Subject : Elective IV - Micro & Nano Manufacturing (ME 474)

Semester : VIII

Course : B Tech - Mechanical Engineering

Kora T Sunny,
Assistant Professor,
Department of Mechanical Engineering,
Mar Athanasius College of Engineering,
Kothamangalam – 686 666, Kerala.

Department of Mechanical Engineering MACE

VISION

Mentoring to ensure excellence

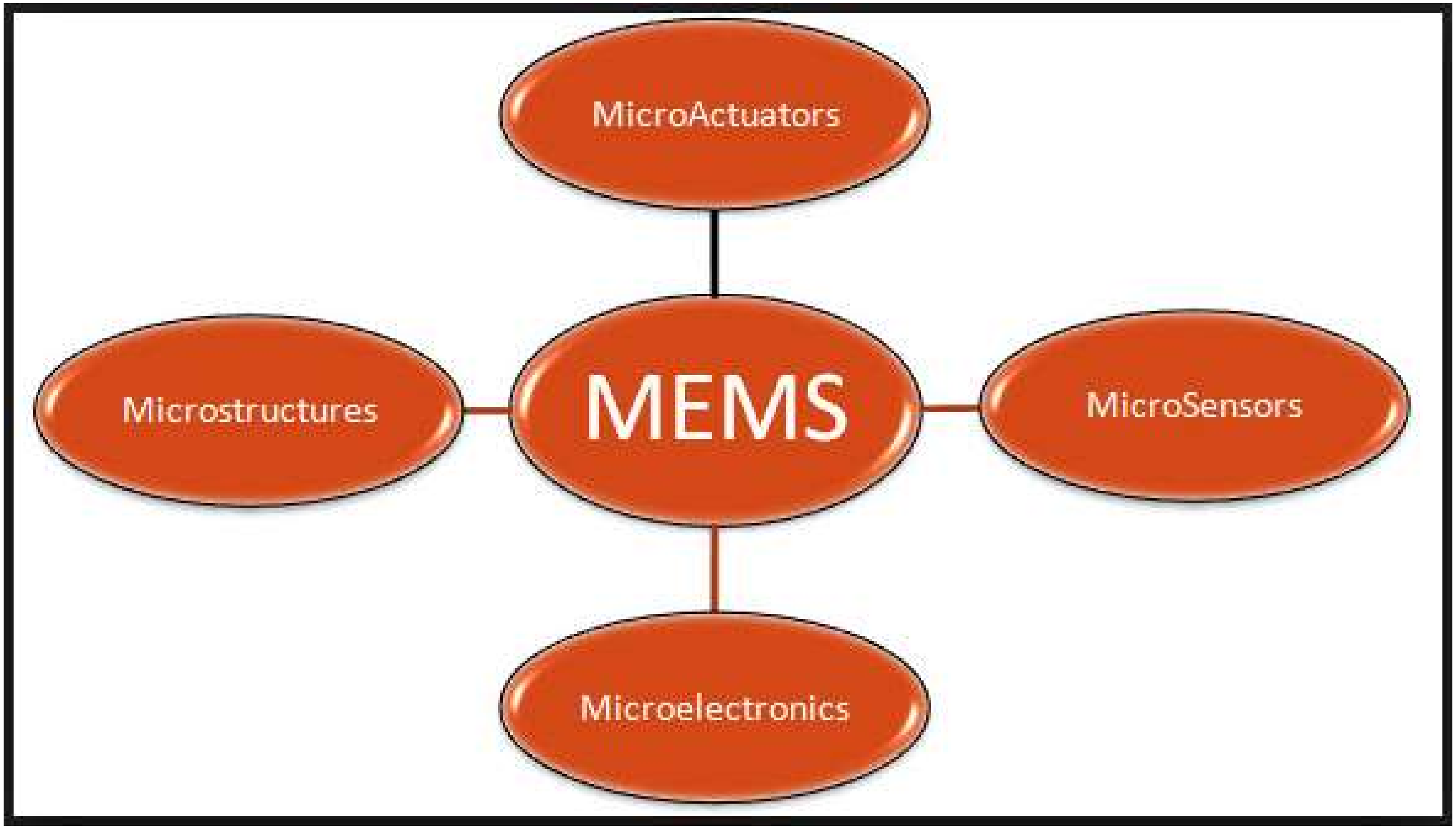
MISSION

- To facilitate comprehensive and integrated development of students by providing quality education
- To mould disciplined and socially committed engineers capable of assuming professional leadership

MODULE 1

Micro electro mechanical systems (MEMS)

Components of MEMS



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

What is MEMS?

- Mems is a technology of very small devices. It is a combination of mechanical functions and electrical functions on the same chip using micro fabrication technology.

- MEMS are made up of components between 1 to 100 micrometers in size
- MEMS devices generally range in size from 20 micrometers to a millimeter

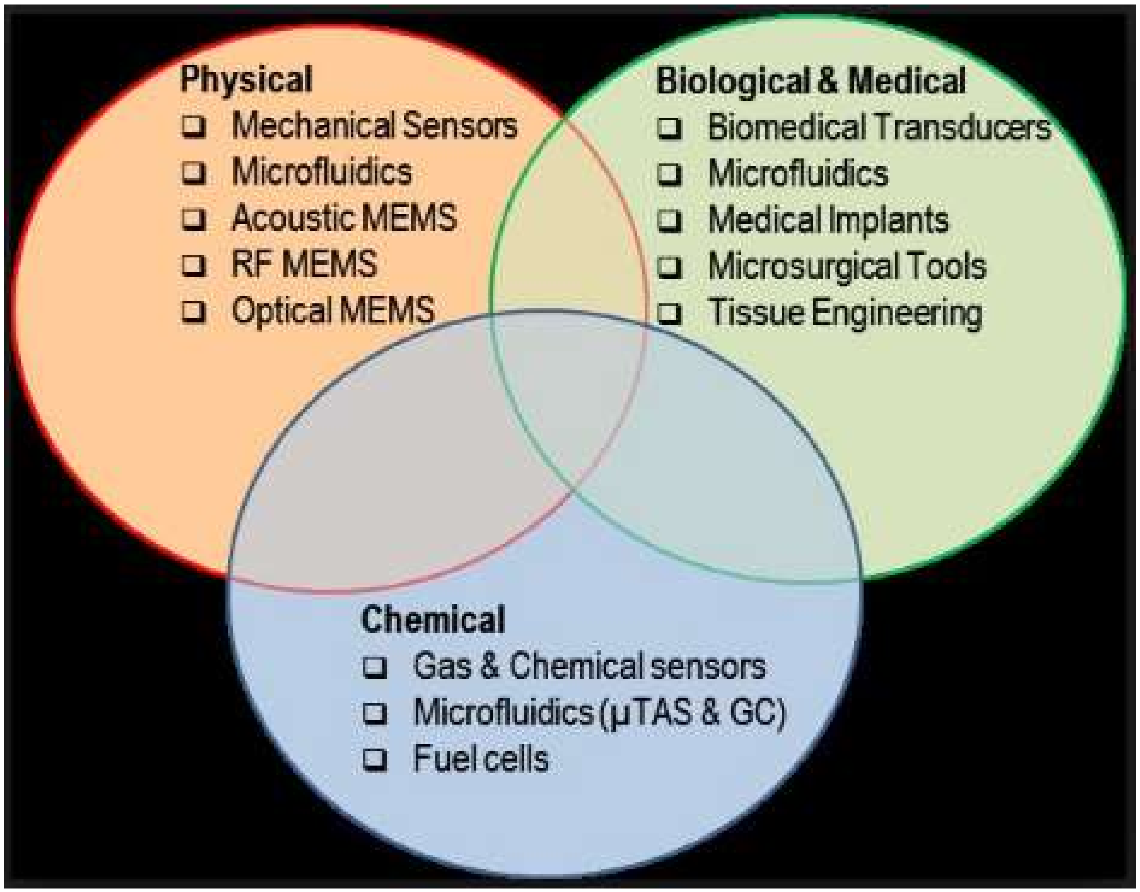
- **Examples** of **MEMS** devices
- 1. accelerometers for airbag sensors
- 2. Microphones,
- 3. Projector display chips
- 4. Blood and tire pressure sensors
- 5. Optical switches
- 6. Analytical components such as chips, biosensors and many other products.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MEMS


Advantages and disadvantages
Minimize energy and materials.
Improved reproducibility.
Improved accuracy and reliability.
Increased selectivity and sensitivity.
Farm establishment requires huge investments.
Micro-components are costly compared to macro components.
Design includes very much complex procedures

Applications of MEMS



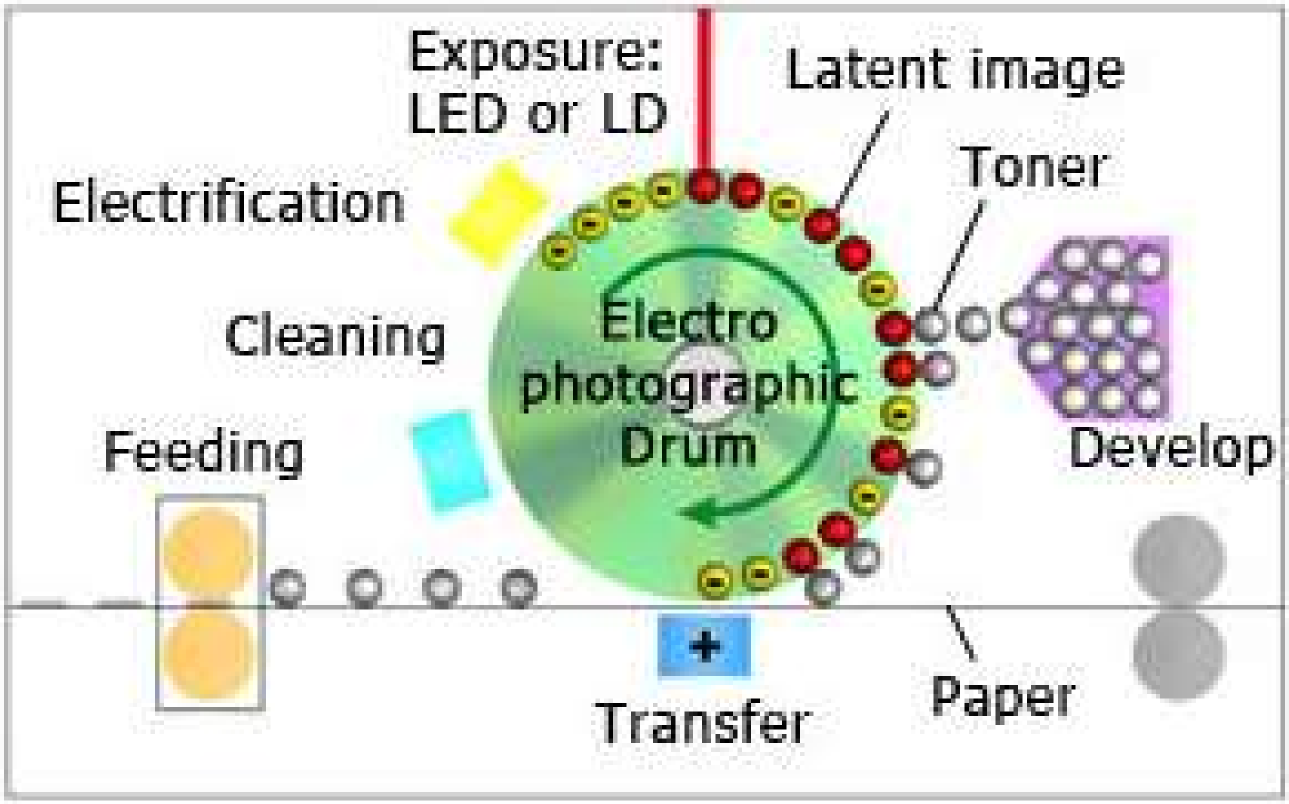
Electro photography

Electro photography, is a printing and photocopying technique that works on the basis of electrostatic charges.

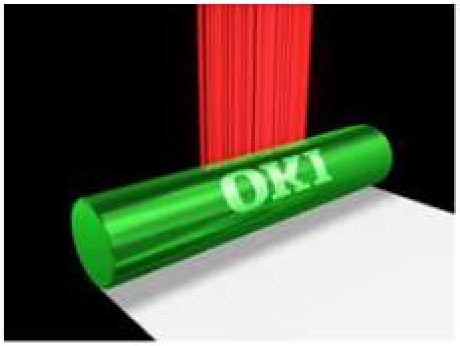
The xerography process is the dominant method of reproducing images and printing computer data and is used in photocopiers, laser printers and fax machines.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electro photography



Electro photographic process



1. Exposure: A latent image is written with LED light on the image drum

2. Developing: Toners are attached to the latent image formed on the image drum.

3. Developing: An image is formed with toners.

4. Transferring: The image formed of toners on the drum is transferred to paper.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electro photographic process

- The electro photographic process consists of charging, exposure, developing, transferring and fusing.

1. **Charging**

- Electric charges uniformly form on the whole surface of the image drum.

2. **Exposure**

- The print pattern is written in dots with light and an electrostatic latent image is formed on the image drum.

3. **Developing**

- Toners are adhered to the latent image.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electro photographic process

4. **Transferring**

- The toners adhered to a latent image are transferred to the surface of paper.

5. **Fusing**

- The toner is fused onto paper by heating it.

- If a light source used in forming an electrostatic latent image on the image drum is laser, then it is a laser printer, and if LED is used it is a LED printer.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro machining

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro machining

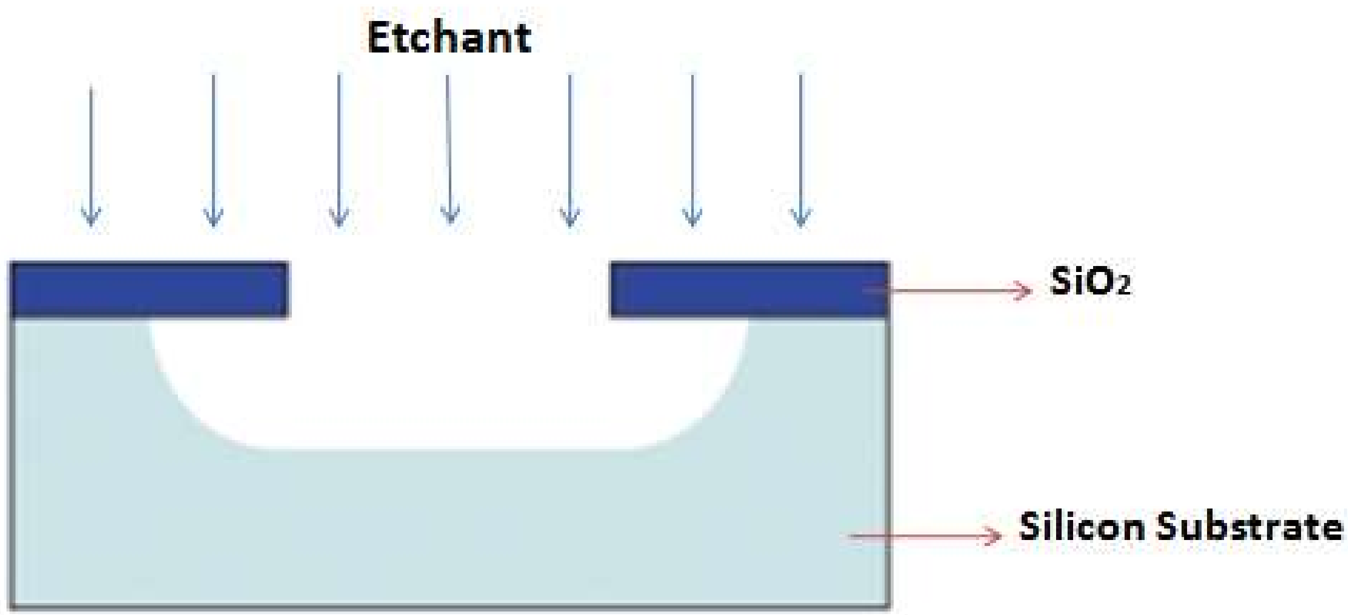
- Bulk micromachining
- Surface micromachining

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Bulk Micromachining

- **Bulk micromachining** is a process used to produce micro machinery or micro electro mechanical systems (MEMS).
- **Bulk micromachining** defines structures by selectively etching inside a substrate.
- Commonly used for etching Silicon for manufacturing MEMS.
- Eg. of etchants: Potassium Hydroxide (KOH), Ethylene diamine pyrocatechol (EDP) and hydrazine water

Etching



Types of Etching

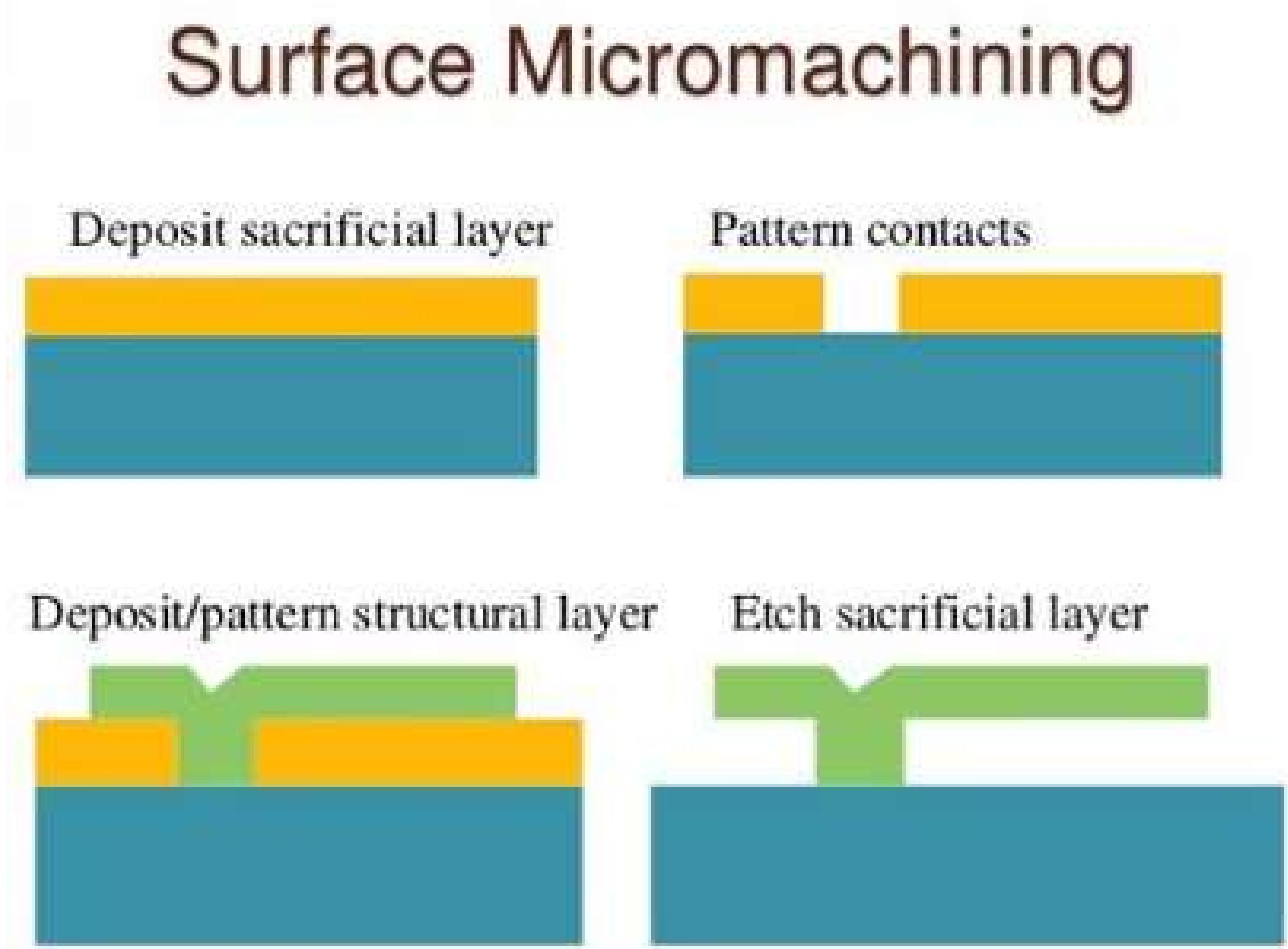
- Wet etching – Uses liquid chemicals as etchants
- Dry etchants – Uses dry powders/ laser/ gas as etchants

  Eg. Powdered XeF_2

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Surface Micromachining

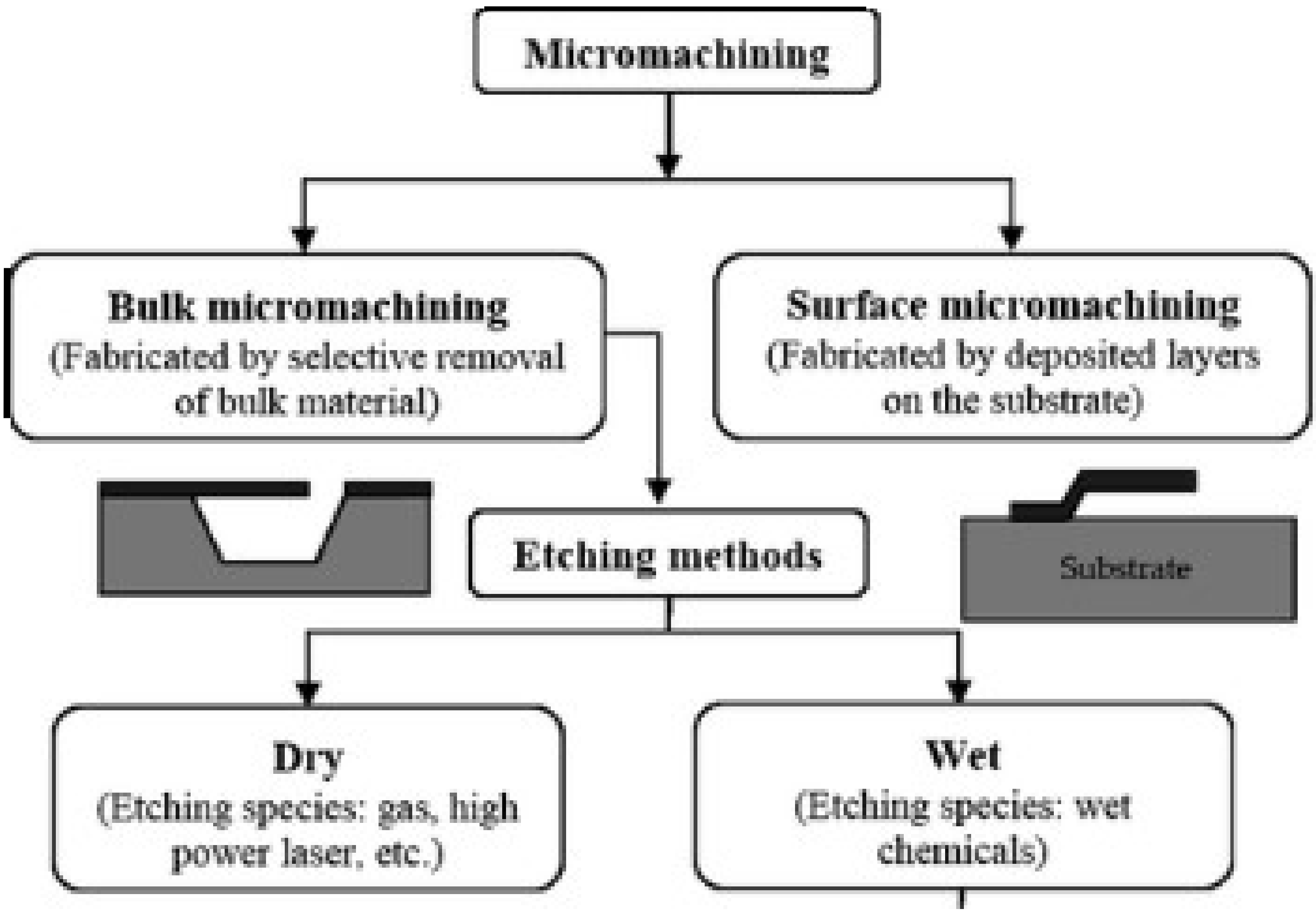
- Surface micromachining builds structures by deposition and etching structural layers over a substrate.



