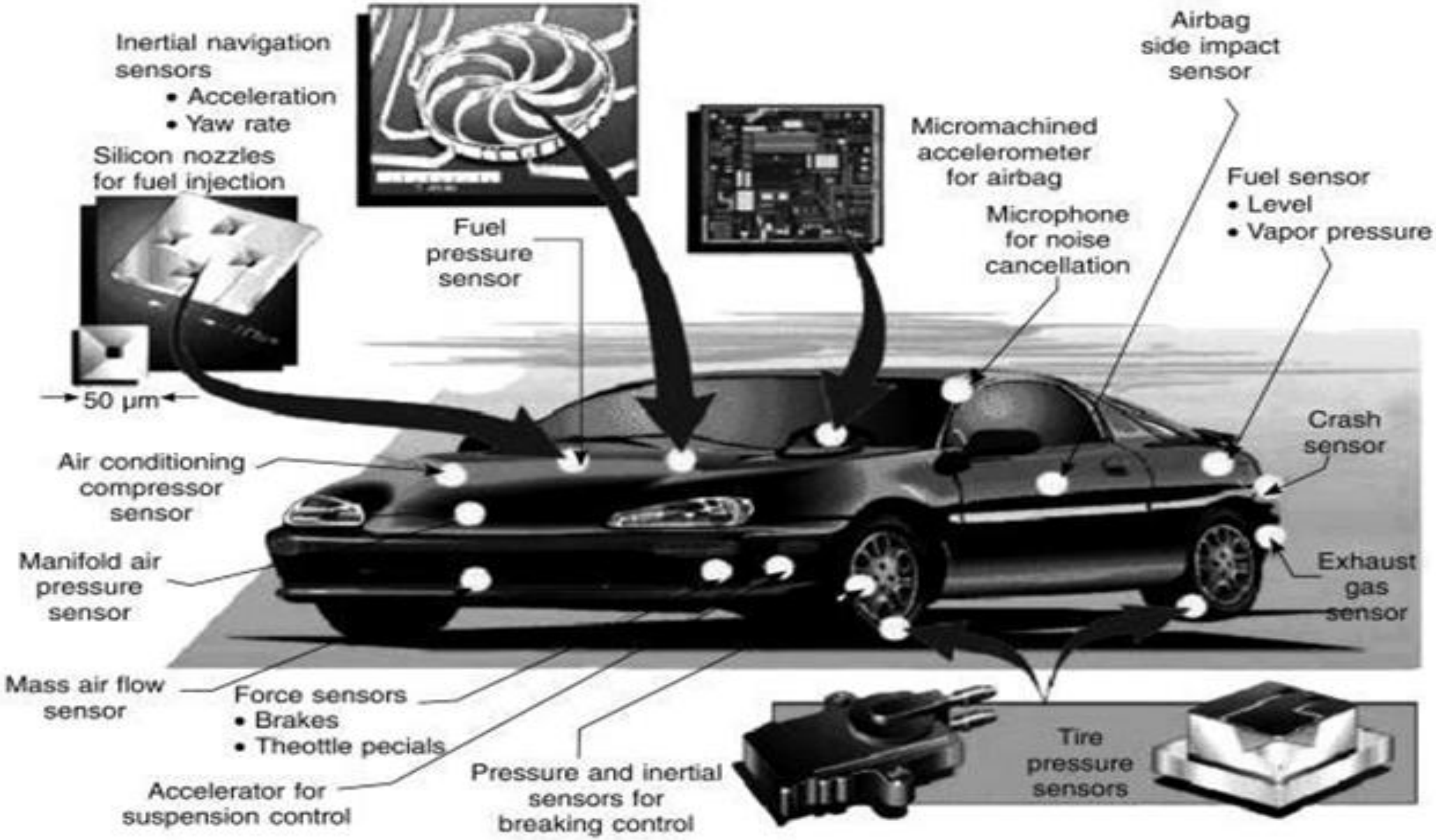
Biomedical Applications

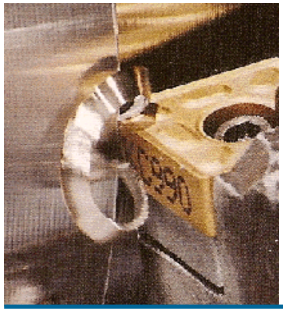
- Usually in the form of pressure sensors
  - Intracranial pressure sensors
  - Pacemaker applications
  - Implanted coronary pressure measurements
  - Intraocular pressure monitors
  - Cerebrospinal fluid pressure sensors
  - Endoscope pressure sensors
  - Infusion pump sensors
- Retinal prosthesis
- Glucose monitoring & insulin delivery
- MEMS acts as surgical tools
- Cell, antibody, DNA, RNA enzyme measurement devices

Blood Pressure sensor on the head of a pin



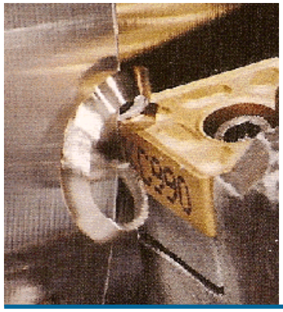
In the Car


Inertial navigation sensors
• Acceleration
• Yaw rate
Silicon nozzles for fuel injection
50 µm
Fuel pressure sensor
Micromachined accelerometer for airbag
Airbag side impact sensor
Microphone for noise cancellation
Fuel sensor
• Level
• Vapor pressure
Crash sensor
Air conditioning compressor sensor
Manifold air pressure sensor
Exhaust gas sensor
Mass air flow sensor
Force sensors
• Brakes
• Theottle pecials
Accelerator for suspension control
Pressure and inertial sensors for breaking control
Tire pressure sensors



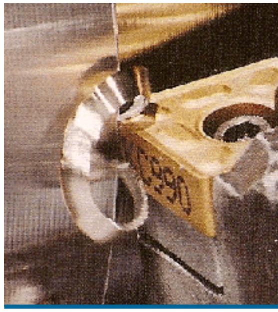
Key Concepts

1. MEMS are made up of microelectronics, microactuators, microsensors, and microstructures.
2. The three basic steps to MEMS fabrication are: deposition, patterning, and etching.
3. Chemical wet etching is popular because of high etch rate and selectivity.
4. The benefits of using MEMS: speed, power consumption, size, system integration(all on one chip).