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Surface micromachining

- Surface micromachining builds microstructures by deposition and etching of different structural layers on top of the substrate.
- Generally polysilicon is commonly used as one of the layers and silicon dioxide is used as a sacrificial layer which is removed or etched out to create the necessary void in the thickness direction.
- Added layers are generally very thin with their size varying from 2-5 Micro metres.
- The size of the substrates can also be much larger than a silicon wafer, and surface micromachining is used to produce TFTs on large area glass substrates for flat panel displays.


Micromachining
Bulk micromachining
(Fabricated by selective removal of bulk material)
Surface micromachining
(Fabricated by deposited layers on the substrate)
Etching methods
Substrate
Dry
(Etching species: gas, high power laser, etc.)
Wet
(Etching species: wet chemicals)

Assignment # 1

(Submit on or before Monday 25.03.2019)

1. Explain about micro instrumentation and its applications.
2. Explain about micro mechatronics.
3. With neat sketches explain about any 3 nano finishing operations.
4. Write short notes about influence of laser technology in micro manufacturing. List few applications of the same.
5. Explain about micro energy and chemical system (MECS)?
6. With neat sketches explain about space micro propulsion system.

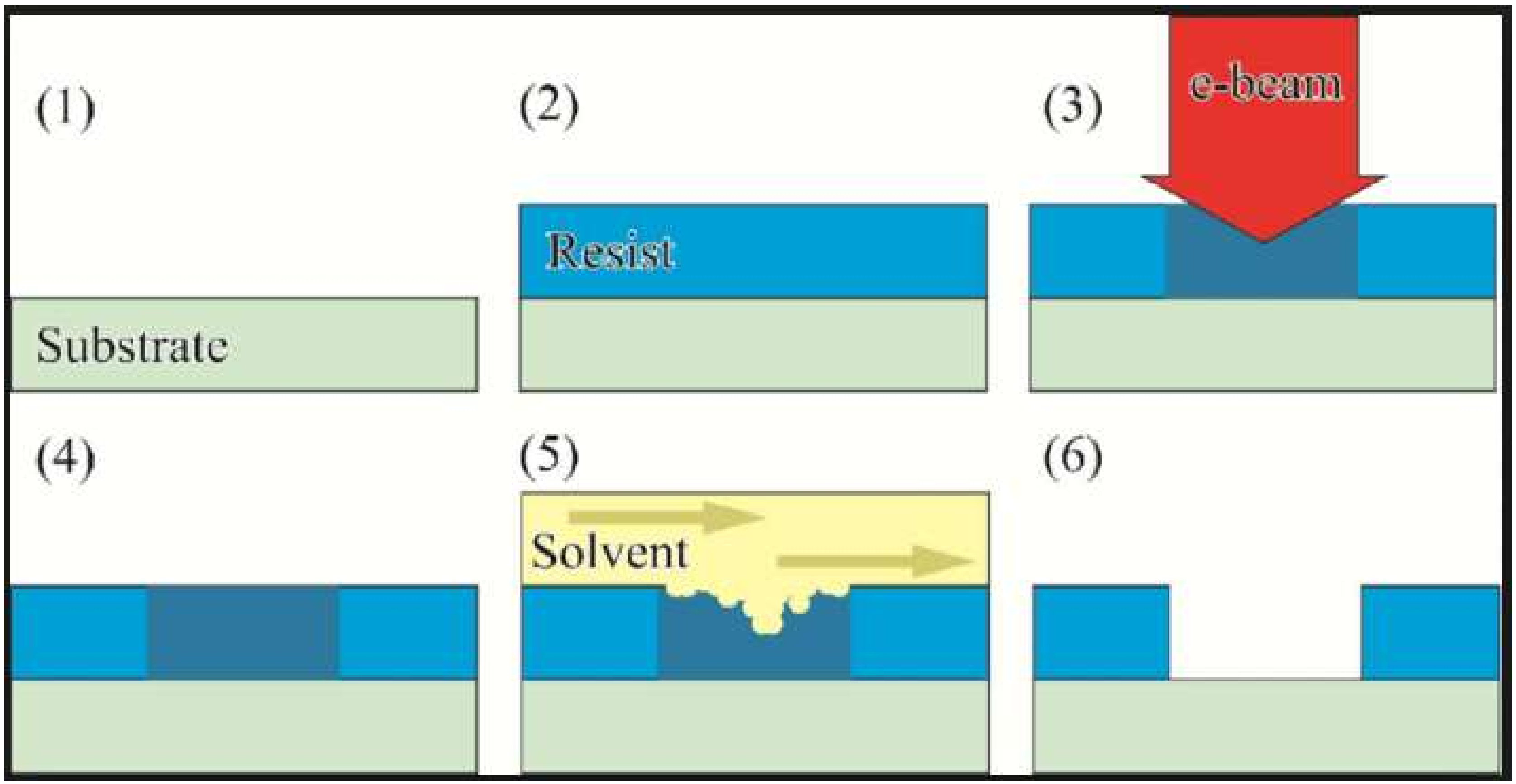
Introduction to nanotechnology

- **Nanotechnology** is manipulation of matter on an atomic/ molecular/ sub molecular scale.

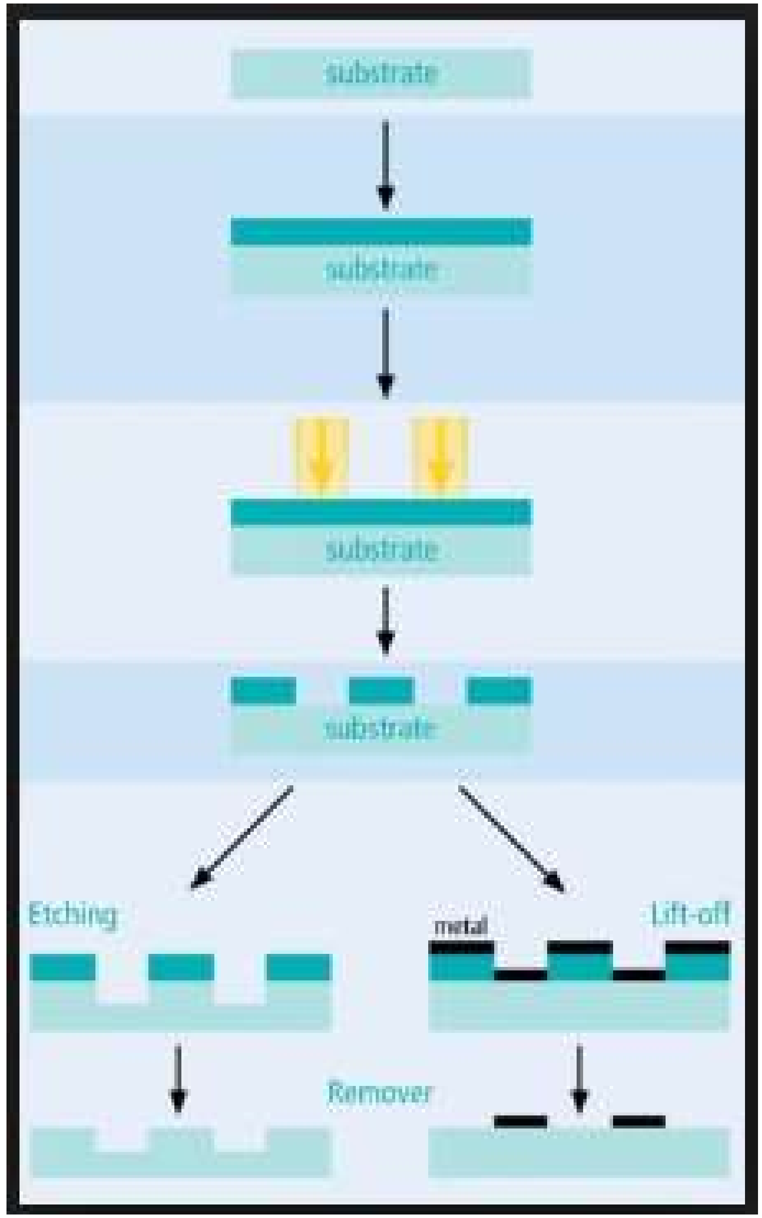
Electron beam nano lithography

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electron beam nano lithography



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electron beam nano lithography

- **Electron beam nano lithography** is the practice of scanning a focused beam of electrons to draw custom shapes on a surface covered with an electron-sensitive film called a resist (exposing).
- The electron beam changes the solubility of the resist, enabling selective removal of either the exposed or non-exposed regions of the resist by immersing it in a solvent (developing).

Electron beam nano lithography

- **Procedure**
- Sample is coated with a thin layer of resist poly methyl meth acrylate (PMMA)
- PMMA breaks down into monomers upon exposure to electrons.
- The exposed regions can be rinsed away using a chemical methyl isobutyl ketone (MIBK)

Electron beam nano lithography

- **Advantages:**

1. Print complex patterns directly on wafers
2. Eliminates diffraction problem
3. High resolution – up to 20 nm.
4. Process is flexible and can cut complex contours

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electron beam nano lithography

- **Disadvantages:**

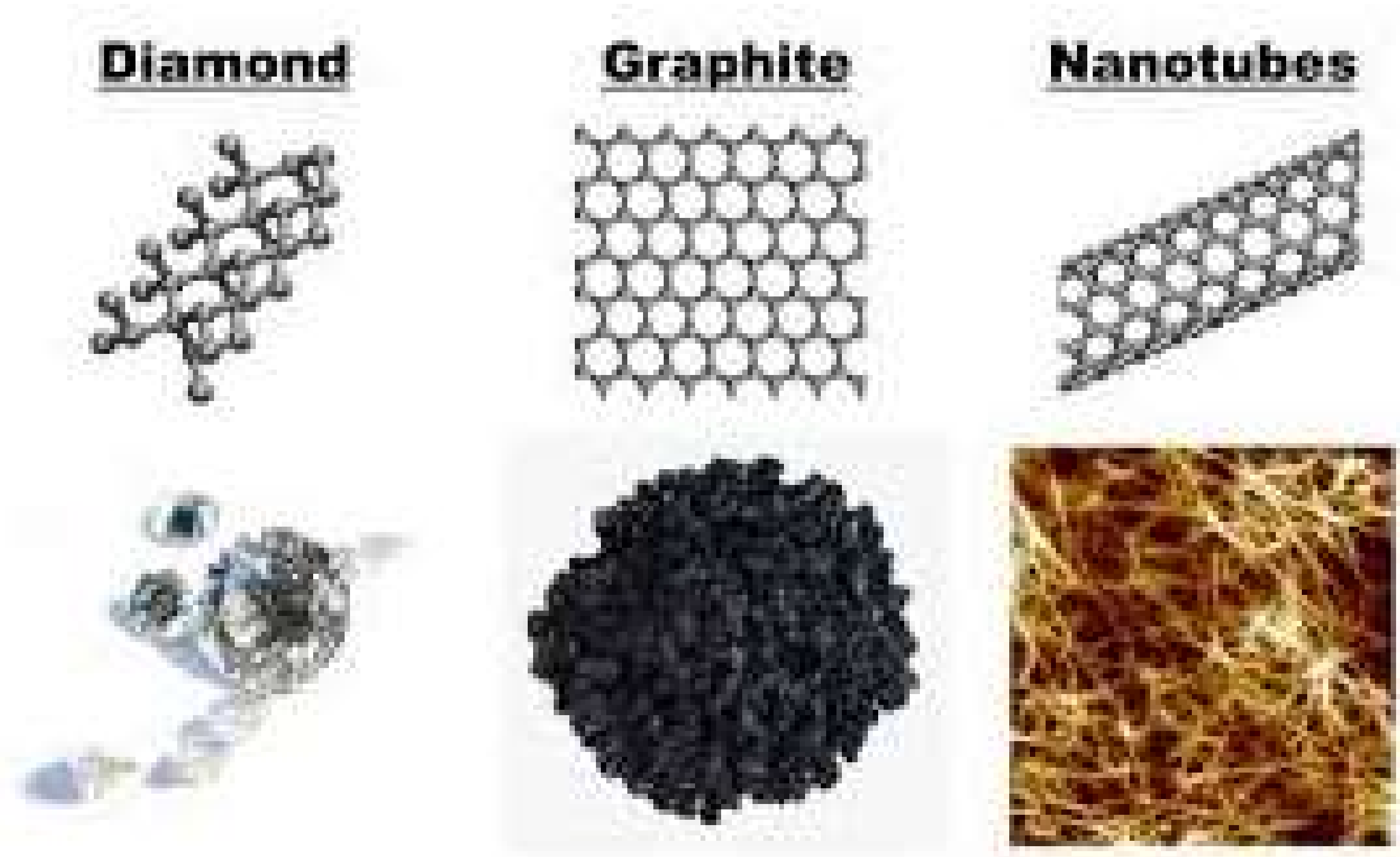
1. Process is slow
2. Expensive & complicated
3. Problems due to secondary electrones

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Carbon nano tubes

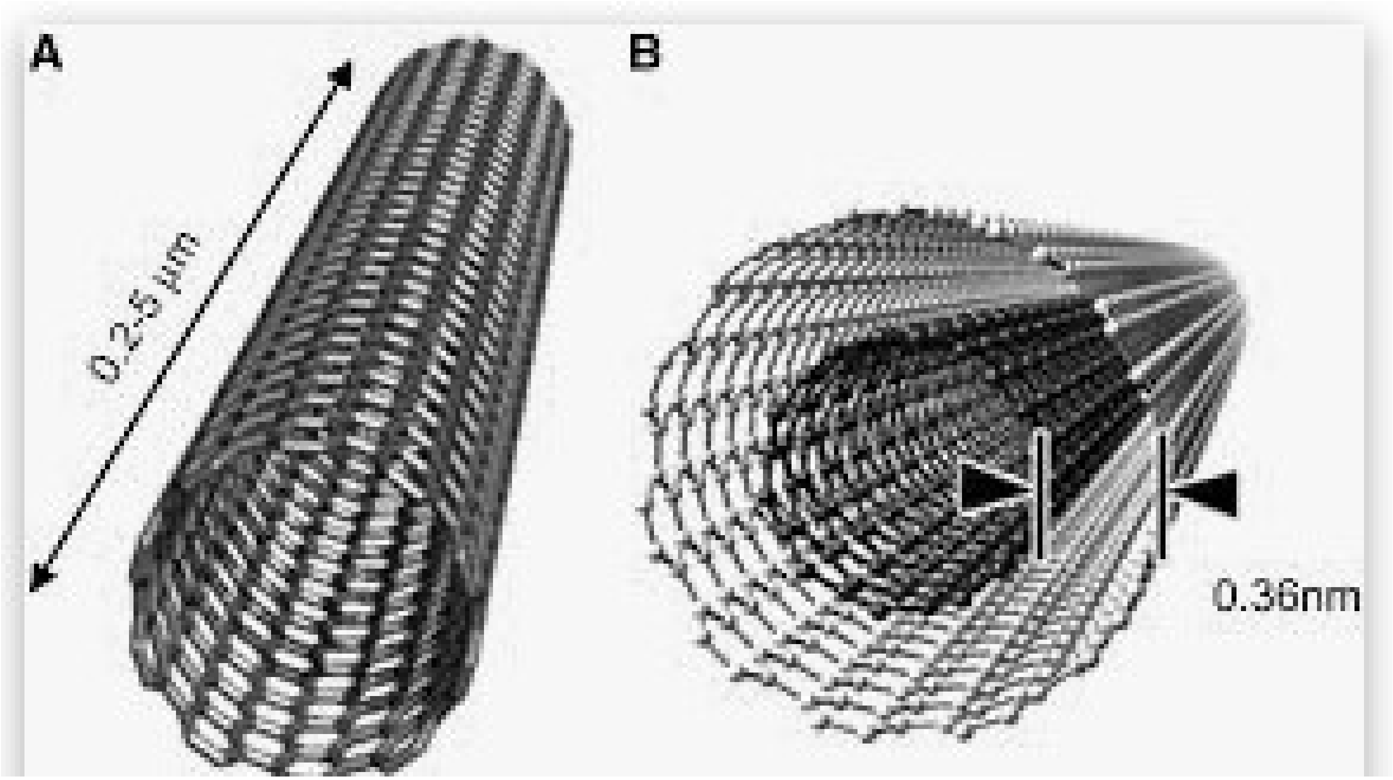
- Allotropes are the different physical forms in which an element can exist.
- **Carbon nano tube** (CNT) is an allotrope of carbon.
- They take the form of cylindrical carbon molecules arranged in the shape of hexagon
- CNTs holds meritorious properties that make them potentially useful in a wide variety of applications in nanotechnology, electronics, optics and other fields of materials science

Allotropes of Carbon



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Single walled & double walled CNT



CNT - Structure

- CNT consists of cylindrical layer(s) of carbon atoms.
- Within the layers the atoms are arranged at the corners of hexagons which fill the whole plane.
- The carbon atoms are strongly (covalently) bound to each other (carbon-carbon distance $\sim$ 0.14 nm).
- The layers themselves are rather weakly bonded to each other