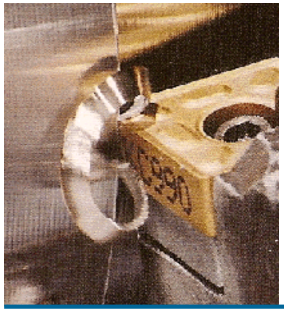
Summary

- Micro-Electro-Mechanical Systems are 1-100 micrometer devices that convert electrical energy to mechanical energy and vice-versa.
- The three basic steps to MEMS fabrication are deposition, patterning, and etching.
- Due to their small size, they can exhibit certain characteristics that their macro equivalents can’t.
- MEMS produce benefits in speed, complexity, power consumption, device area, and system integration.
- These benefits make MEMS a great choice for devices in numerous fields.



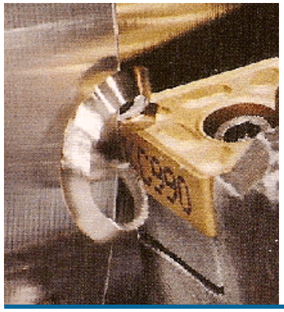
LIGA Process/LIGA Lithography

- LIGA is a German acronym that stands for Lithographie, Galvanoformung and Abformung.
- When translated it means lithography, electroplating and molding.



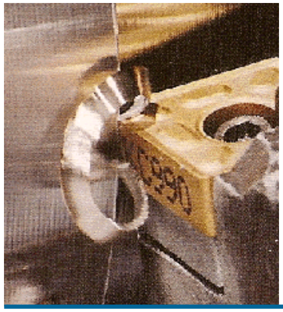
LIGA Process

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



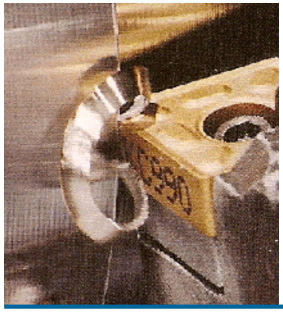
Background

- LIGA is a three stage micromachining technology used to manufacture high aspect ratio microstructures.
- Originally LIGA technology was researched in Germany in order to be used for the separation of uranium isotopes.



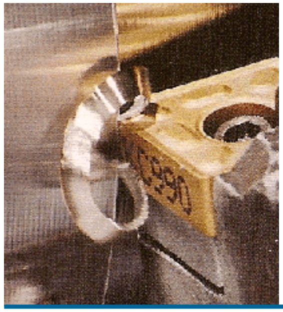
Background

- Two main types of LIGA Technology: X-ray LIGA and Extreme Ultraviolet (EUV) LIGA.
- X-ray LIGA can fabricate with great precision high aspect ratio microstructures.
- EUV LIGA can fabricate lower quality microstructures.



LIGA Process

- LIGA is a hybrid fabrication technique
- The LIGA Process
  - Lithography
    - Electron beam lithography
    - Focused ion beam lithography
    - Optical and exciter laser lithography
    - Deep X-ray lithography using synchrotron radiation
  - Electroplating
    - metalized layer (seed layer)
  - Molding
    - Machining process to remove overplated metal region



Function of LIGA

- To produce high aspect ratio
- To manufacture 3-D microstructures from a wide variety of materials

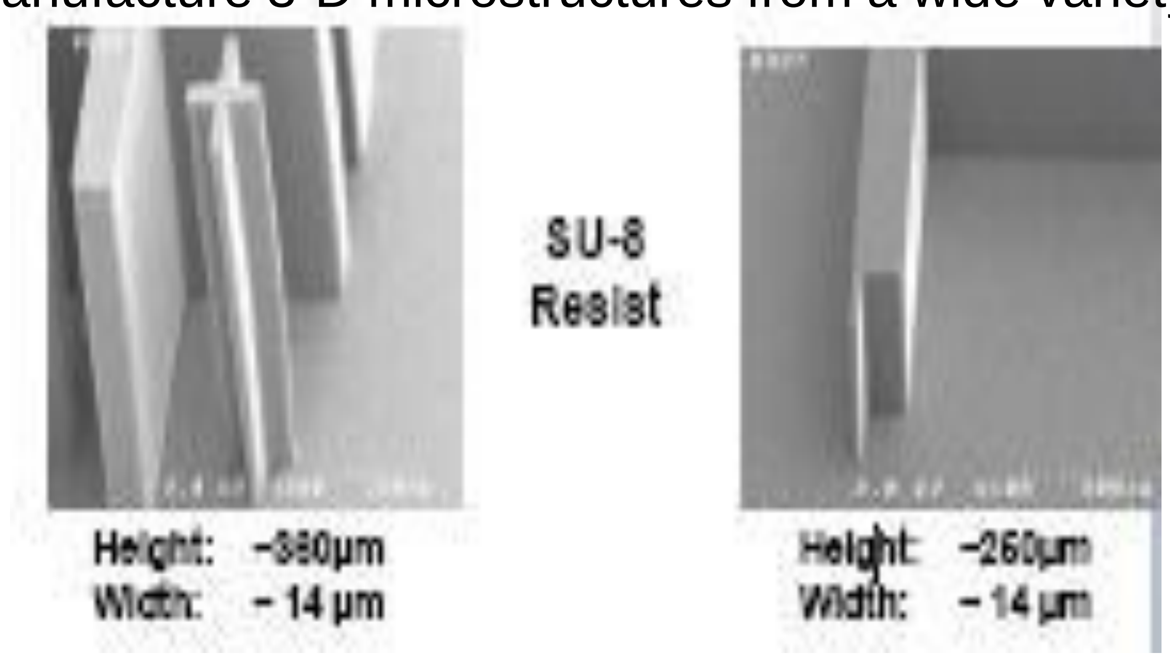
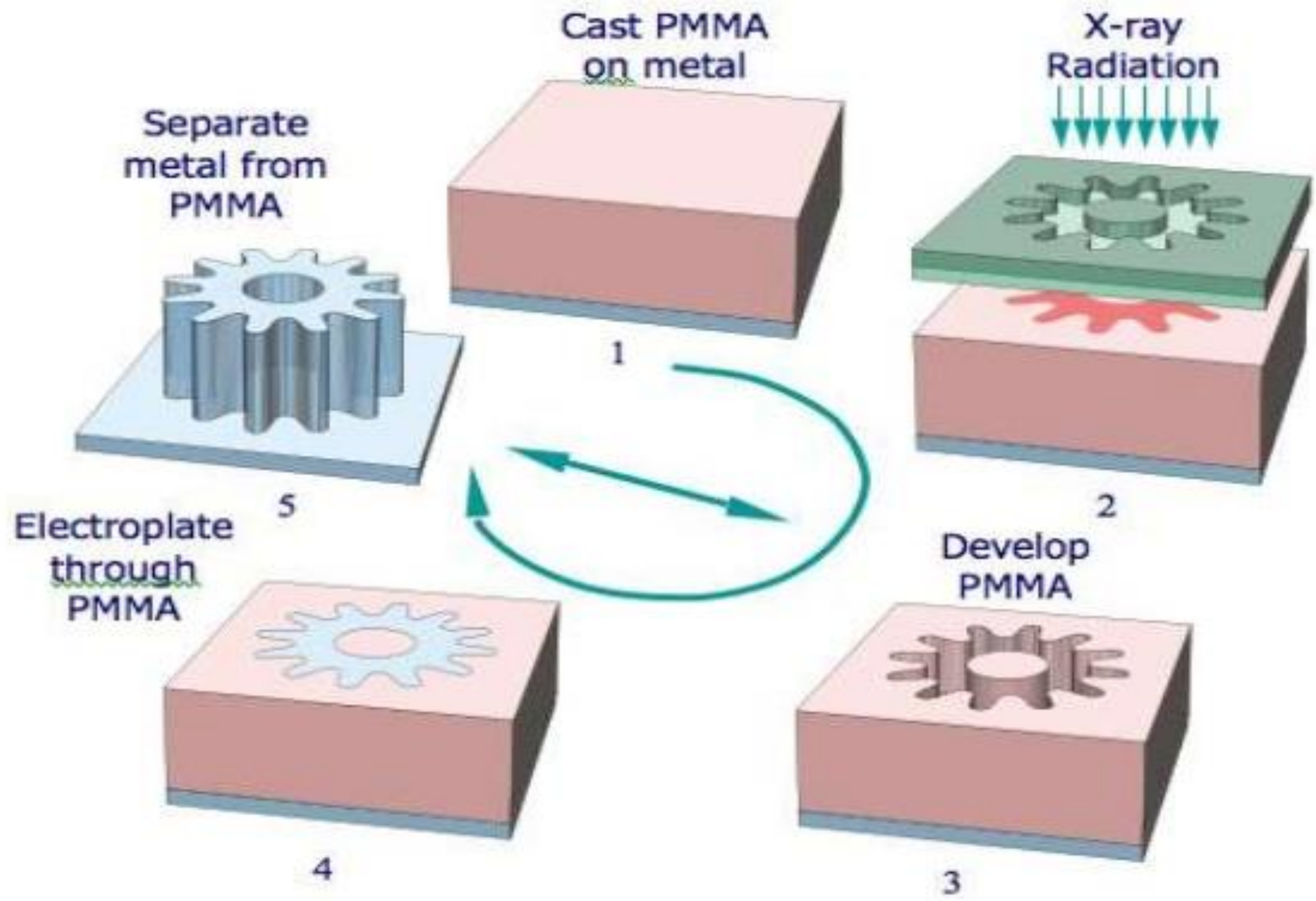
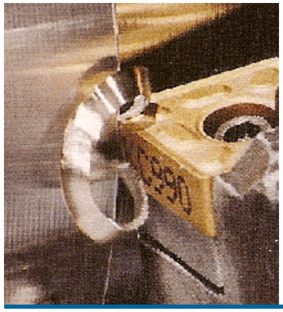