CNT - Types

- Based arrangement of carbon atoms

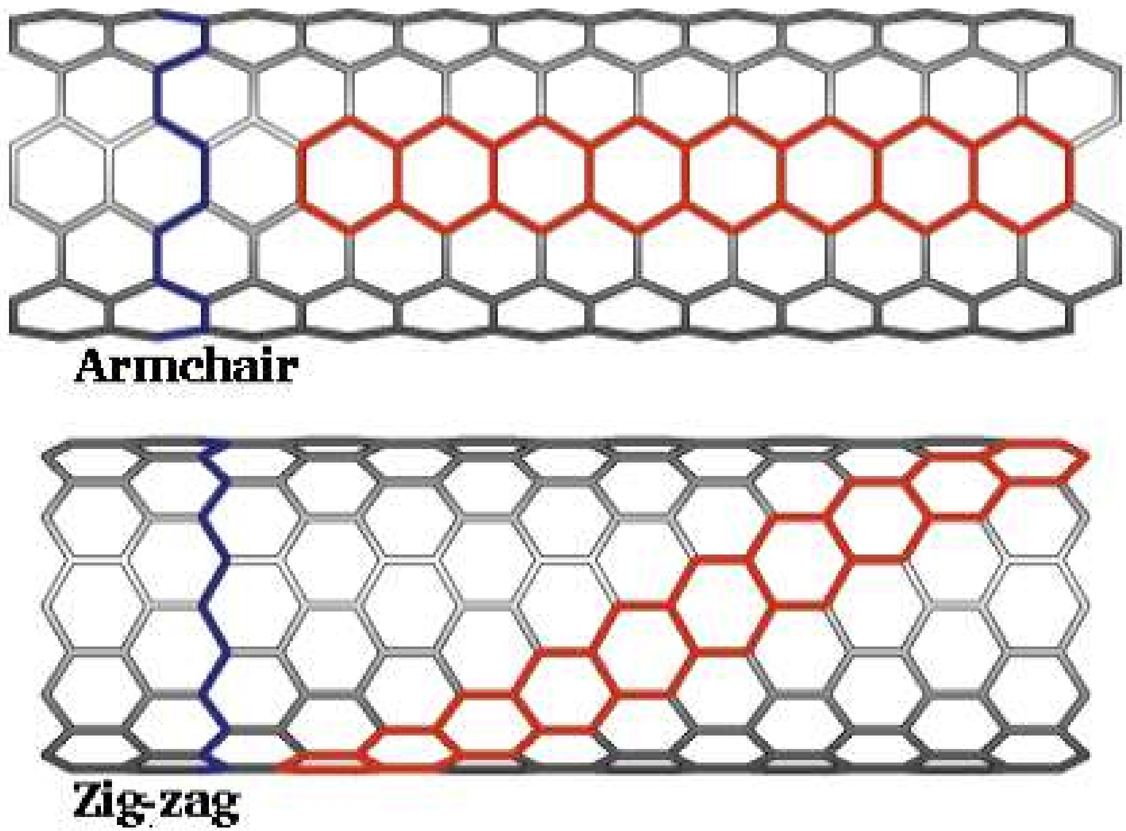
1. Armchair CNT
2. Zig zag CNT

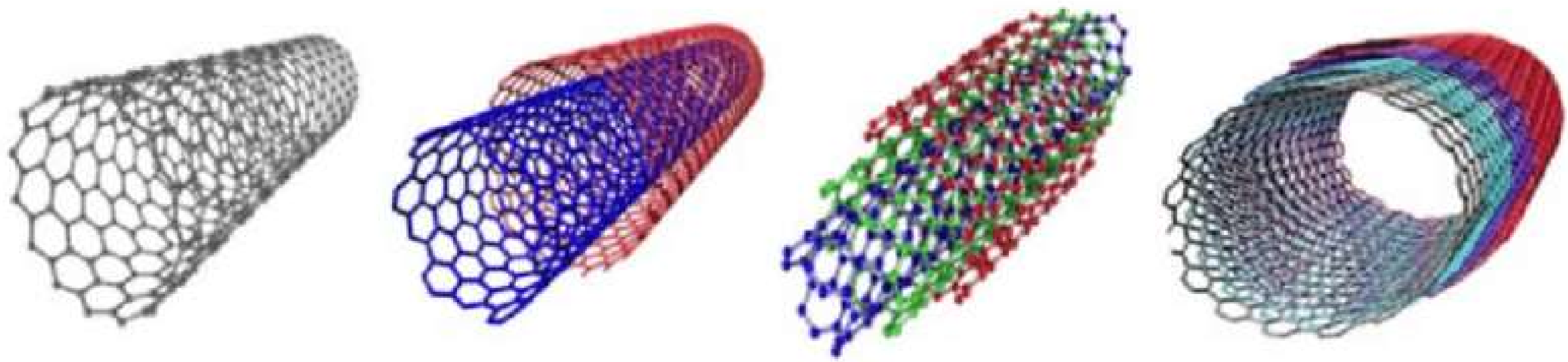
- Based on number of cylindrical layers of carbon

1. SWCNT
2. DWCNT
3. TWCNT
4. MWCNT

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Armchair & zig zag CNT





SWCNTs
Length = 20-1000 nm
Diameter = 0.4-2.5 nm

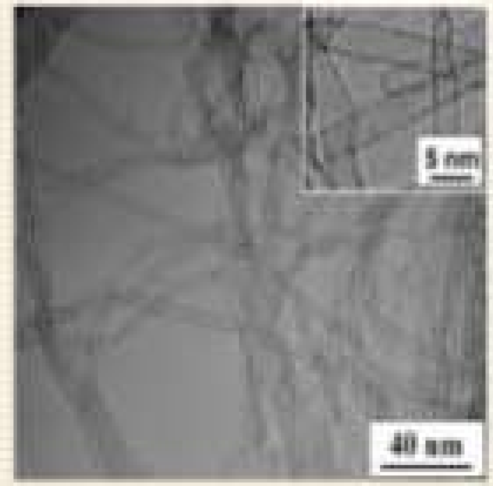
DWCNTs
Length = 50μm
Diameter = Less than 2 nm

TWCNTs
Length = 100 mm
Diameter = 3-5nm

MWCNTs
Length = 1-50 μm
Diameter = 1.4-100 nm

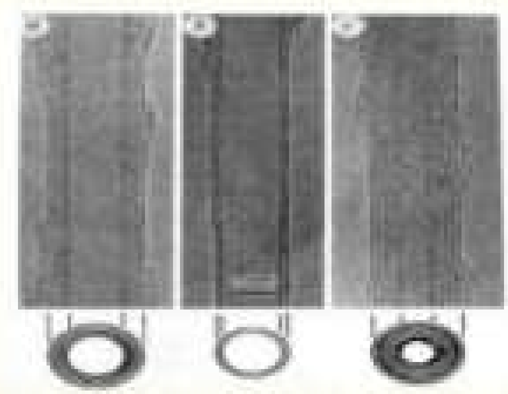
Types of Carbon Nanotubes

❖ Single-walled Nanotubes(SWNTS)



- A single-walled carbon nanotube (SWNT) may be thought of as a single atomic layer thick sheet of graphene rolled into a seamless cylinder.
- Most single-walled nanotubes (SWNT) have a diameter of close to 3 nanometer, with a tube length that can be many 10^4 times longer.

❖ Multi-walled Nanotubes (MWNTs)



- Multi-walled nanotubes (MWNT) consist of multiple rolled layers (concentric tubes) of graphite.
- MWCNTs can have OD ~ 20nm, ID ~ 3nm length can be 10^4 times longer.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Nano level biosensors

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

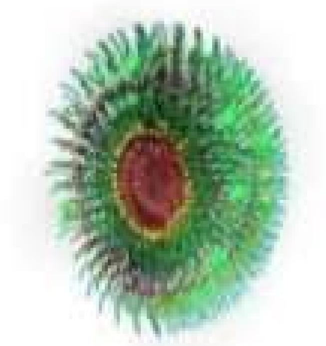
WHAT IS SENSOR…??

A sensor is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

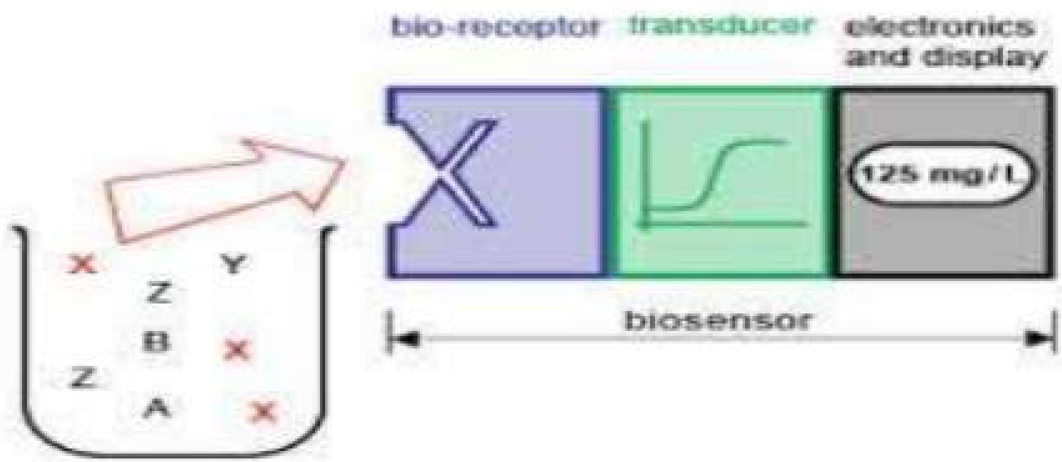
WHAT IS NANO - SENSOR…??

➢ Nanosensors are any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world.



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

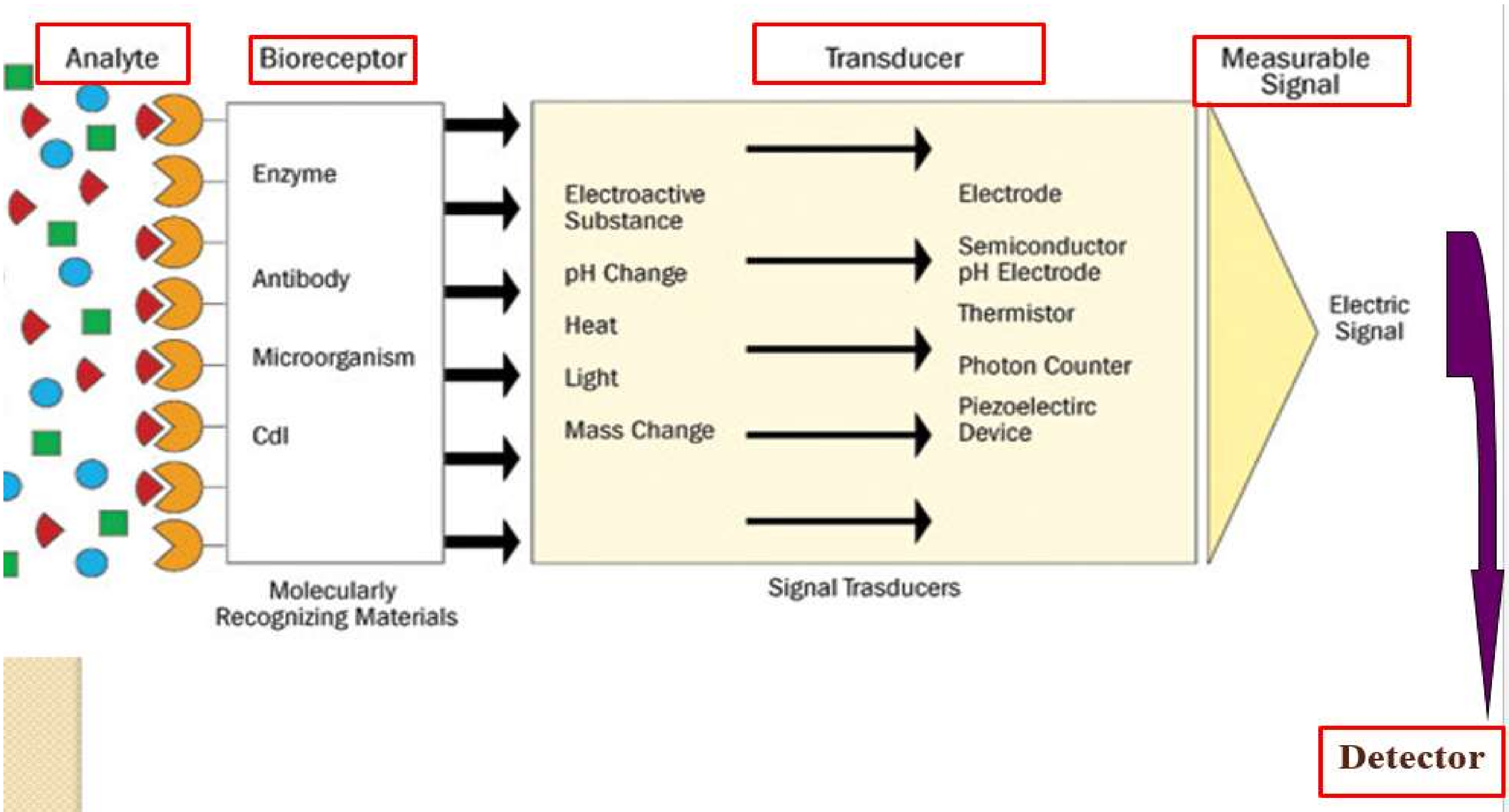
WHAT IS BIO - SENSOR…??



A biosensor is an analytical device, used for the detection of an analyte, that combines a biological component with a physicochemical detector.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Components of biosensor

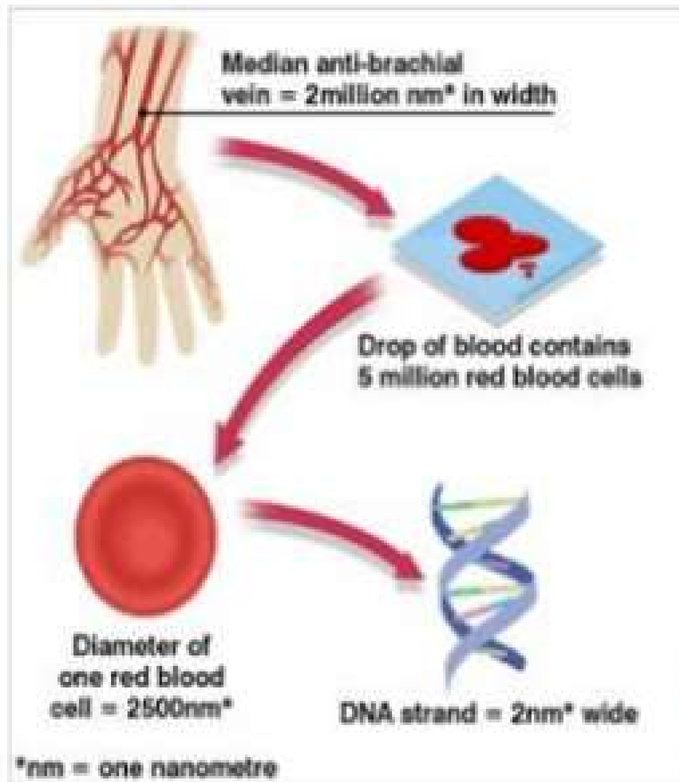


WHAT IS NANO BIOSENSOR…??

- Nano - very small
- Includes many fields
- Its the Miniatured Biology
- Nanotechnology- manipulating matter at nanoscale.

➢ BIO-SENSOR AT NANOSCALE

Comparison of nano-range



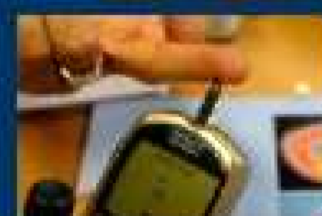
Applications of Nanobiosensors

Biological Applications

- DNA Sensors; Genetic monitoring, disease
- Immunosensors; HIV, Hepatitis,other viral diseas, drug testing, environmental monitoring...
- Cell-based Sensors; functional sensors, drug testing...
- Point-of-care sensors; blood, urine, electrolytes, gases, steroids, drugs, hormones, proteins, other...
- Bacteria Sensors; (E-coli, streptococcus, other): food industry, medicine, environmental, other.
- Enzyme sensors; diabetics, drug testing, other.

Environmental Applications

- Detection of environmental pollution and toxicity
- Agricultural monitoring
- Ground water screening
- Ocean monitoring



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

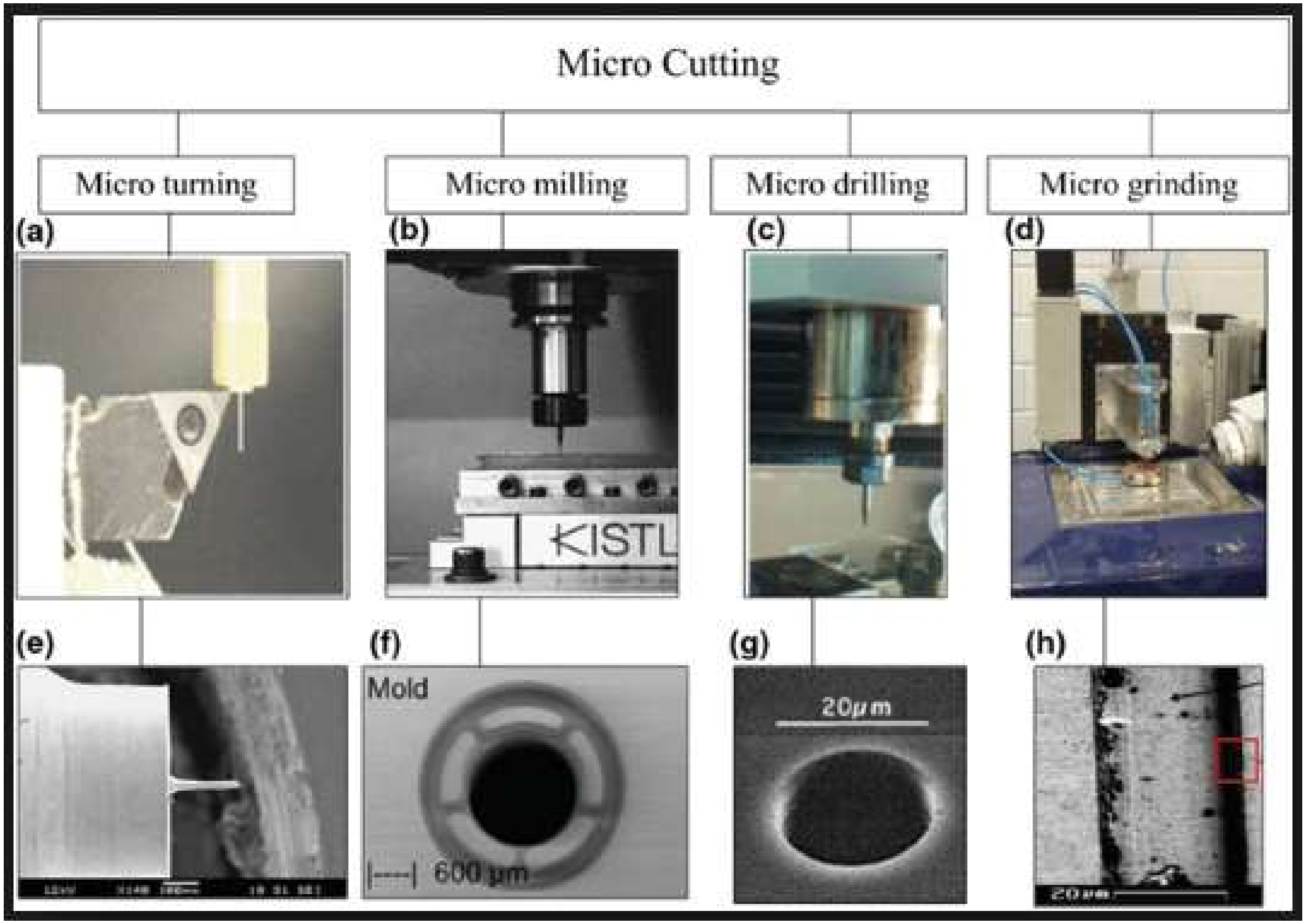
End of Module 1

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MODULE 2

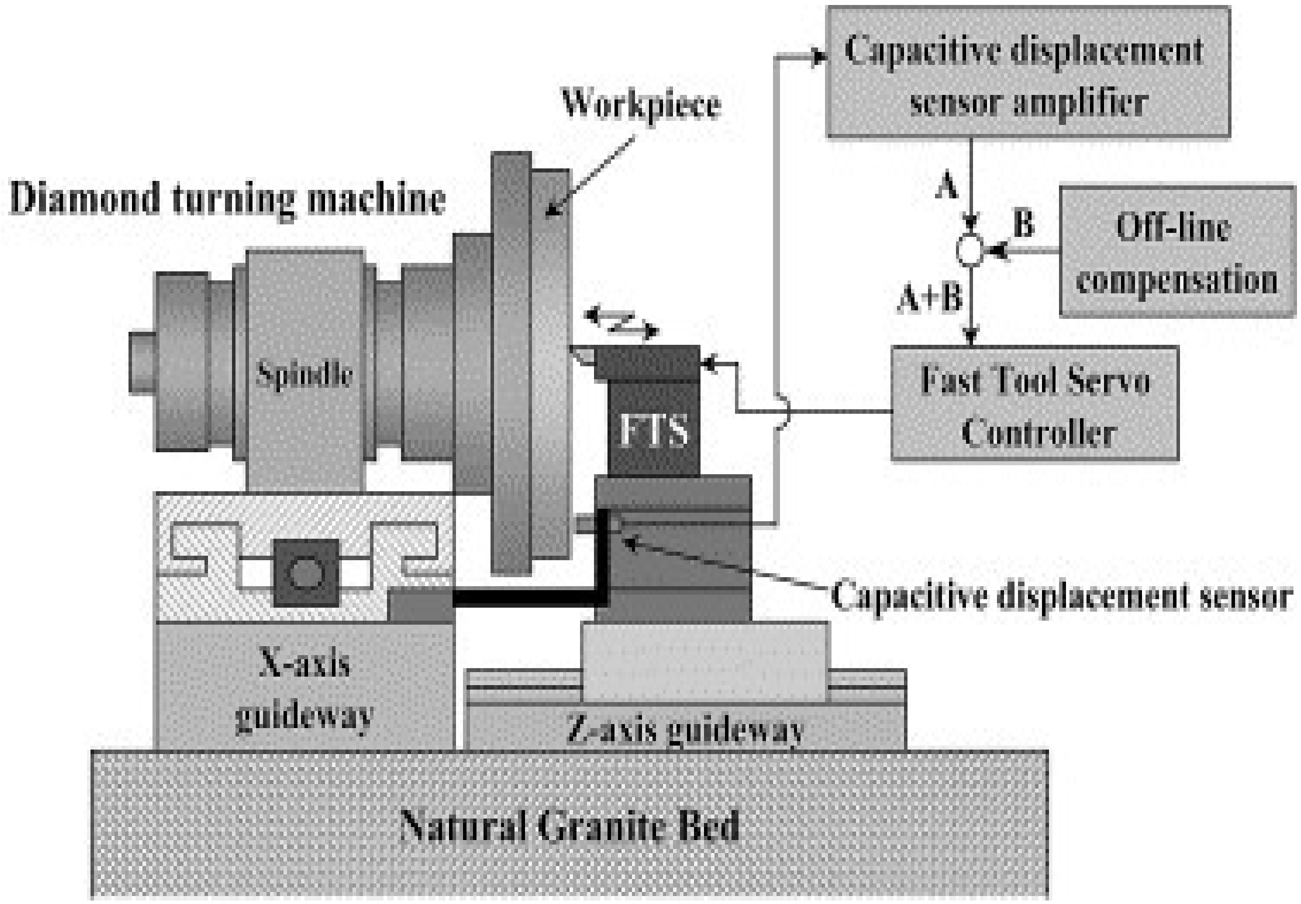
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro cutting - classifications



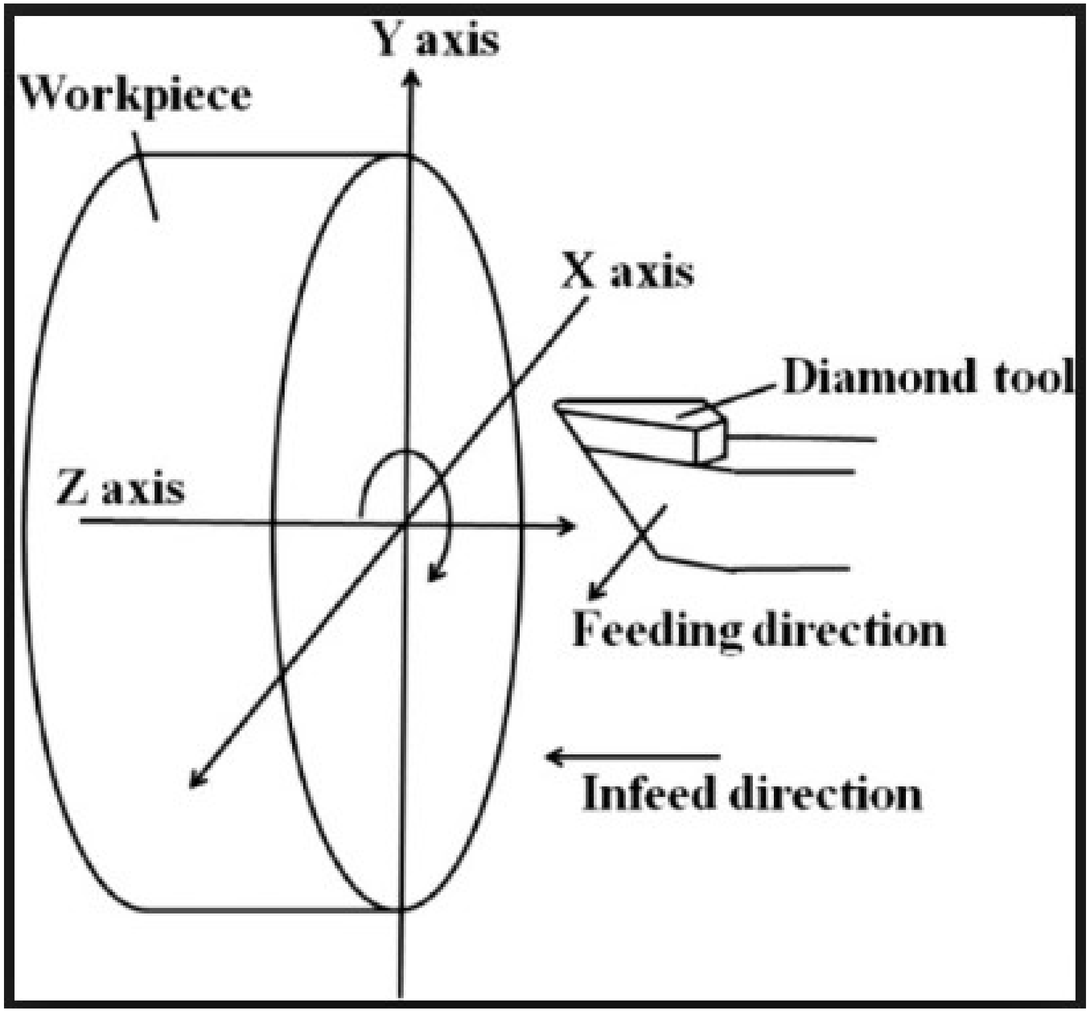
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MicroTurning
Diamond Turn Machining (DTM)



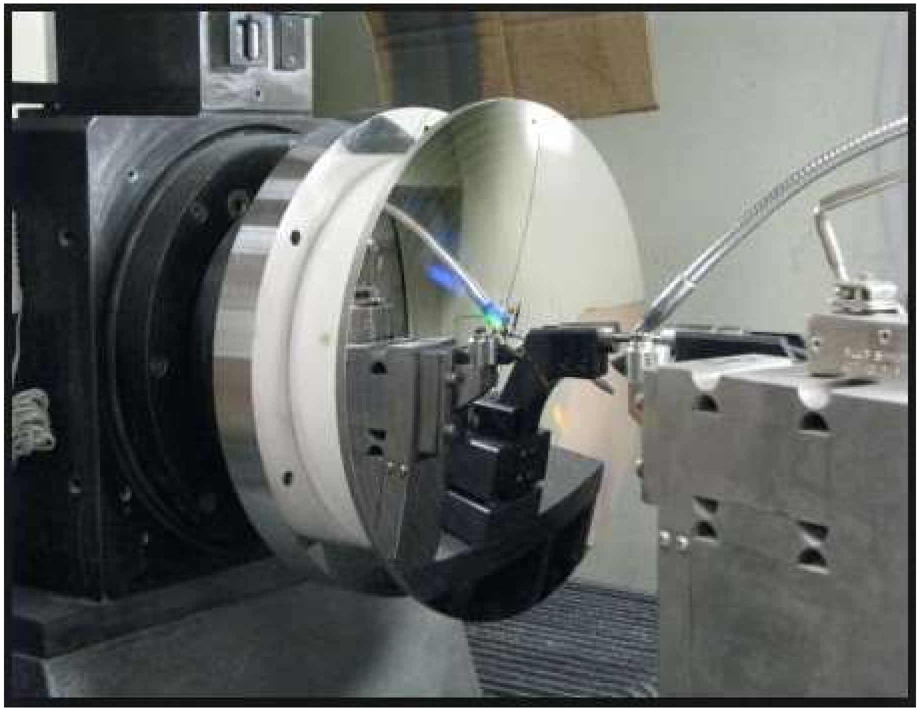
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Diamond Turn Machining (DTM)



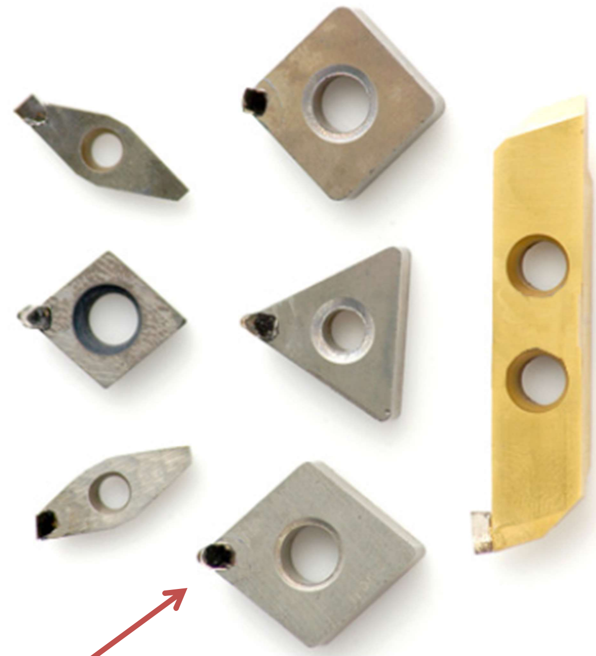
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

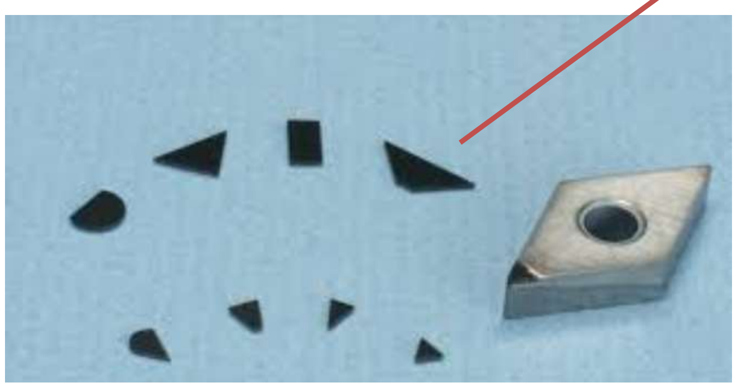
DTM Process



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

DTM Tools





Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Tool

- Diamond tipped tools (inserts) are used for DTM
- Tool should be clamped properly to tool shank
- Presence of air gap between tool and shank reduces rigidity of the machining process, so it should be eliminated.

Requirements of DTM tools

- ❖ Tools should retain sharpness over a long period of time.
- ❖ Tool should also have good

1. Strength
2. Hardness & hot hardness
3. Heat conduction
4. Wear resistance
5. Toughness
6. Elastic & shear modulus to withstand deformation

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Tool Measurement System

- The main function of tool measurement system is to set-up the tool with respect to machine co-ordinate system.
- Parameters to be considered for a tool measurement system are

1. X and Z offset values of the cutting tool
2. Tool nose radius
3. Position of the centre of the tool nose radius
4. Tool center height
5. Waviness of the cutting edge

Tool Measurement Systems

1. LVDT Type (Linear Variable Differential Transformer)
2. Optical Type (Machine Vision)

Material Removal Mechanism

Ductile Material

- Material in front of cutting tool is pushed ahead and the material slides on the shear plane.
- The shear plane offers least resistance to the flow of material which becomes a chip.
- Controlled material removal process which produces good surface finish.
- Point defects, grain boundary defects, voids facilitates easy material removal.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Material Removal Mechanism

Brittle Material

- ❖ Material is removed by crack propagation
- ❖ When the cutting load exceeds the critical value, radial and axial cracks beneath the surface are generated.
- ❖ The crack grows until it reach the surface and a chip of material is formed.
- ❖ Process is difficult to control and results in poor surface finish as the cracks extent below machined surface.

Ductile Machining vs. Brittle Machining

Ductile	Brittle
Well defined & straight edges	Jagged edges & chipped material
Controlled material removal process	Hard to control as microcracks extend below the machined surface
Final depth of cut can be predicted below the DBT depth	No direct control of the resultant depth beyond the DBT depth
Good surface finish and mechanical properties	Poor surface finish and could end in a catastrophic failure at times

Applications of DTM

1. Non spherical lenses & mirrors
2. Aluminium substrate for compact discs
3. Drums of photo copying machines
4. Moulds for lens manufacturing
5. Metal mirrors for laser applications
6. Aerospace and military applications.....

Applications of DTM

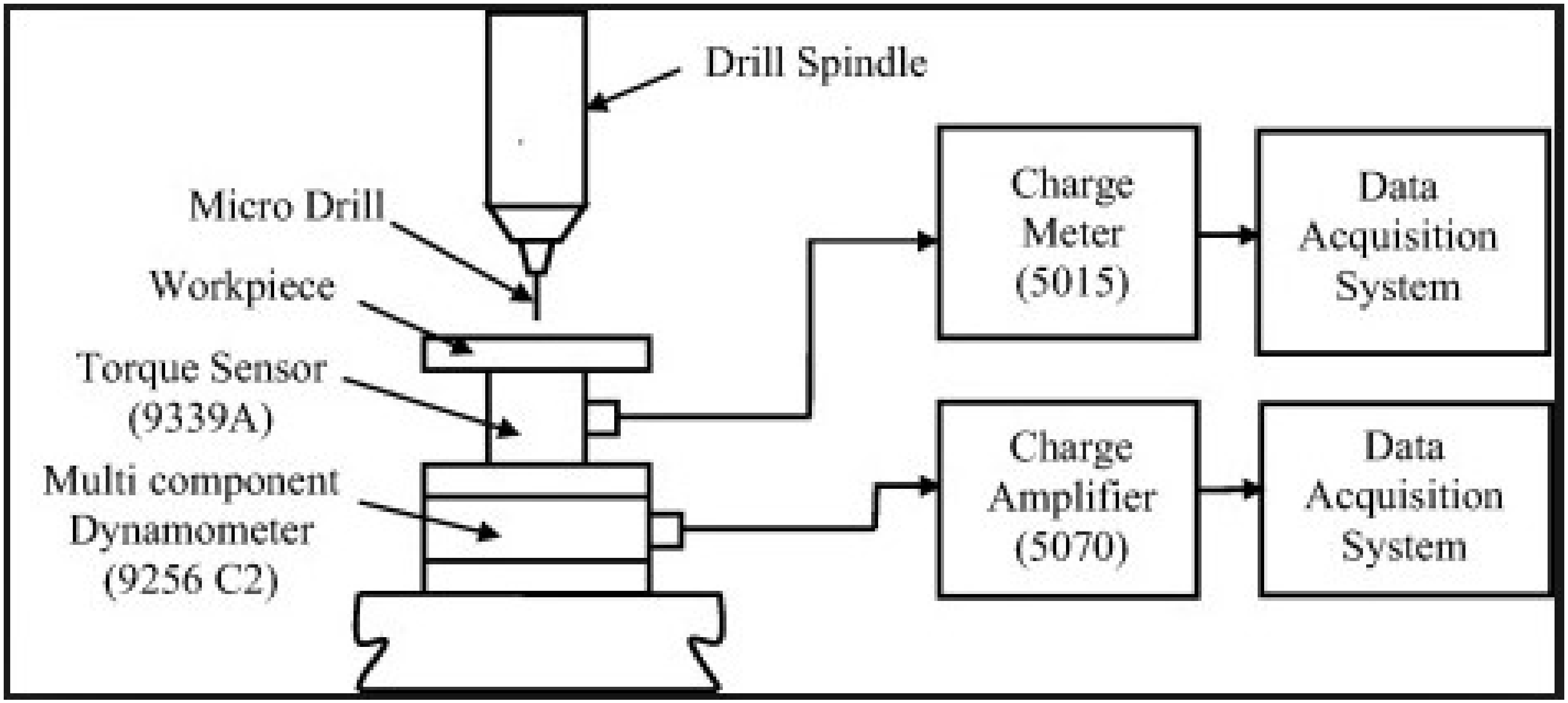
- **Characteristic Features and application**
  - Swiss-type machine tools, *ultra-precision* lathes for diamond turning and miniature desktop machines, are used to perform micro turning operations on parts made of different materials.
  - Maximum Machining Diameter – 7 mm
    Maximum Machining Length – 40 mm

  - Hard to machine surfaces such as electroless nickel, glass , ceramics, quartz etc. without any subsurface damage.
  - Mirror surfaces of less than 10 nm surface finish can be obtained.
  - Ultra-precision diamond turning – electroless nickel dies – plastic optical parts for LCD Tv's (less than 6 nm)

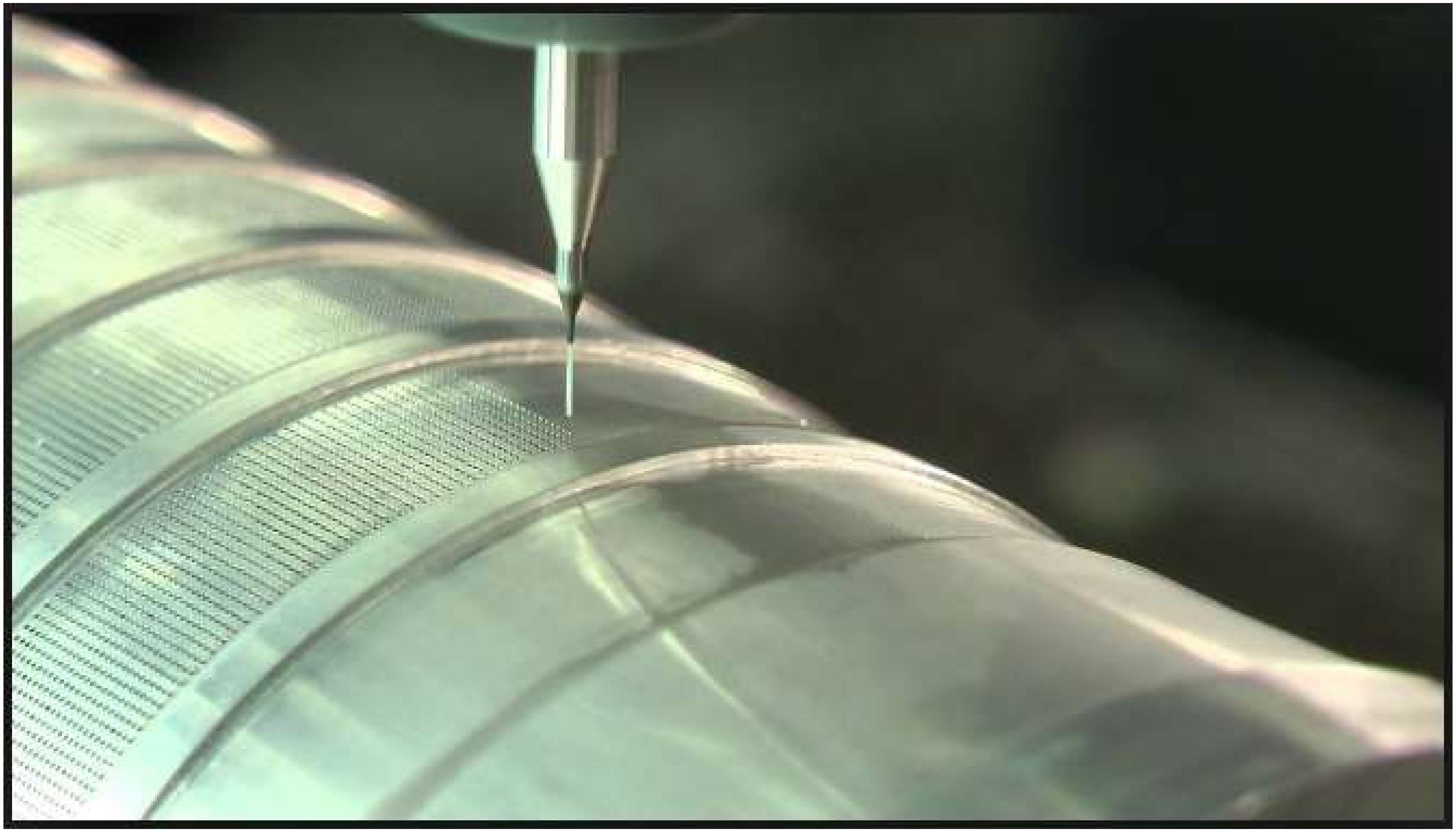
Micro drilling

- Micro - drilling is the process of generating holes of diameter less than 1 mm on a work piece.
- Removes metal with micro level accuracy and surface finish.
- Uses micro drilling tool with micron level accuracy.
- Entire process is CNC controlled.

Micro drilling



Micro drilling



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro drilling applications

- Graphite electrodes
- Optical & medical applications
- Electronic components
- Circuit board prototyping
- Aero space applications
- Electronic industry

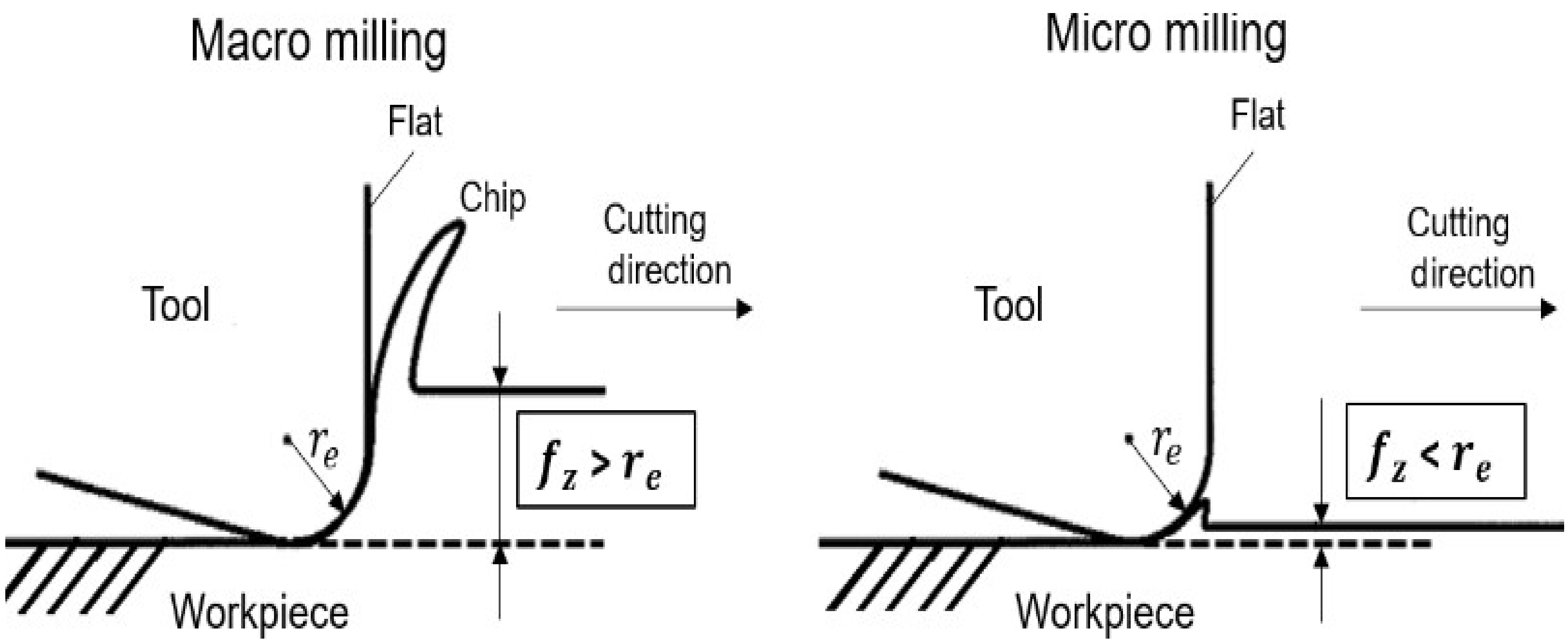
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro milling

- Similar to conventional milling process.
- Uses precise micro milling cutters.
- Removes metal with micro level accuracy and surface finish.
- CNC controlled.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Macro Vs Micro milling



Micro milling

ADVANTAGES:

- Wide range of materials, steel up to HRC 65, stainless steels, ceramics (green ceramic, pre-sintherized and sintherized ceramics), glass, plastic materials, woods, resins, copper (electrods), graphite,...