Figure: 3-D microstructure

Processing Steps in LIGA

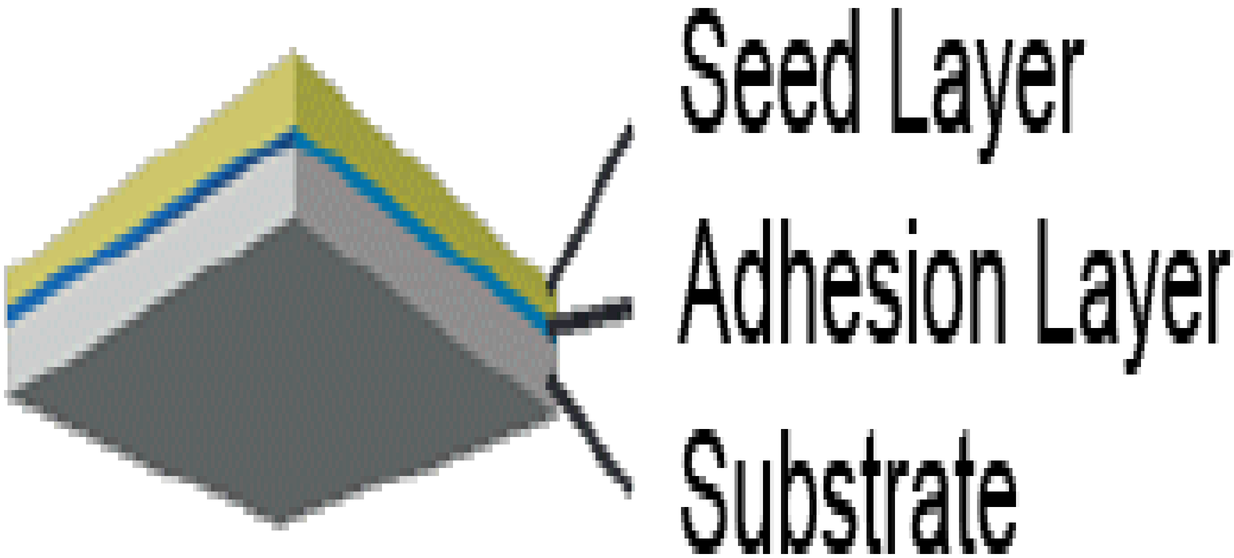


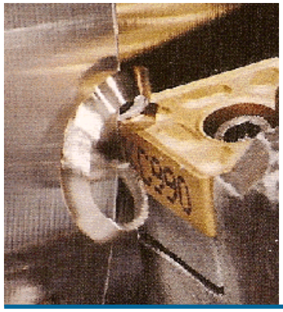
LIGA Processess



Processing Steps in LIGA

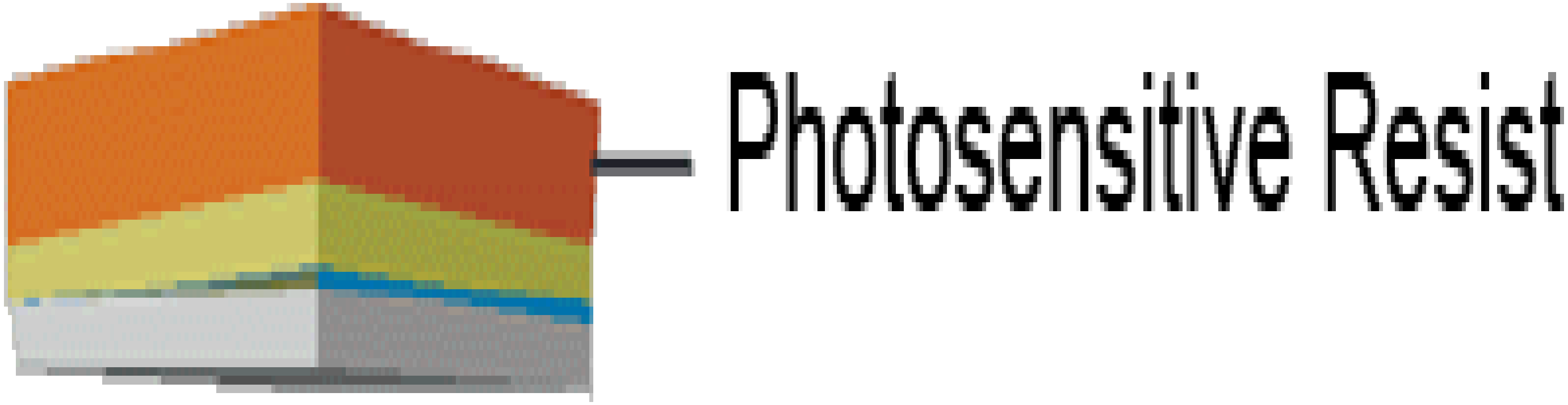
- Step 1:
- -Deposition of Adhesion
- -Seed layer

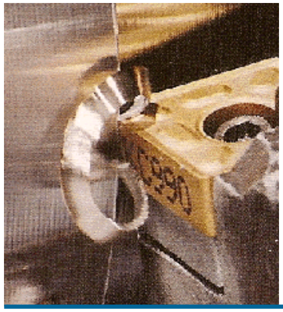




Processing Steps in LIGA

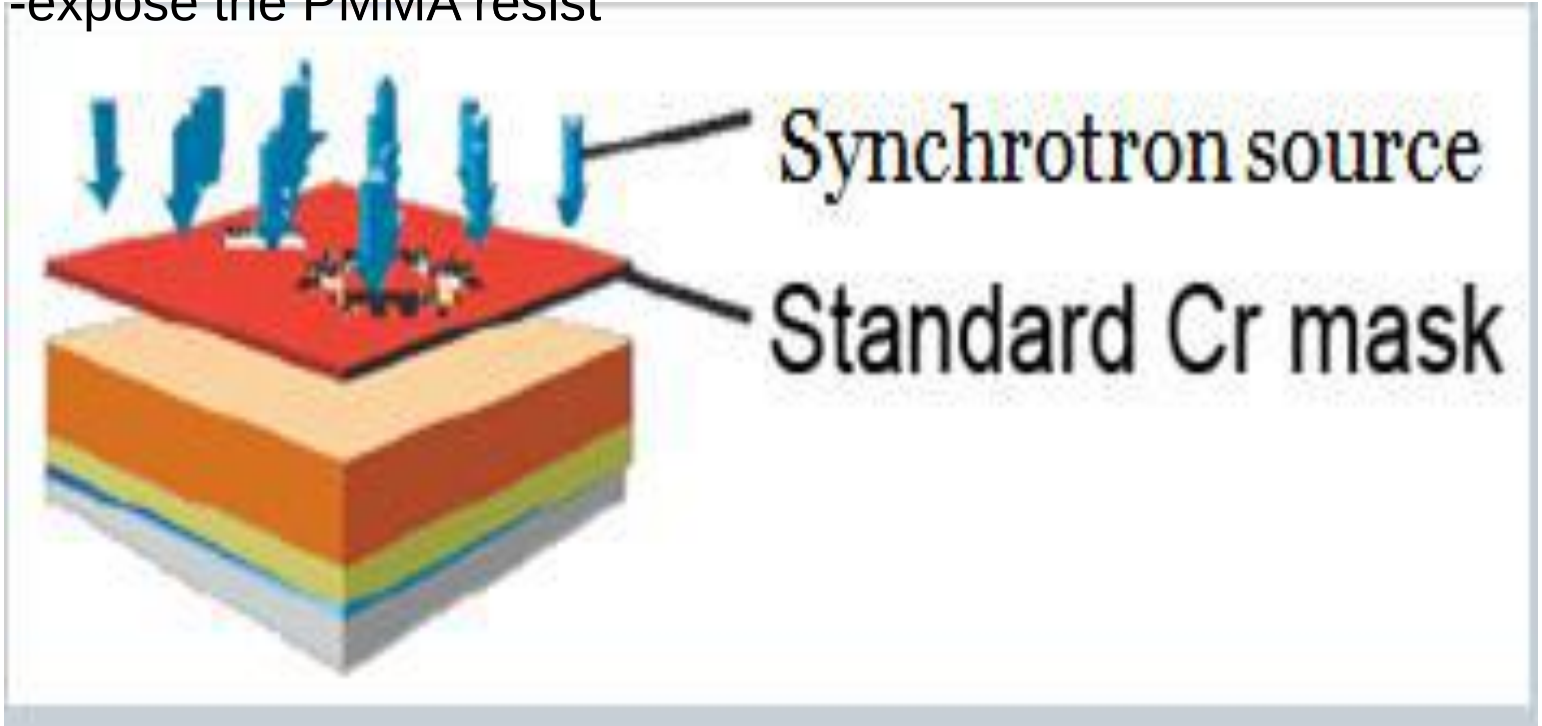
- Step 2:
- -resist coating

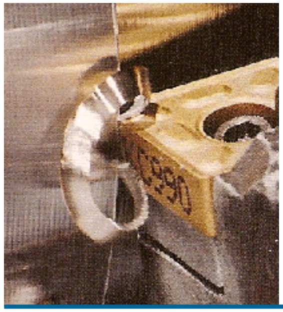




Processing Steps in LIGA

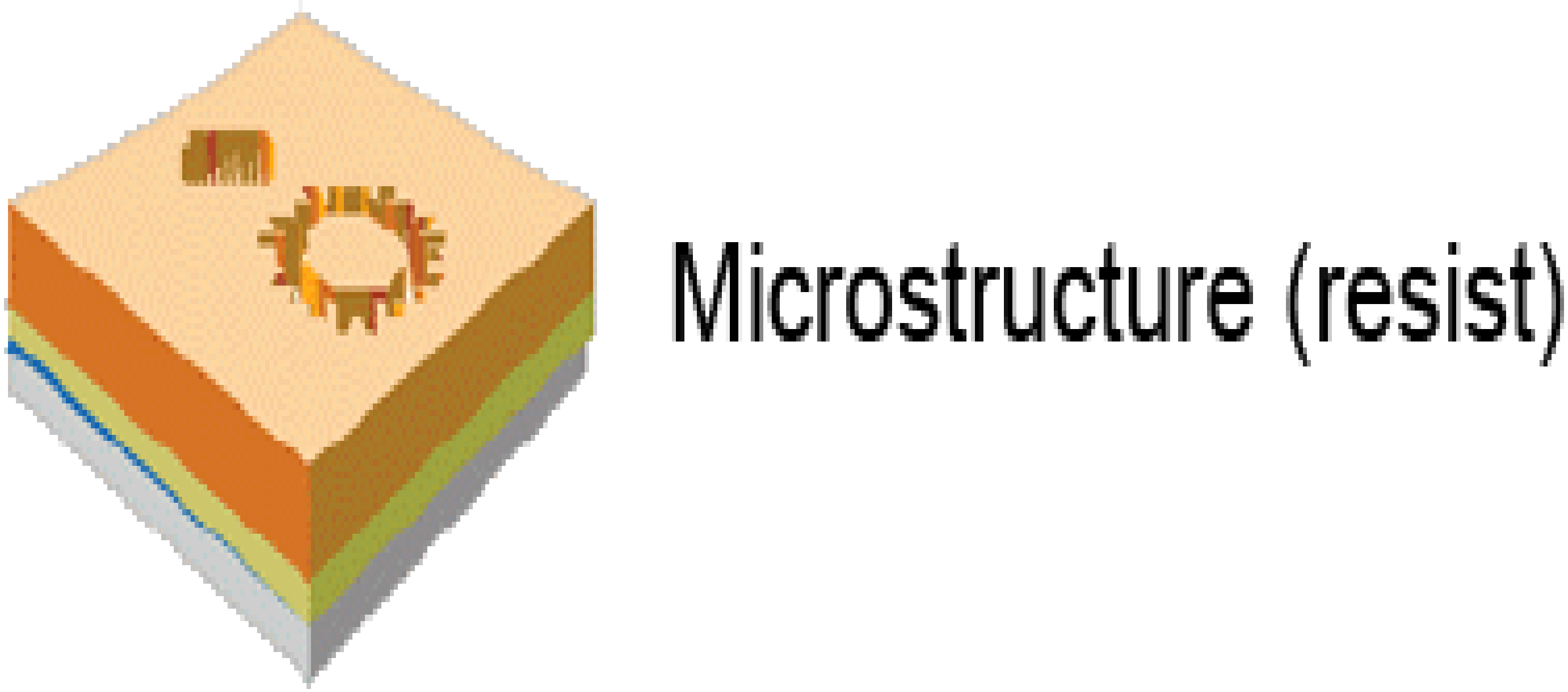
- Step 3:
- -expose the PMMA resist

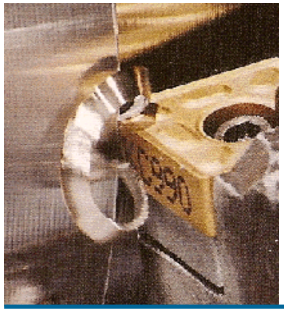