- Complex geometries, 5 axes micromilling.

- Automatic process by means of CNC programing.

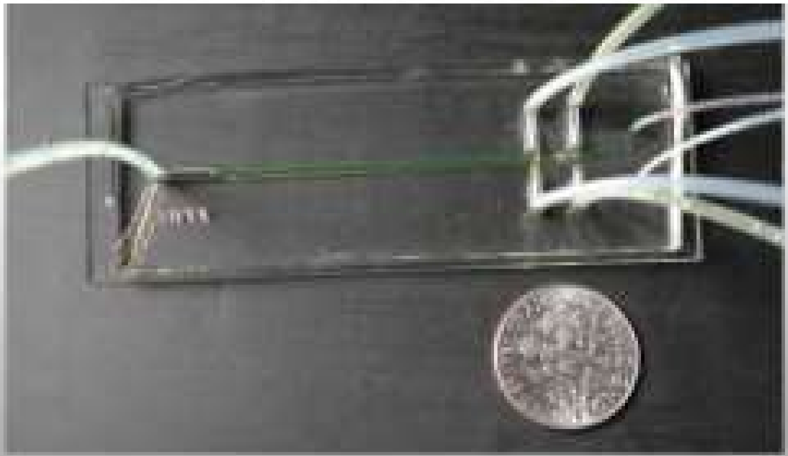
- Tolerance ±2 μm.

- Accurate control of machining process by means of a non-touching laser control of tools.

Micro milling applications

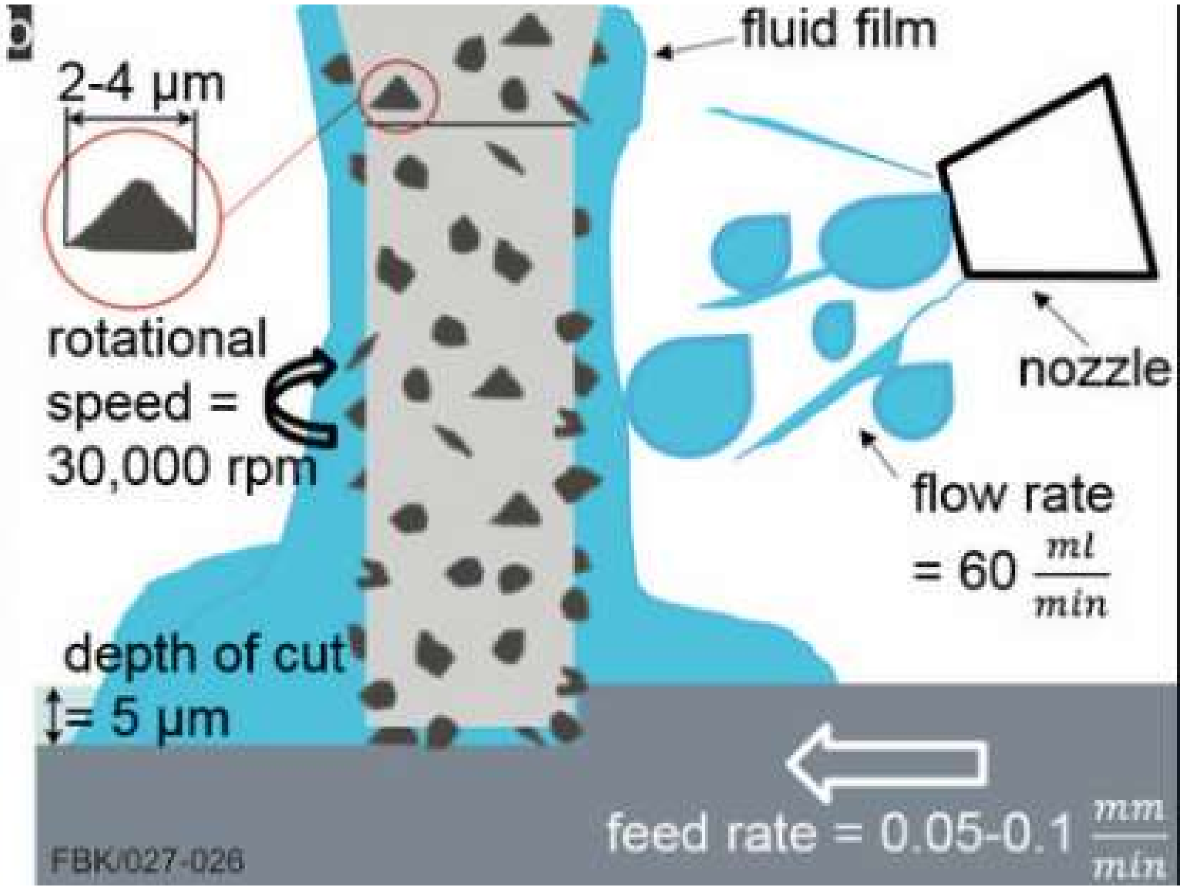
Potential Microfluidics Applications:

- Micromilling can be used to fabricate stamping dies or directly fabricate micro channels
- Geometries useful for microfluidic devices
  - Shaped walls
  - In-channel features for fluid mixing
  - Transitions between channel elevations



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro grinding



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro grinding

- Removes metal with micro level accuracy and surface finish.
- Uses micro drilling tool with ultra fine abrasive particles.
- Entire process is CNC controlled.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro grinding applications

- Electronic industry
- Aerospace applications
- For finishing micro holes and orifices
- Medical applications

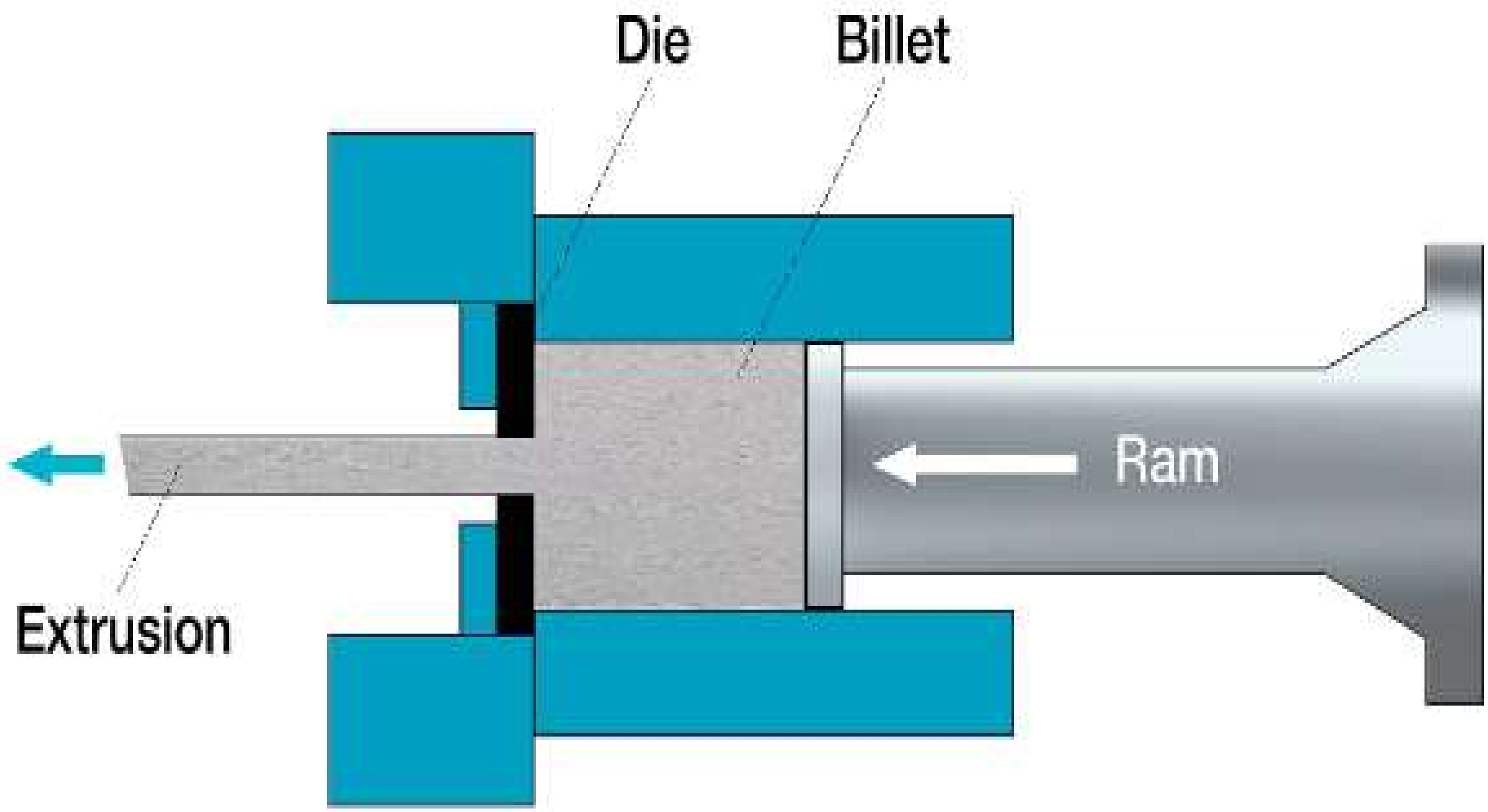
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Extrusion & micro extrusion

- **Extrusion** is a process used to create objects of a fixed cross-sectional profile. The material is pushed through a die of the desired cross-section. The extrusion process can be done with the material in hot or cold state.

- **Micro extrusion** is a micro forming extrusion process performed at the sub millimeter range. Like extrusion, material is pushed through a die orifice, but the resulting product's cross section can fit through a 1mm square.

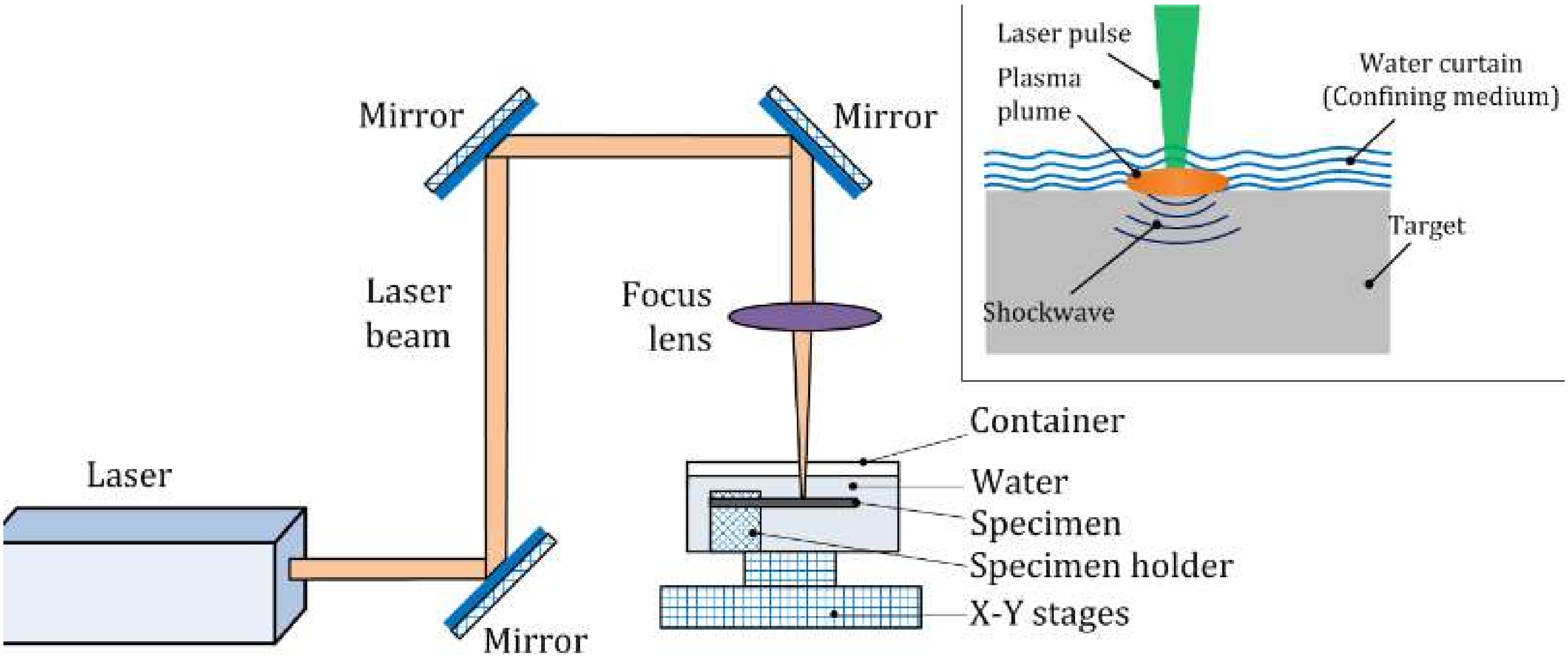
Extrusion



Applications of micro extrusion

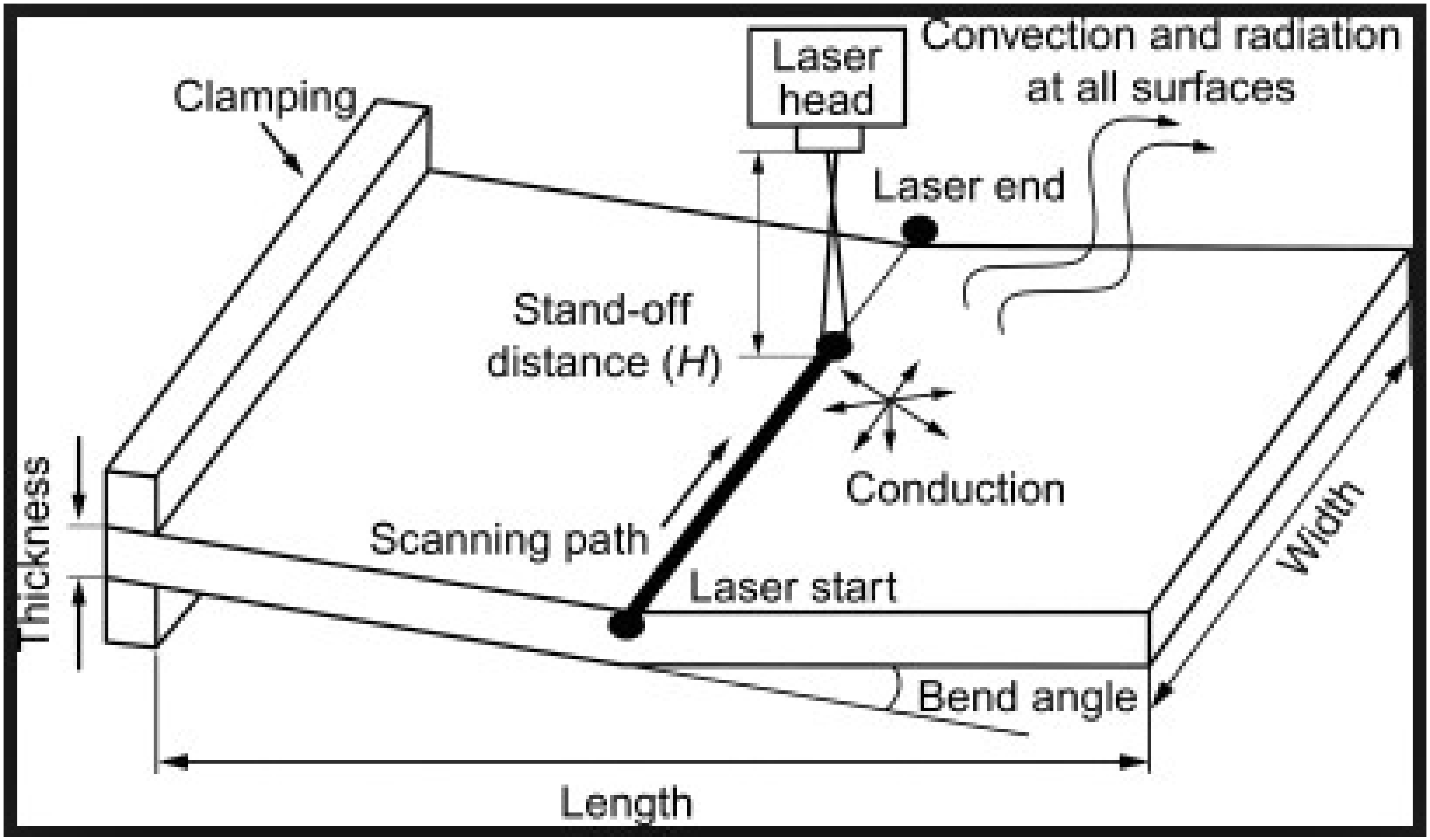
- For making thin wires and cables for endoscopy equipment in medical application
- For making thin wires for electronic applications
- For making components in precise aerospace applications.

Micro bending with laser



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro bending with laser

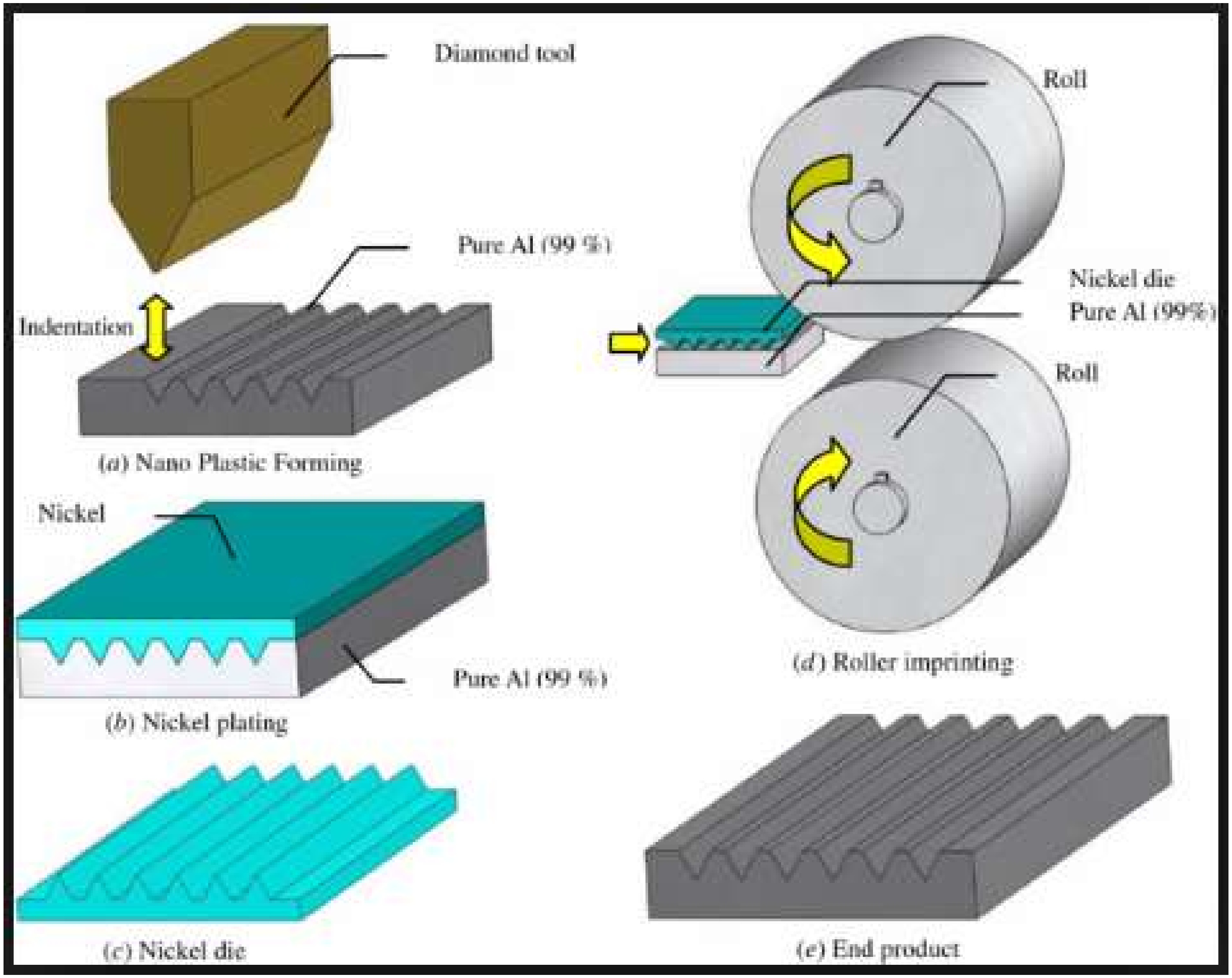


Micro bending with laser

APPLICATIONS

- Non contact bending
- Bend is stronger that the parent sheet
- Bending of pipes and extrusions
- A forming tool for astronauts
- Adjustment of sealed electric contacts
- Straightening of rods