Processing Steps in LIGA

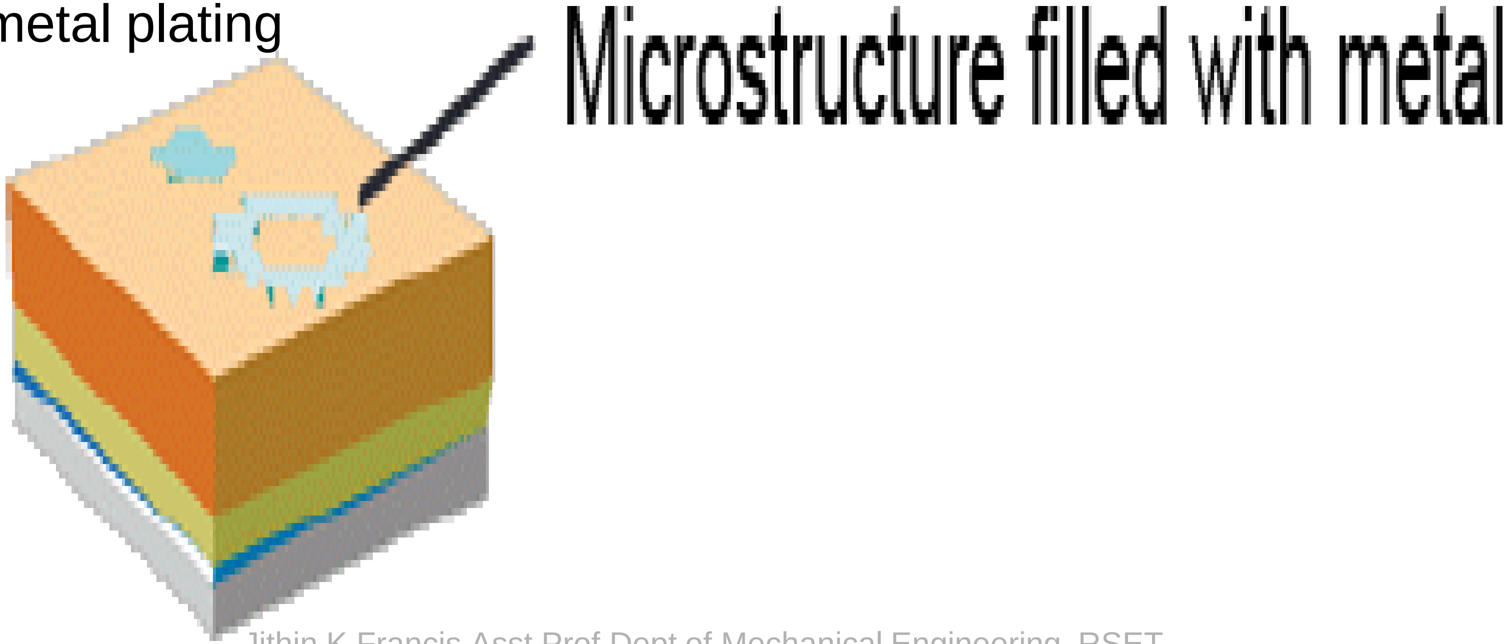
- Step 4:
- -development of the exposed resist

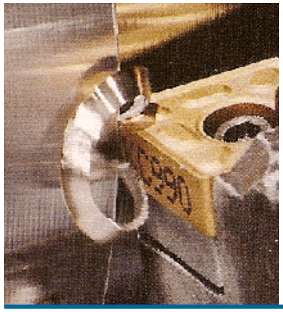




Processing Steps in LIGA

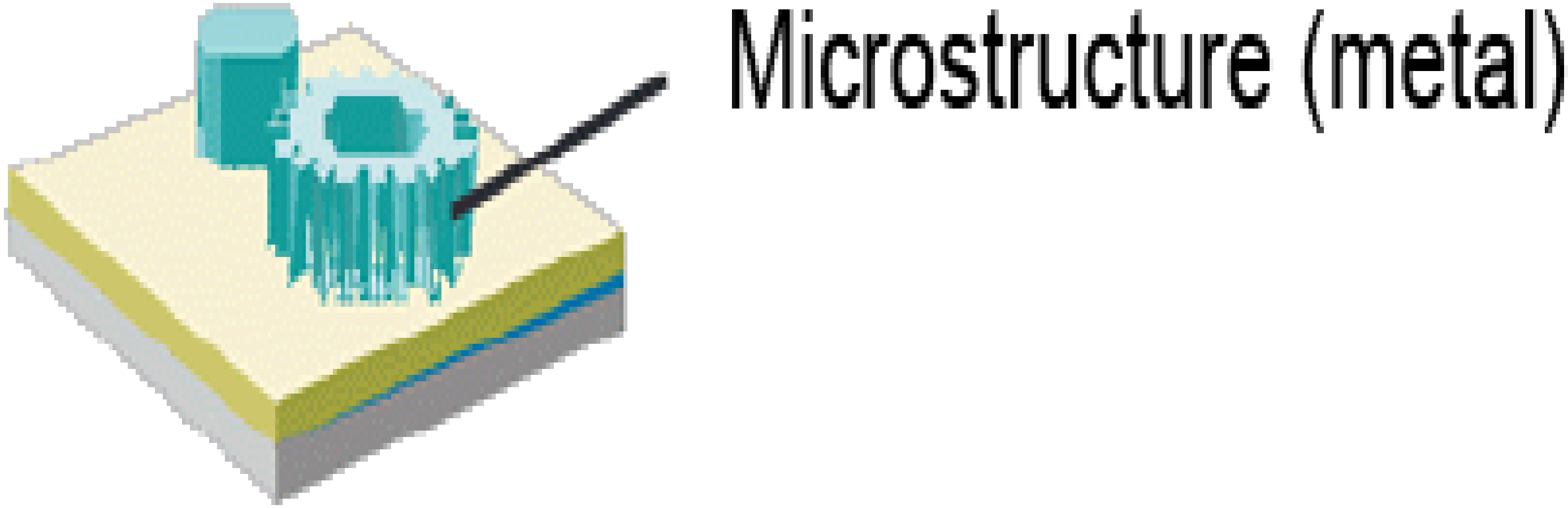
- Electroplating is a process to fill in the voids between the polymeric features.
- Step 5:
- -metal plating

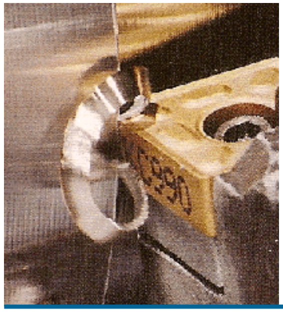




Processing Steps in LIGA

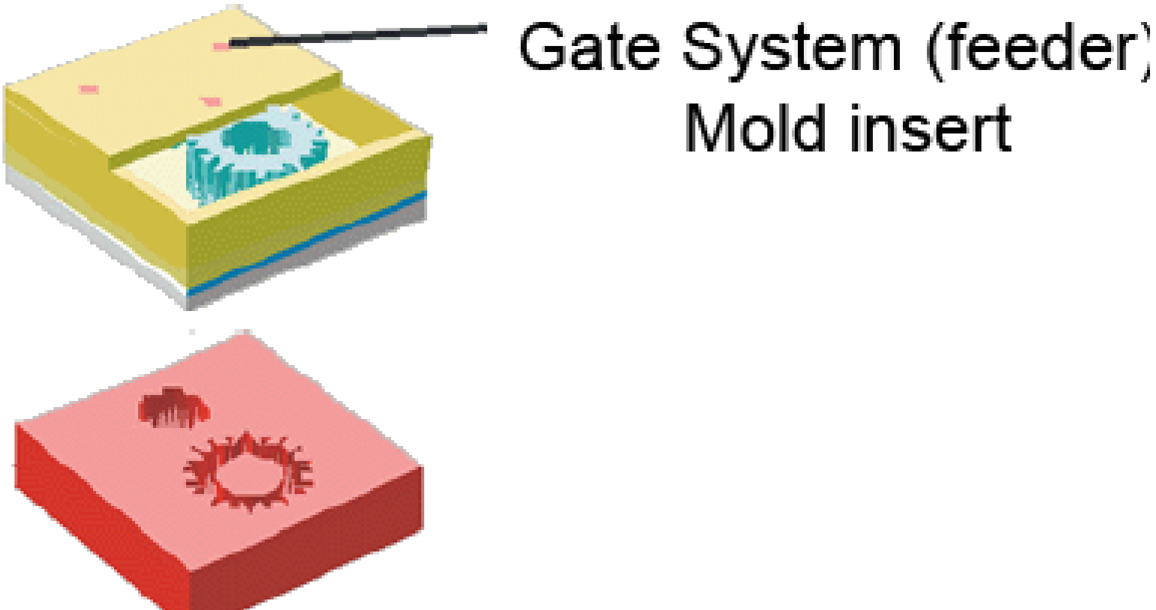
- Step 6:
- -removal of the remaining resist