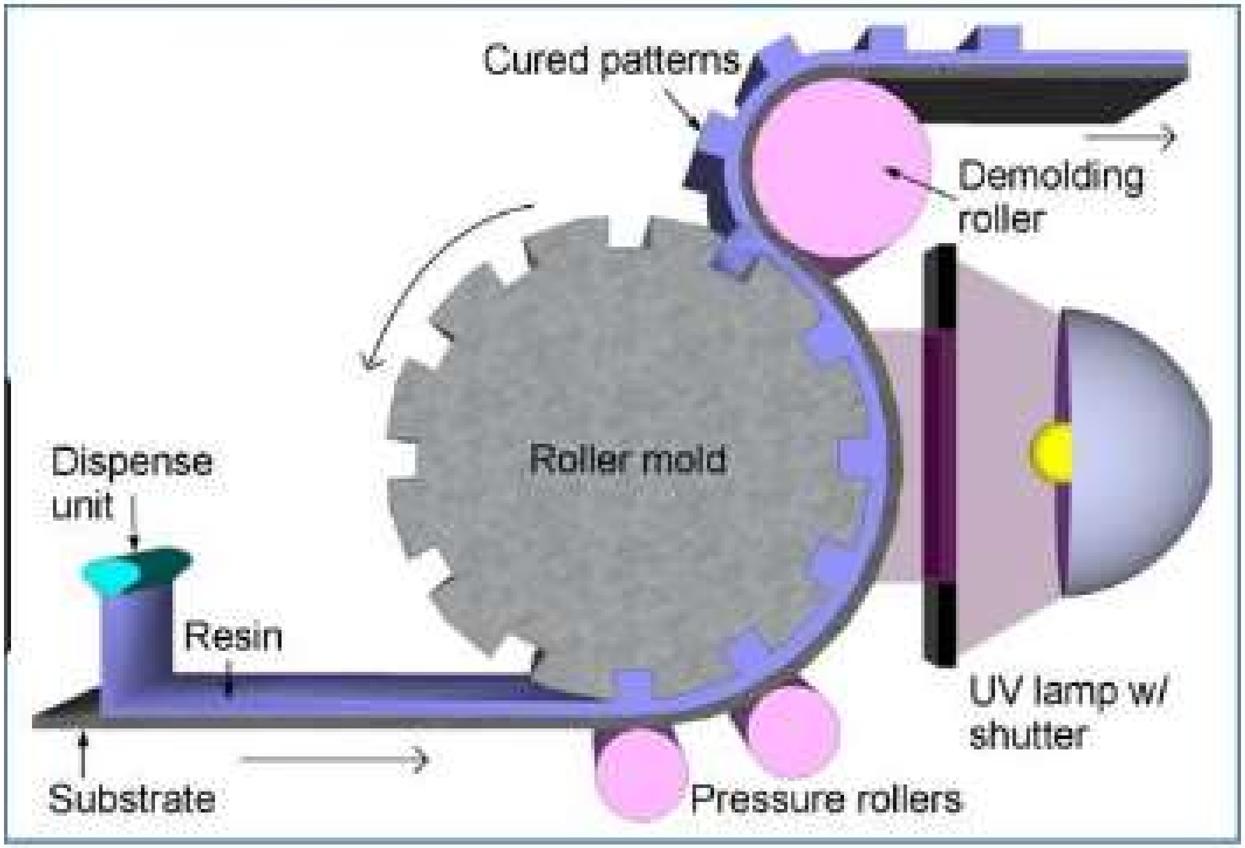
Nano plastic forming



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

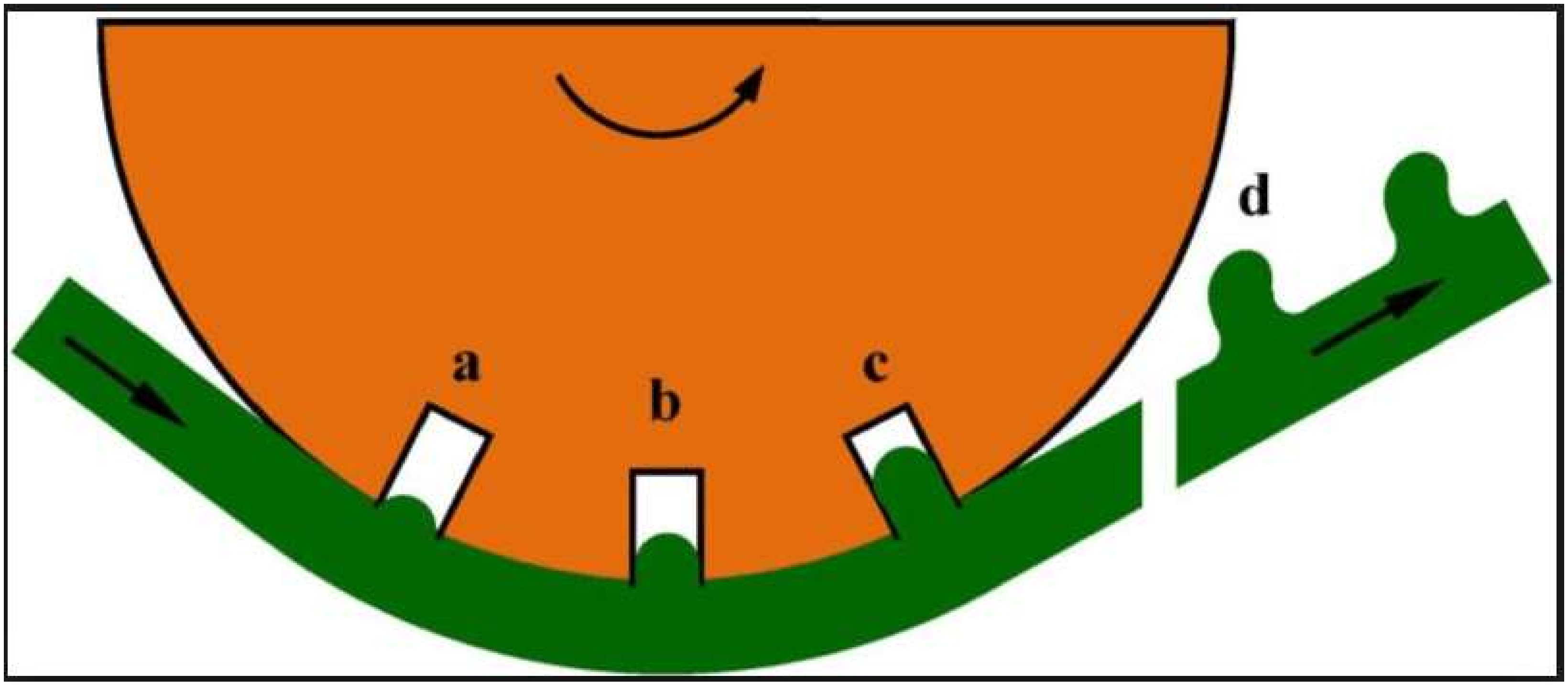
Roller imprinting - 1

Roll to roll



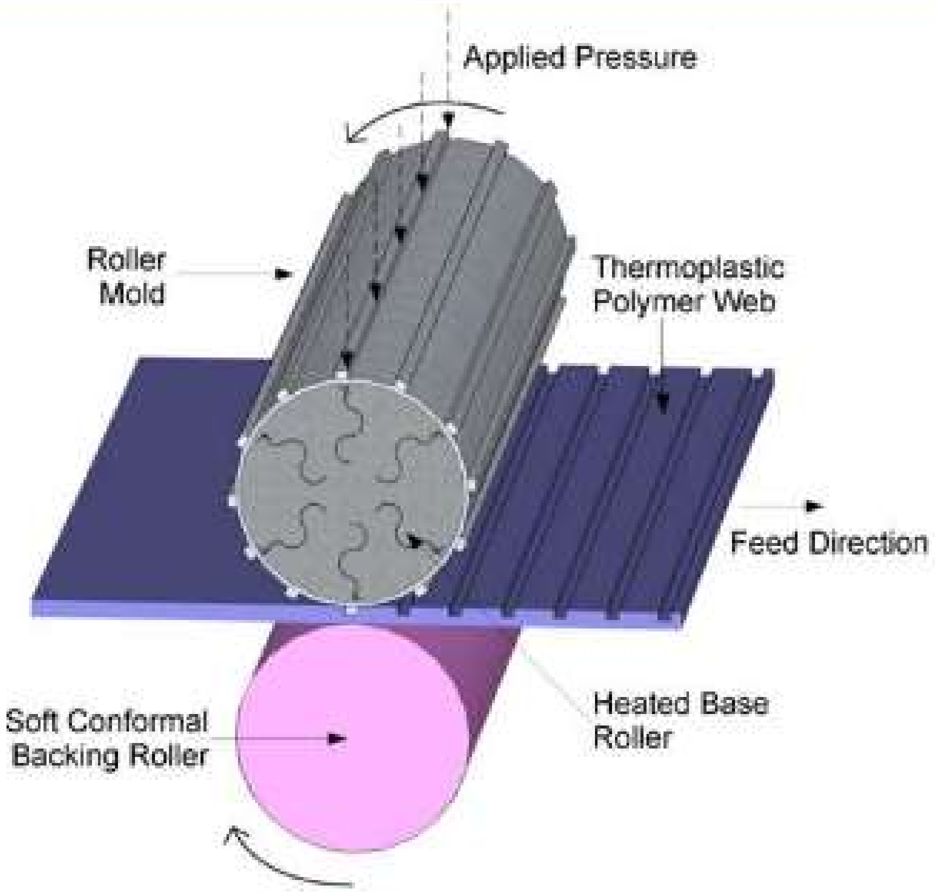
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Roller imprinting



Roller imprinting - 2

Roll to plate



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

End of Module 2

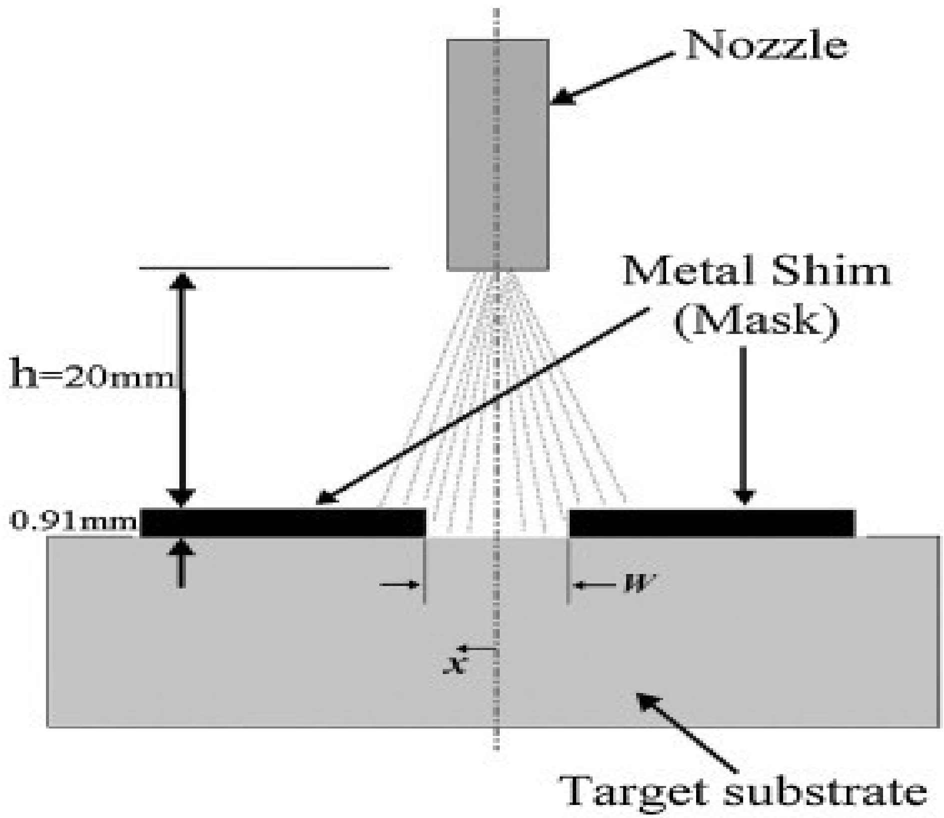
MODULE 3

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Need for Advanced Machining Processes

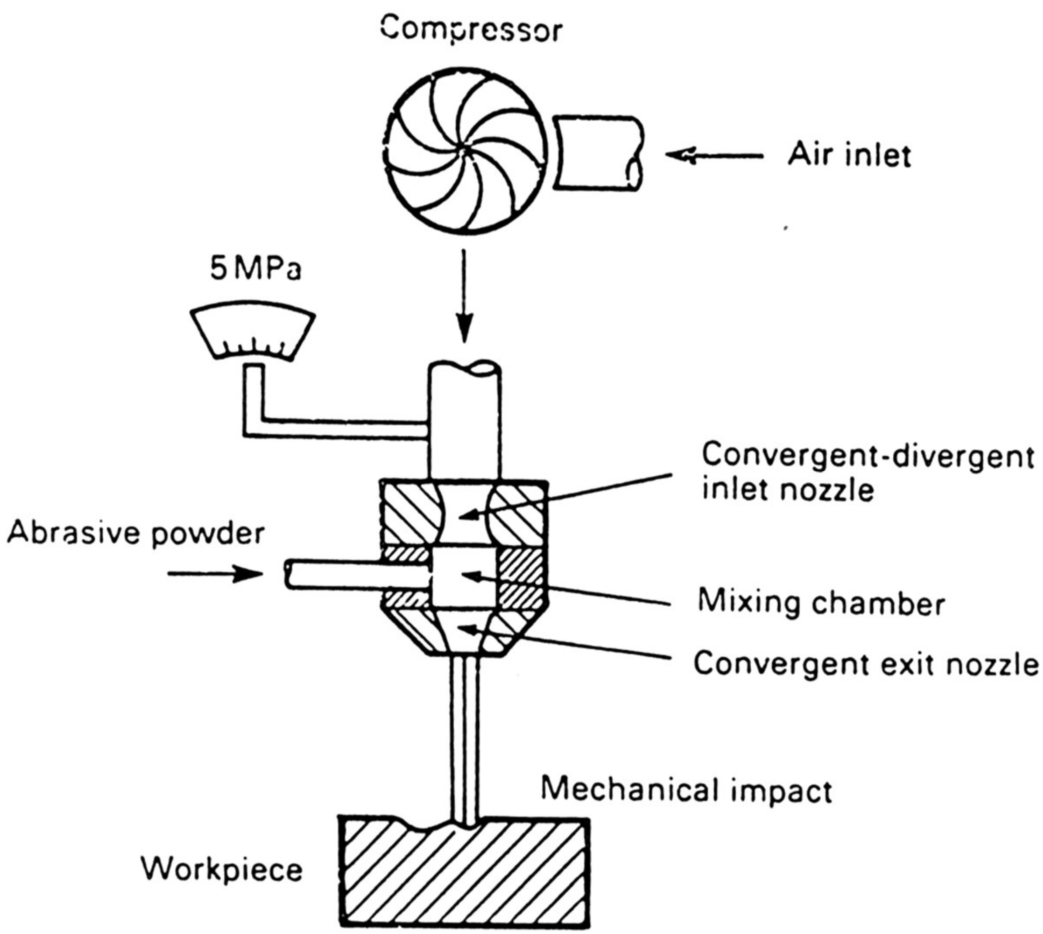
- Traditional machining processes
  - Material removal by mechanical means, such as chip forming, abrasion, or micro-chipping
- Advanced machining processes
  - Utilize chemical, electrical, and high-energy beams
- The following cannot be done by traditional processes:
  - Workpiece **strength and hardness** very high, >400HB
  - Workpiece material too **brittle**, glass, ceramics, heat-treated alloys
  - Workpiece too **slender and flexible**, hard to clamp
  - Part shape **complex**, long and small hole
  - Special **surface and dimensional tolerance** requirements

Abrasive Jet Micro Machining (AJMM)



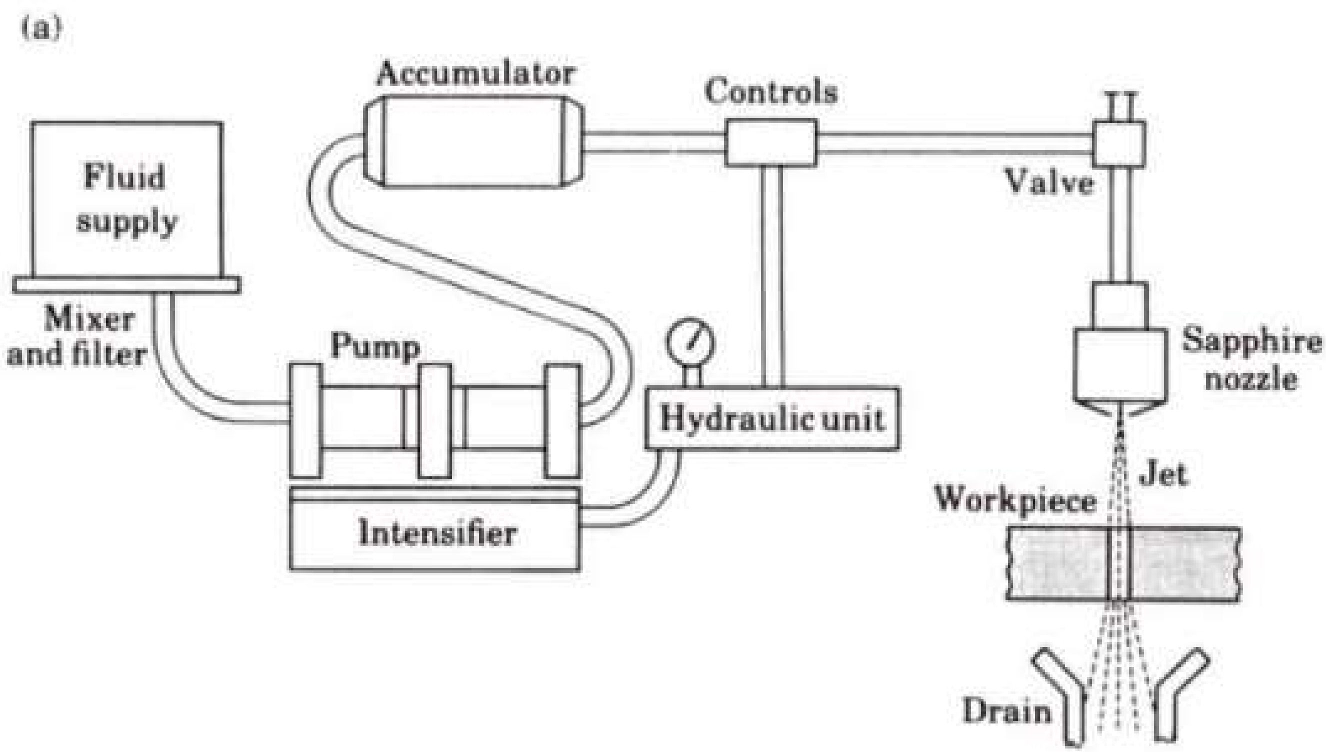
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Abrasive Jet Micro Machining (Dry type)



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Water Abrasive Jet Micro Machining (WAJMM)
(Wet type)



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

AJMM

- Removal of material is by the application of a high-speed stream of abrasive particles carried in a high pressure – high velocity fluid medium from nozzle.
- It differs from conventional sand blasting as much finer (60 μm) abrasive is used and cutting parameters are carefully controlled.
- Typical values:

Pressure of air jet	: 2 - 8 MPa
Orifice diameter of nozzle	: 0.15 – 2 mm
Stand off distance	: 2 – 15 mm
Mass flow rate	: 4 – 15 g/min

AJMM

- ❖ Influencing elements/ factors/ parameters
- ➢ 1.Nozzle – geometry, stand off distance.
- ➢ 2.Abrasives – Composition, Strength, size, shape and flow rate.
- ➢ 3.Carrier medium – Composition, pressure, velocity

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Elements of AJMM

- 1.Nozzle
- Abrasive particles are directed into the work surface at high velocity.
- Material of nozzle should be very hard and should have high resistance to wear.
- Eg. Tungsten carbide, sapphire.
- Nozzle can have either circular or rectangular shape.
- 2.Abrasives –
- Aluminium oxide (Al_2O_3) is used for majority of applications.
- Silicon carbide (SiC), Sodium bicarbonate, dolomite etc are also used.
- Abrasives cannot be re-used.
- 3.Carrier medium
- Eg. Water, mineral oil etc…

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Applications of AJMM

- Machining of brittle and heat sensitive materials like glass, quarts, sapphire etc.
- Drilling holes, cutting slots, cleaning hard surface, deburring, scribing, grooving, polishing etc.

Masking Technology in AJMM

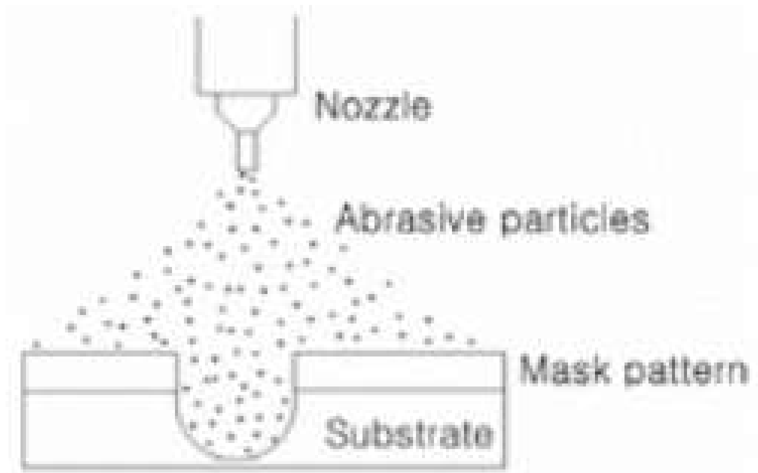
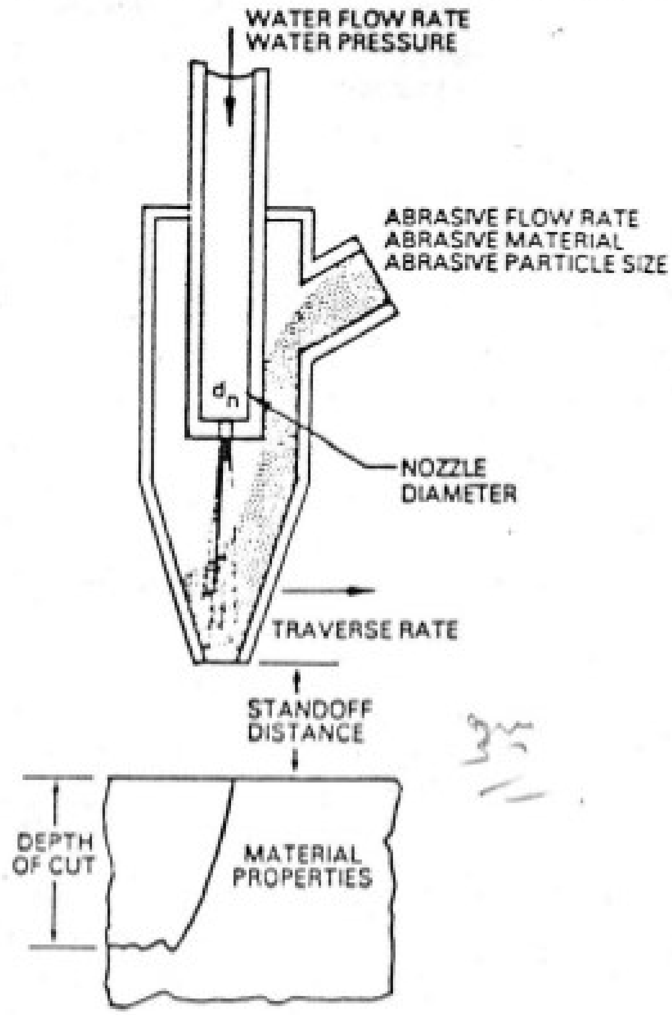


Fig. 1. The principle of micro-AJM with mask pattern.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters



AJMM – Process Parameters and their effects

1. **Air flow rate** – As flow increases, MRR increases.
2. **Air pressure** – As pressure increases, MRR increases
3. **Abrasive flow rate** – As flow rate increases, MRR increases
4. **Abrasive material** – As hardness increases, MRR also increases.
5. **Abrasive particle size** – As size increases, MRR increases but surface finish decreases.
6. **Nozzle diameter** – Determines the particle velocity.
7. **Traverse speed** – As speed increases, depth of cut reduces, surface finish increases.
8. **Stand off distance** – As distance increases, MRR reduces.
9. **Material property** – As hardness of work piece increases, MRR reduces.
10. **Depth of cut** – As depth of cut increases, surface finish reduces.

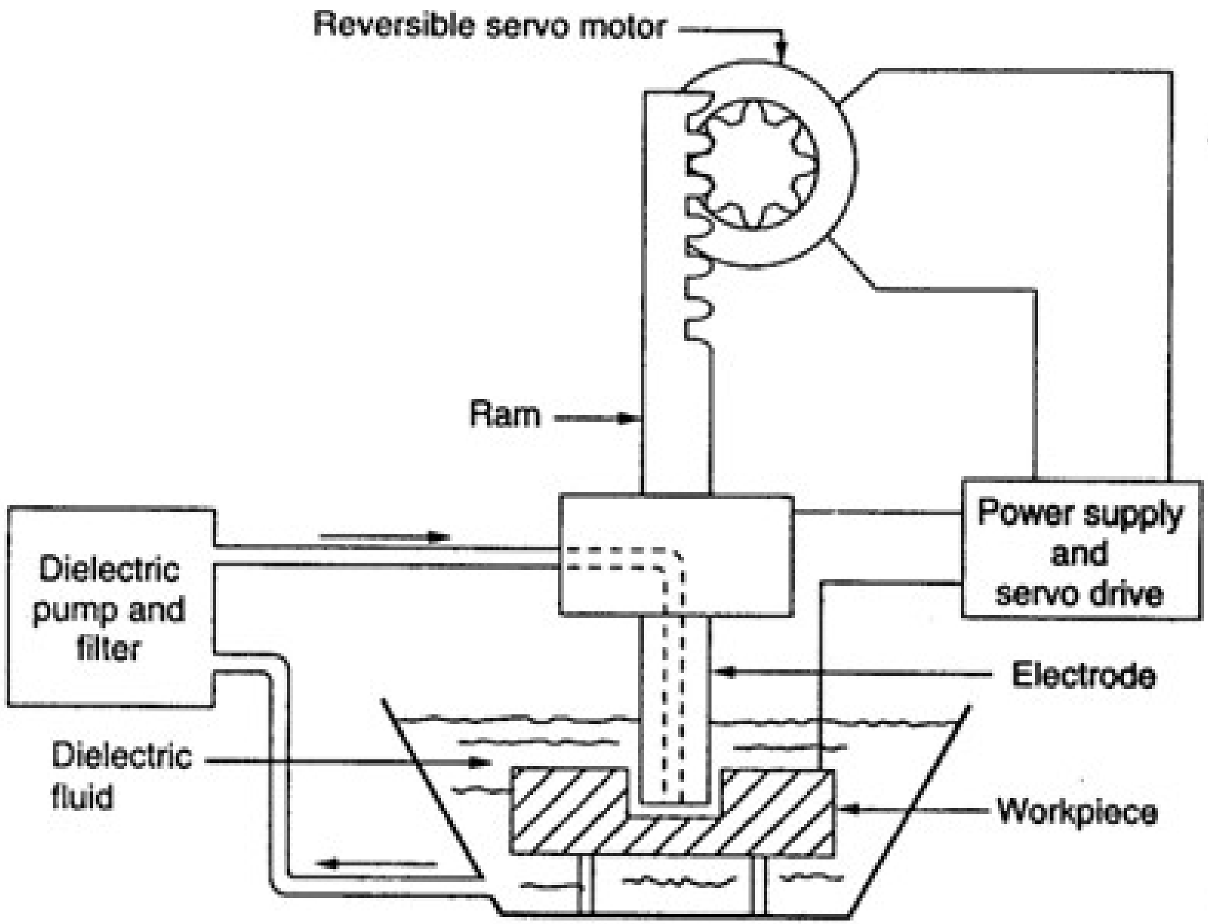
Advantages & Disadvantages of AJMM

- **Advantages:**
  - Ability to cut complex hole shapes in materials of any hardness and brittleness.
  - Ability to cut fragile and heat sensitive materials without damage.
  - Low capital cost.
- **Disadvantages:**
  - MRR is slow and hence its applications are limited.
  - Accuracy is less as stray cutting can occur.
  - Embedding of the abrasive in the work piece may occur while machining soft materials.

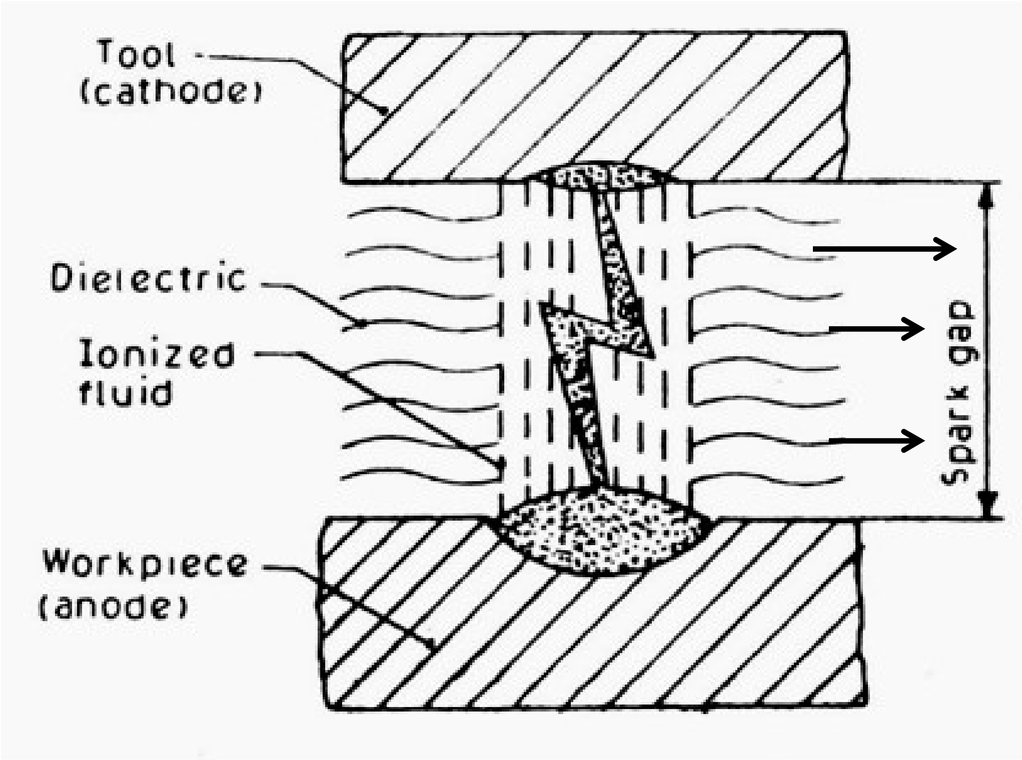
MICRO ELECTRIC DISCHARGE MACHINING (MEDM)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro Electric Discharge Machining (MEDM) - Setup



MEDM – Spark generation



EDM – Working principle

- Electrical Discharge Machining (**EDM**) is a controlled process that is used to remove metal with the help of an intensified electric spark.
- Spark is generated when the tool and work piece with high potential difference is separated by a spark gap.
- In this process an electric spark is used as the cutting tool to cut (erode) the work piece to produce the finished part to the desired shape.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Dielectric fluid

- Dielectric fluids should have

1. Adequate viscosity
2. High flash point
3. High corrosion resistance
4. Good electrical discharge efficiency
5. Low cost and ease of availability

Eg: Hydro carbon oil, Kerosene, Tri ethylene glycol…

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Recast layer

- The sparks produced during the EDM process melt the metal's surface, which then undergo ultra rapid quenching.
- The layer formed on the work piece surface after solidification is called recast layer

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Pulse Characteristics

- Energy of a pulse:

$$\mathbf{E = VIT}$$

Where, V = Voltage, I = Current, T = Time.

- Energy of pulse with ON/OFF times:

$$\mathbf{E = V_p I_p ((t_{on}/(t_{on} + t_{off}))}$$

Where, V_p & I_p are Voltage and Current of a single pulse, t_{on} = Pulse ON time, t_{off} = Pulse OFF time.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Material Removal Rate (MRR)

$$MRR = \boldsymbol{\alpha} \, \mathbf{V_p I_p} \, \mathbf{((t_{on}/(t_{on} + t_{off}))}$$

- Where, α = Material removal constant of the work piece.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters of EDM

- Electrode/ Work piece based parameters

1. Diameter of electrode

- (As diameter of tool increases, peak temperature attained reduces)

2. Material Hardness

- (As work piece material hardness increases, MRR reduces)

3. Melting point

- (As melting point of specimen increases, MRR reduces)

4. Thermal diffusivity

- (As thermal diffusivity of work piece increases, heat energy utilized for ablation reduces which reduces MRR)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters of EDM

- Dielectric fluid & flushing based parameters:

1. Specific resistance of the fluid
2. Pressure of fluid
3. Contamination
4. Flow rate
5. Supply method
   i) Internal type (Recommended)
   ii) External type

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters of EDM

- Processing / Machining Parameters:

1. Voltage applied
2. Polarity
3. T_{on} & T_{off}
4. Spark gap
5. Electrode rotation

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Influence of process parameters

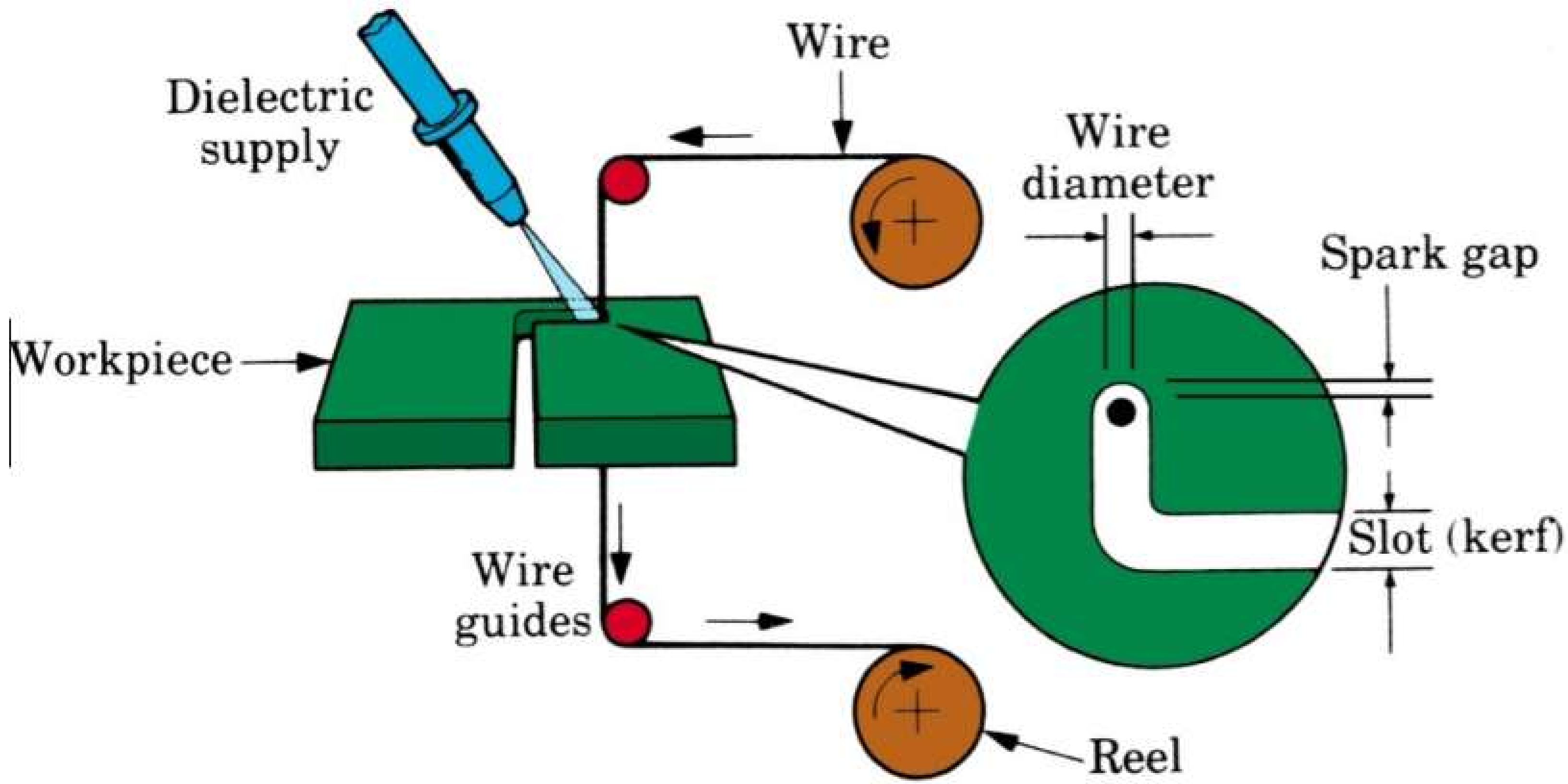
- Negative polarity to work piece increases accuracy & reduces hole over size (HOS)
- HOS increases with increase in voltage.
- Electrode rotation (Max. speed 50 rpm) improves debris removal & accuracy.
- Horizontal spindle configuration improves debris removal.
- Planetary motion of the electrode improves accuracy as it provides extra space for the removal of air bubbles & debris.
- The maximum machined depth is attained when the gap control speed is 0.01 - 0.02 mm/sec.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Heat Affected Zone (HAZ) in EDM

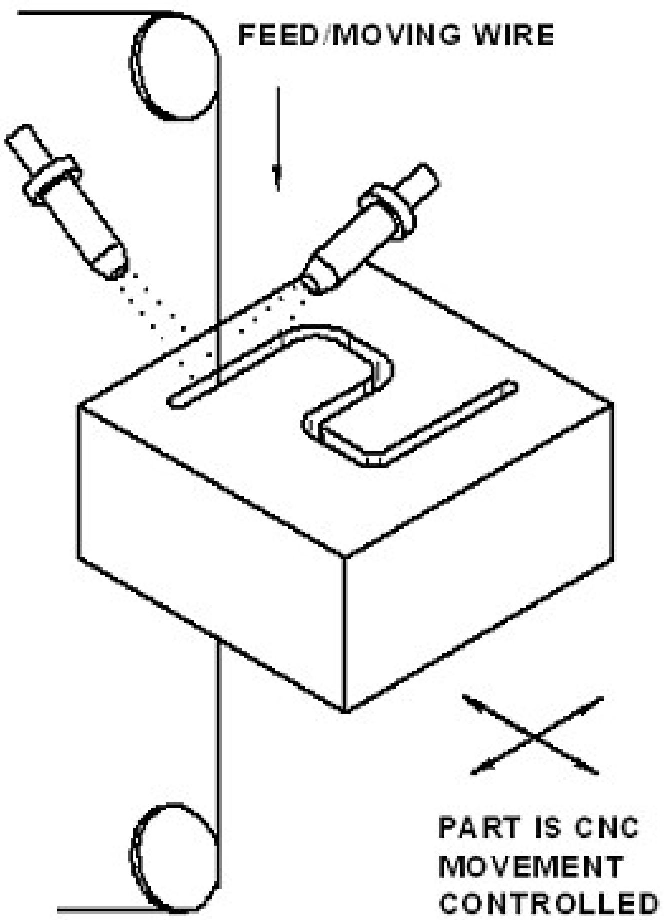
- Compared to other non conventional process, EDM produces less damage & HAZ.
- The HAZ of EDM comprises of region of low hardness.
- Grain size & structure of material around the machined spot hardly changes.

Wire EDM



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Wire EDM



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

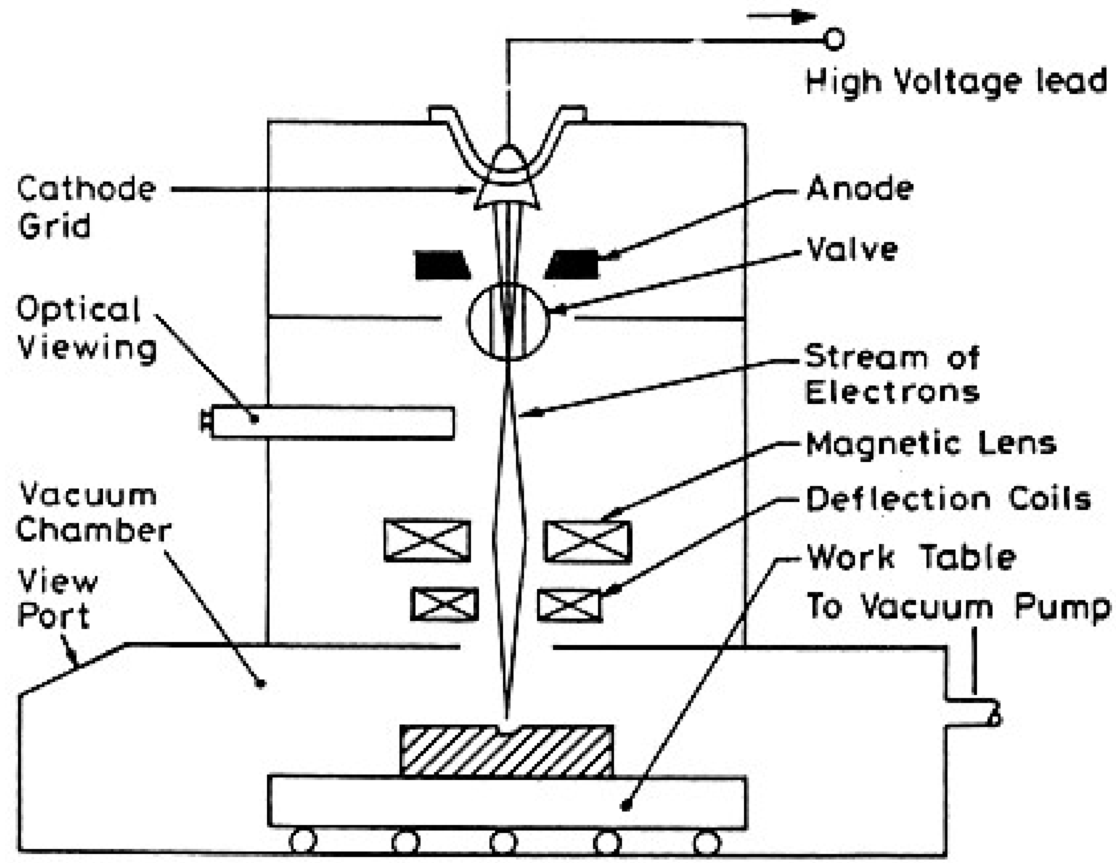
Applications of EDM

- EDM is used **for making die** for wire drawing, extrusion, heading, forging etc. from **hardened steel** and **stamping tool** with intricate cavities.
- In machining of **exotic materials** that are used in aerospace and automatic industries.
- For making **fragile parts** which cannot take the stress of machining.
- **Deep cavities**, **slots** and **ribs** can be easily made by EDM for collets, jet engine blade slots,
- Micro-EDM process can successfully produce **micro-pins, micro-nozzles and micro-cavities**.