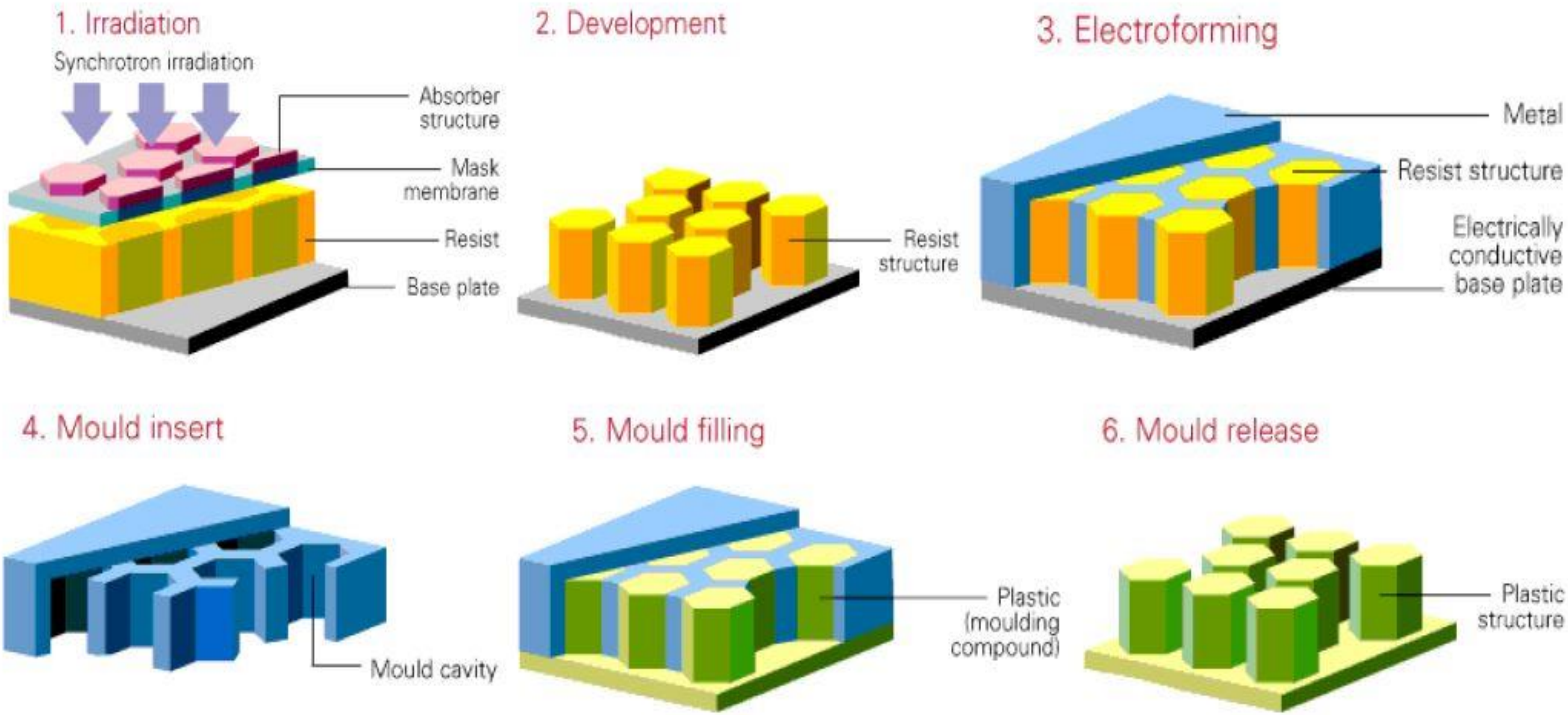


Processing Steps in LIGA

- Molding is process of machining the overplated region filling the microstructure
- Step 7:

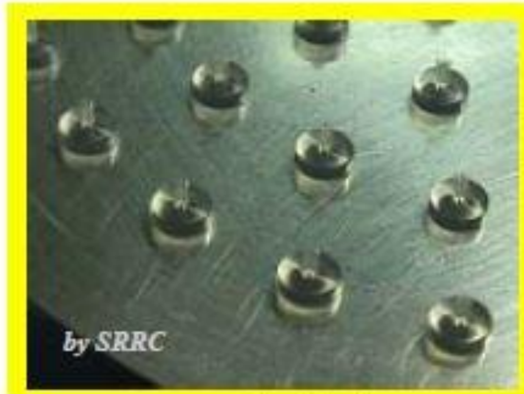


Typical LIGA Process

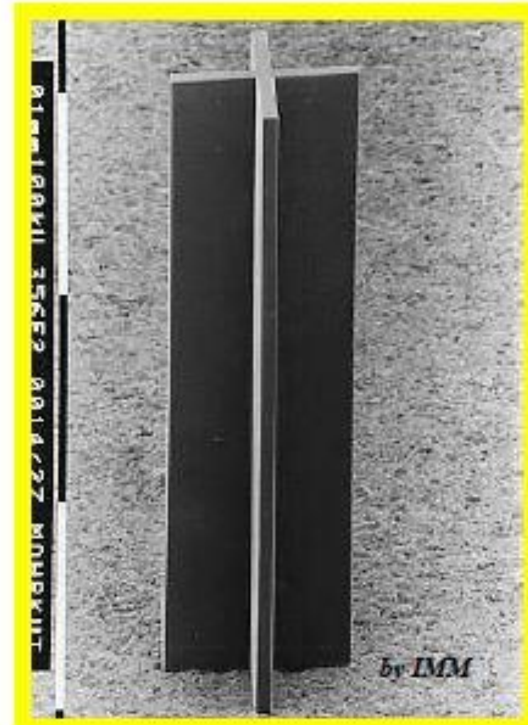


Why "LIGA"?

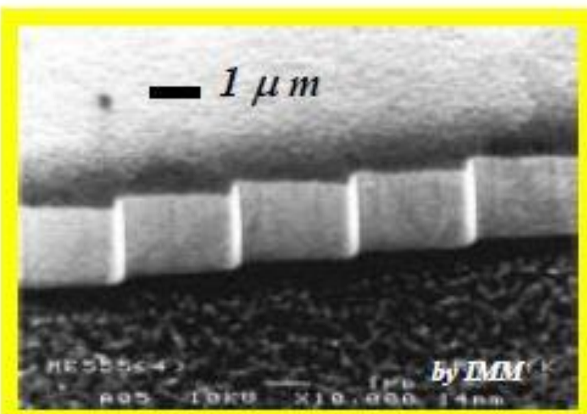
• *mass production*



• *any materials*
(polymer, metal, ceramic)



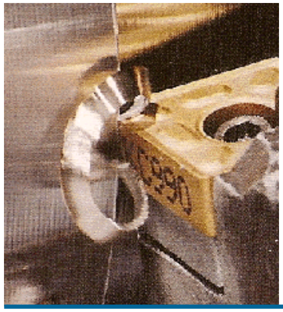
• *high aspect ratio (>50)*



• *high precision (submicron)*
• *low surface roughness (~30 nm)*

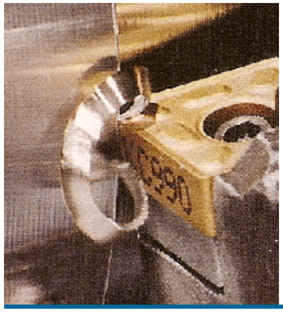
• *any lateral pattern*


Commercialized LIGA Products
Magnetic Reed Switch
Impact Sensor
250
ZENITH
DIAVOLO
ULYSSE NARDIN
60



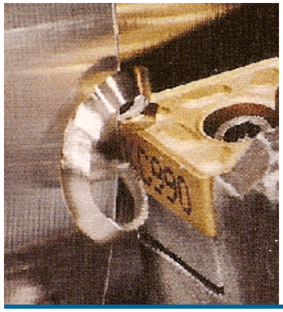
Advantages of LIGA

- 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)
- Wide range of part sizes is feasible - heights ranging from micrometers to centimeters
- Close tolerances are possible



Disadvantages of LIGA

- LIGA is a very expensive process
  - Large quantities of parts are usually required to justify its application
- LIGA uses X-ray exposure
  - Human health hazard



Other Microfabrication Processes

- Soft lithography
- Nontraditional and traditional processes and rapid prototyping adapted for microfabrication
  - Photochemical machining
  - Electroplating, electroforming, electroless plating
  - Electric discharge machining
  - Electron beam machining
  - Ultrasonic machining
  - Microstereolithography