Micro Electron Beam Machining (MEBM)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro Electron Beam Machining (MEBM)



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

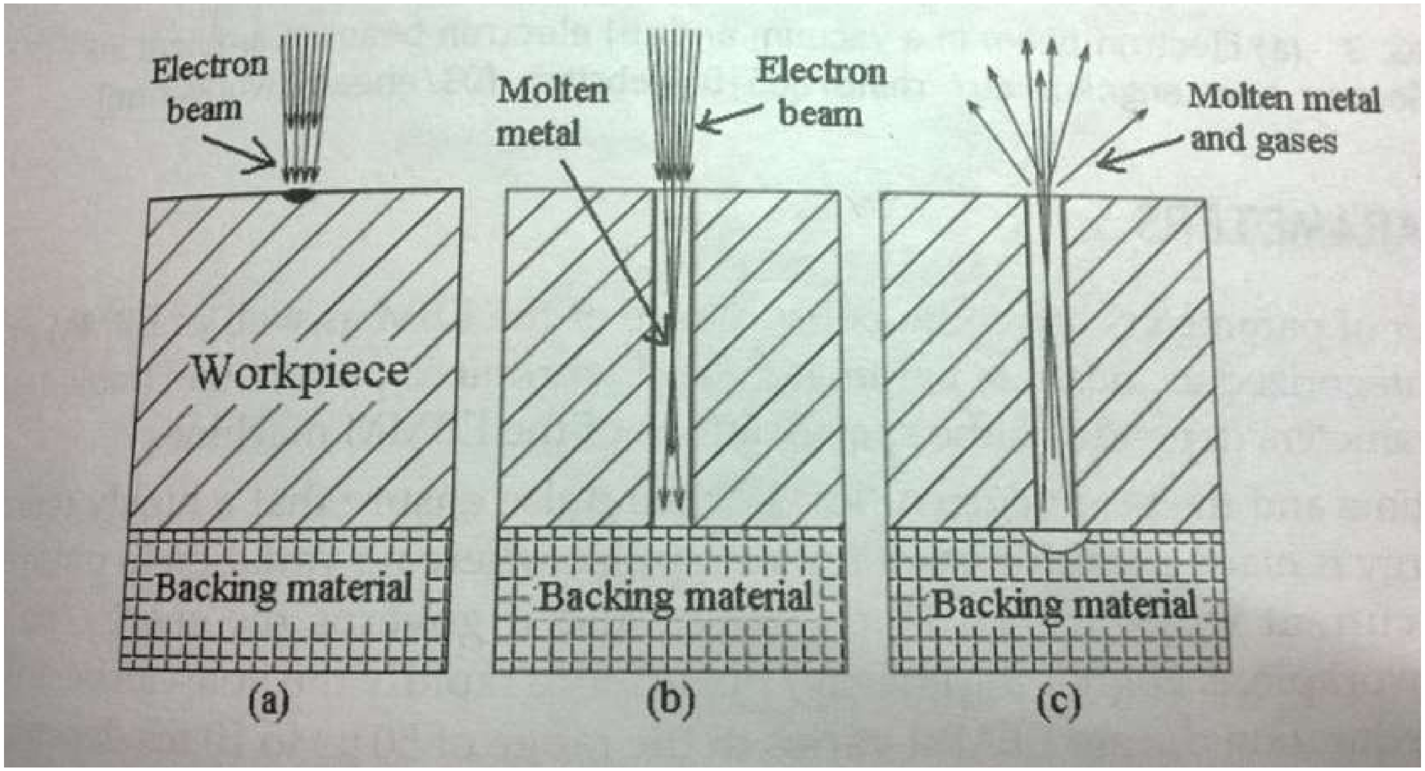
MEBM

- Electrons are accelerated due to the potential difference between anode and cathode.
- The concave shape of the cathode is intended for concentrating the electron stream through the anode.
- Applied voltage: 50,000 – 200,000 Volts.
- Velocity of electrons: Above 200,000 km/s.
- The valve is used for controlling the beam & duration of machining process.
- An electromagnetic lens is used for reducing the diameter of beam to as small as 25 μm.
- The deflection coils are used to control the electron beam movement.

Material Removal Mechanism in MEBM

- In EB drilling, energy is created & precisely focused on the work piece to bring about highly localized melting.
- On impinging the surface, the kinetic energy of the electrons is converted into thermal energy of high density, which melts and vaporizes the material in a local area.

Material Removal Mechanism in MEBM



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Material Removal Mechanism in MEBM

- As the depth of cut increases, the beam gets in the way of the molten metal, preventing it from escaping out of the hole.
- To expel the molten material, a backing material is applied to the reverse side of the work piece material being drilled.
- When the electron beam breaks through the work piece material, the backing material reacts to the beam by producing large volume of gas that expands explosively, which removes the molten metal.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Importance of vacuum in MEBM

- The air molecules can adversely interact with the beam of electrons.
- The collision between the electrons and air molecules causes the electrons to veer/change its direction.
- These deviated electrons will hit the un indented areas on the work piece, which will affect the accuracy of the work.
- Atmospheric oxygen will readily react with molten metal to form metal oxides. To avoid formation of oxides, vacuum is important during EBMM.

Importance of vacuum in MEBM

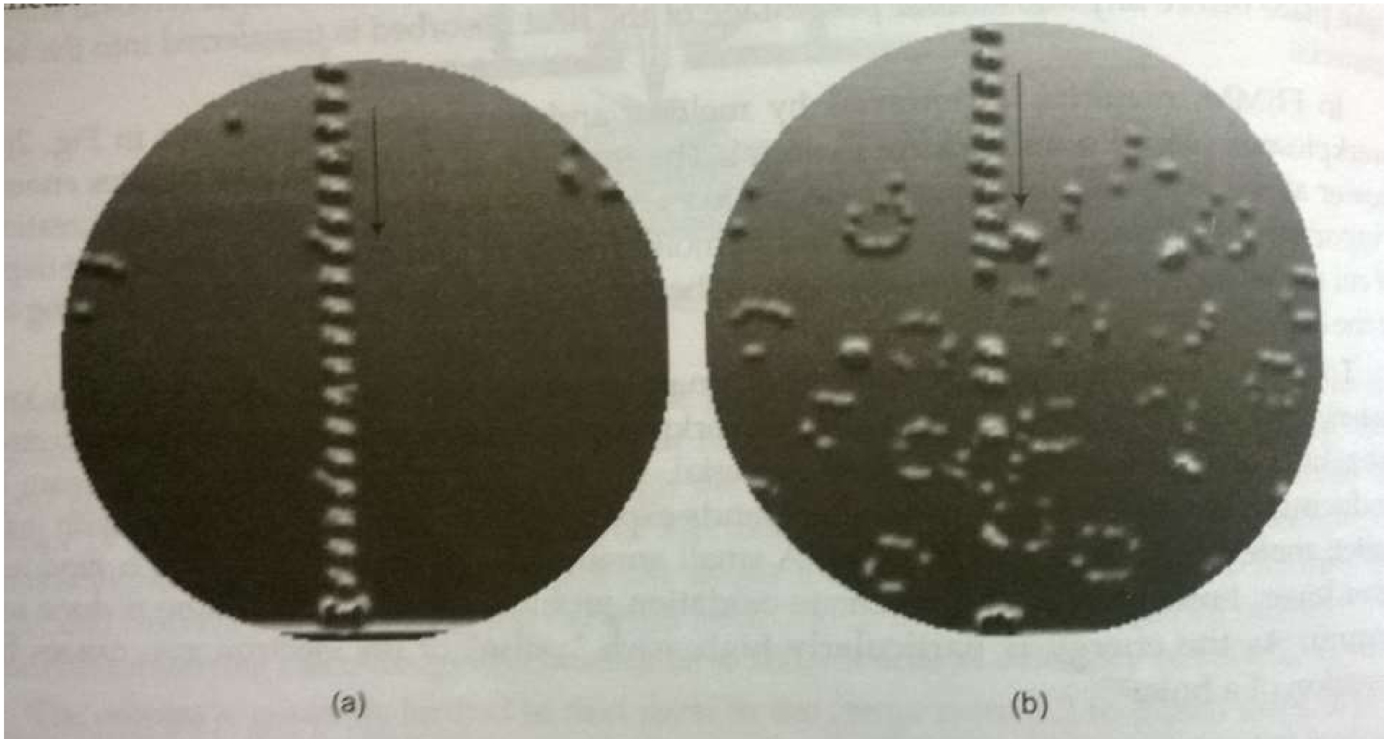


FIG. 3 (a) Electron-beam in a vacuum and (b) electron beam in ambient air

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process parameters

1. Machine based parameters
2. Work piece parameters

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Machine based parameters

1. Pulse duration
2. Beam current
3. Working distance
4. Roundness of beam
5. Consistency of beam diameter
6. Symmetry of focusing lens
7. Vacuum system
8. Movement of work piece.

Work piece parameters

1. Melting temperature
2. Vaporization temperature
3. Thermal conductivity
4. Thermal diffusivity

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Heat Affected Zone (HAZ)

- The dimensions of the heat affected zone depends on

1. Energy of incident electrons,
2. Beam current,
3. Diameter of the focused spot,
4. Work piece properties,
5. Pulse duration.

Effect of cutting speed on HAZ

- To minimize thermal diffusion problem, the beam should be rapidly scanned across the surface to be machined.
- As cutting speed increases, problems due to thermal diffusion & HAZ reduces.

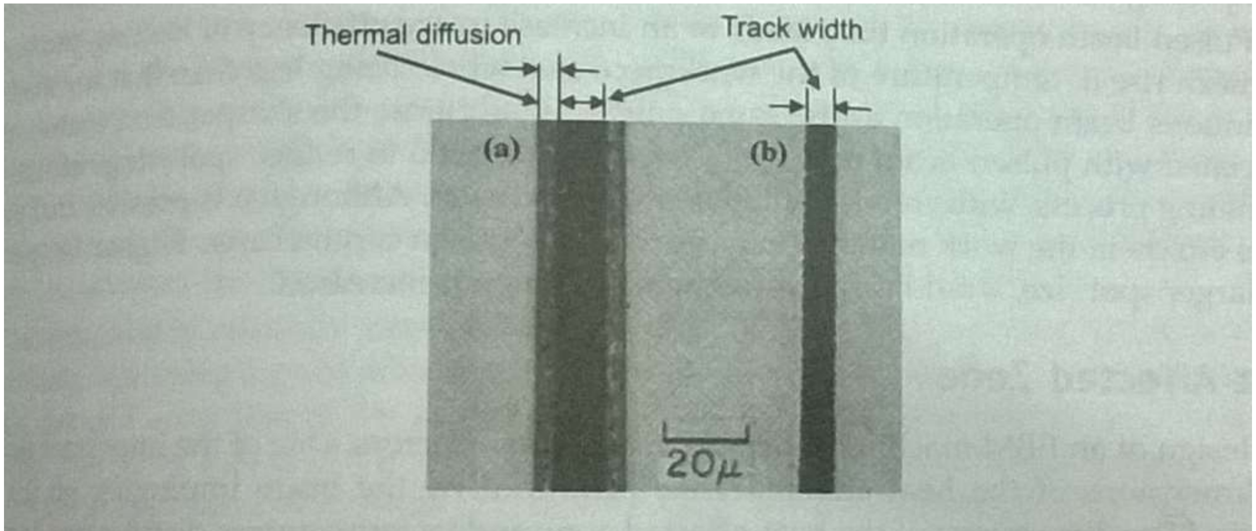


FIG. 4 Cuts in Ta showing variations of track width due to (a) normal cutting speed (b) 3 times higher cutting speed than (a)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Advantages of pulsed beam operation

- To reduce the effect of conduction loss, pulsed beam should be used instead of continuous stream of electrons.
- During pulsed beam operation, the focused spot is heated to high temperature before conduction of heat takes place.
- Due to the reduced heat conduction loss, the efficiency of the process is improved & HAZ is reduced.

Applications of MEBM

1. Electron Beam Drilling

- Precision: +/- 25 μm, Accuracy: +/- 12.7 μm, Aspect Ratio 25:1

2. For making fine gas orifices in nuclear reactors,
3. Holes in wire drawing dies,
4. Cooling holes in turbine blades.

Advantages & Disadvantages of MEBM

- Advantages:

1. Non-contact type thermal tool,
2. High aspect ratio is attained (25:1) even at inclined angle,
3. Parameters can be easily adjusted.
4. Can produce holes ranging from 6 μm – 1.0 mm

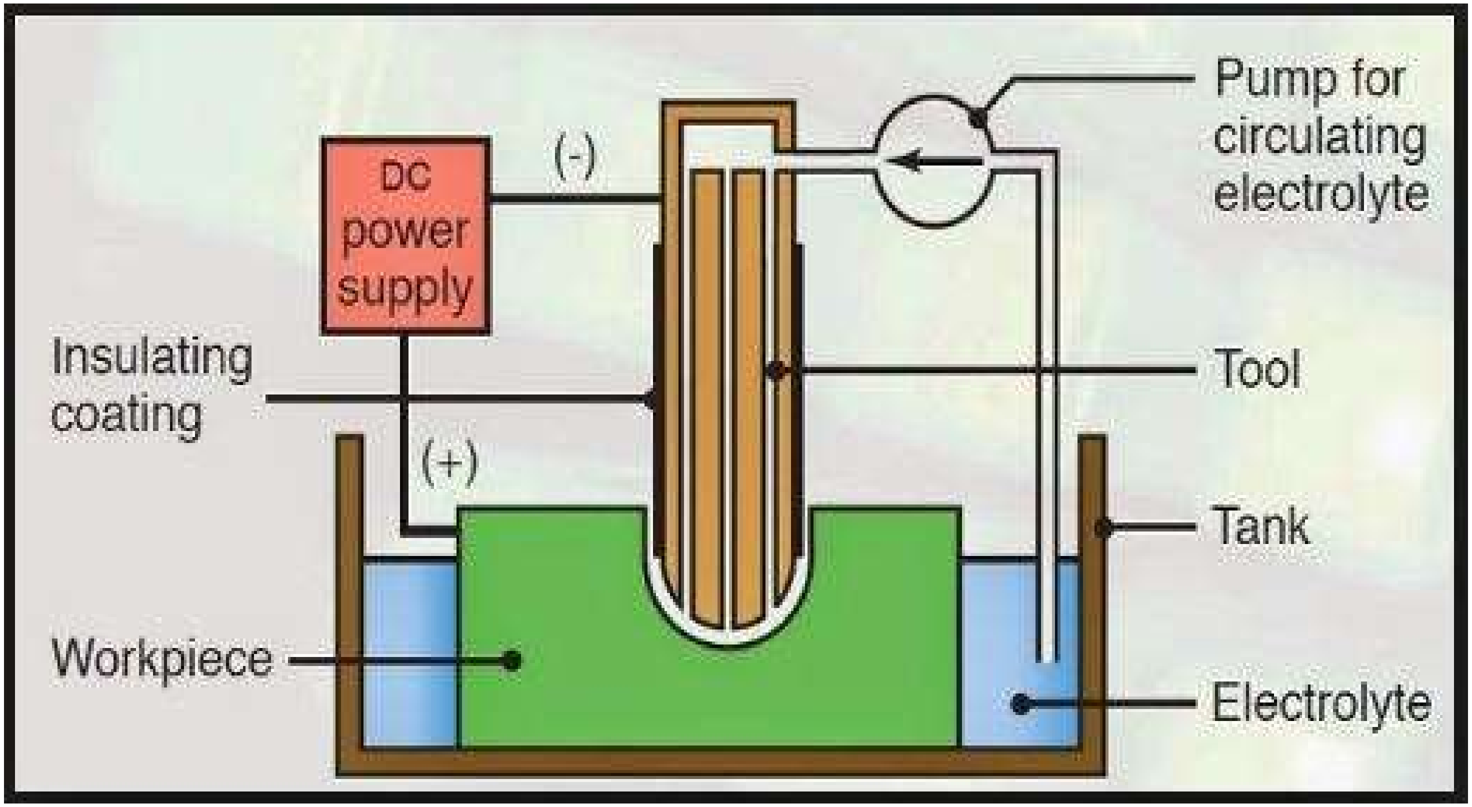
- Disadvantages:

1. Size of vacuum chamber limits the size of work piece.
2. High initial investment & running cost,
3. Skilled programmer & labor is required.

Micro Electro Chemical Machining (MECM)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro Electro Chemical Machining (MECM)



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Working principle of MECM

- Electrical energy is used to produce a chemical reaction, therefore, the machining process based on this principle is known as Electrochemical machining (ECM). This process works on the principle of Faraday's laws of electrolysis.

- Michael Faraday discovered that if the two electrodes are placed in a bath containing a conductive liquid and DC potential (5-25V) is applied across them, metal can be depleted from the anode and plated on the cathode This principle was in use for long time. ECM is the reverse of the electroplating.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Electro Chemical Machining (ECM)

- Faraday's law of electrolysis :

  The Weight of the substance produced during electrolysis process is directly proportional to

  1. the current which passes

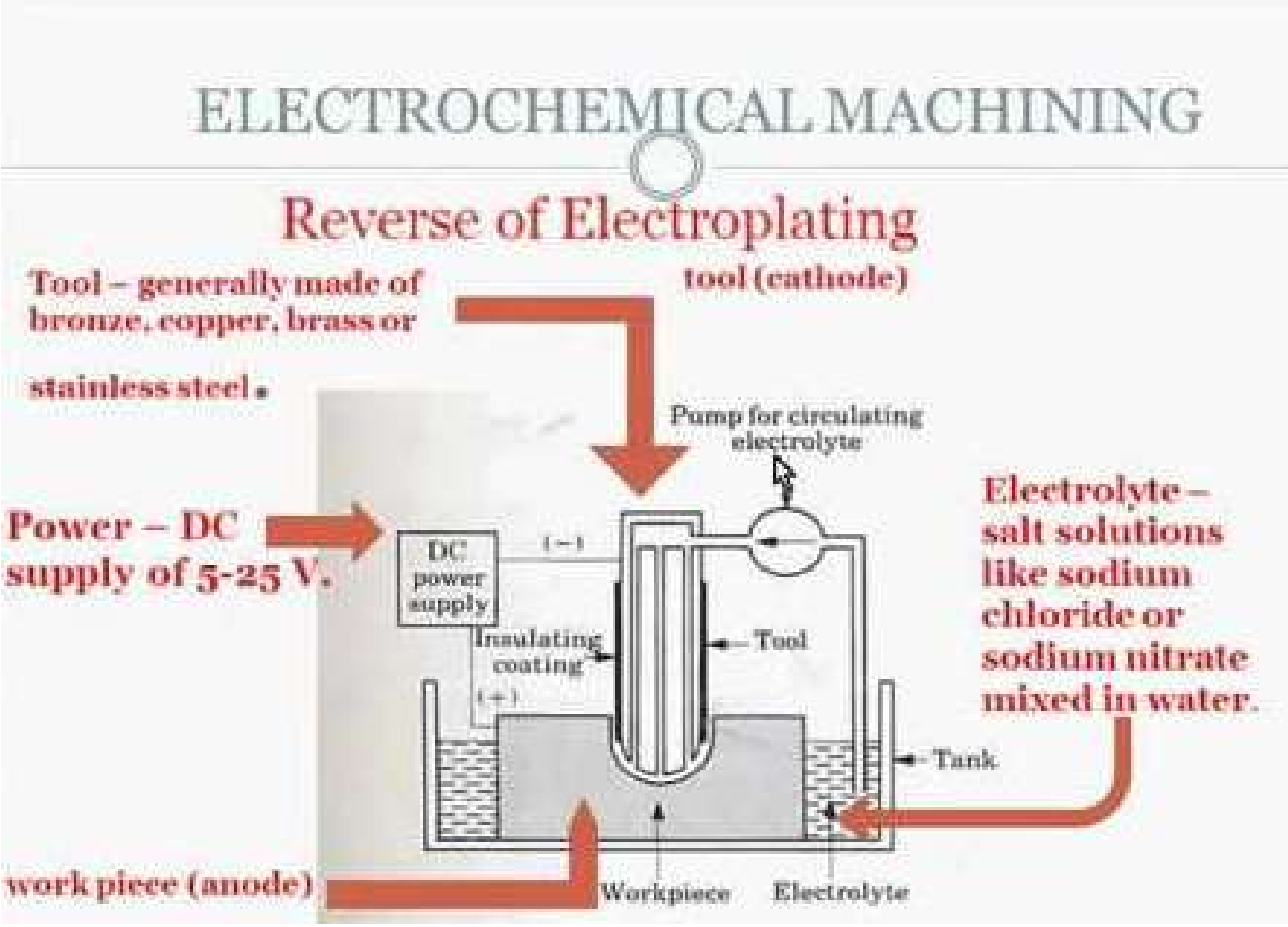
  2.the length of time of process

  3.The equivalent weight of the material
- Two dissimilar metals are in contact with an electrolyte and anode loses metal to cathode

•Anode : Workpiece
•Cathode : Tool
•Electrolyte : An electrically conductive fluid

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Elements of MECM



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Influence of process parameters of MECM

Feed Rate: High feed rate results in higher metal removal rate.

Voltage: Low voltage results in better surface finish and tolerance control

Nature of power supply: Pulse machining improves accuracy and surface finish

Electrolyte Flow:

Tool : Tool materials used in ECM must have good thermal and electrical conductivity and corrosion resistance

Applications of MECM

- The most common application of ECM is high accuracy duplication. Because there is no tool wear, it can be used repeatedly with a high degree of accuracy.
- It is commonly used on thin walled, easily deformable and brittle material because they would probably develop cracks with conventional machining.
- It is used in machining of hard-heat-resisting alloys.
- It is used in cutting cavities and holes in various products, machining of complex external shapes like that of turbine blades, aerospace components and machining of tungsten carbide and nozzles of alloy steels.
- Any conducting material can be machined by this method.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Advantages of MECM

- There is no cutting forces therefore clamping is not required except for controlled motion of the work piece.
- It can machine configurations which is beyond the capability of conventional machining processes.
- Very accurate (tolerance of ±0.02 mm).
- Relatively fast.
- Can machine harder metals than the tool.
- Extremely thin materials can be easily worked without distortion.
- Tool wear is nearly absent.
- Better surface finish (0.2 to 0.8 micron).

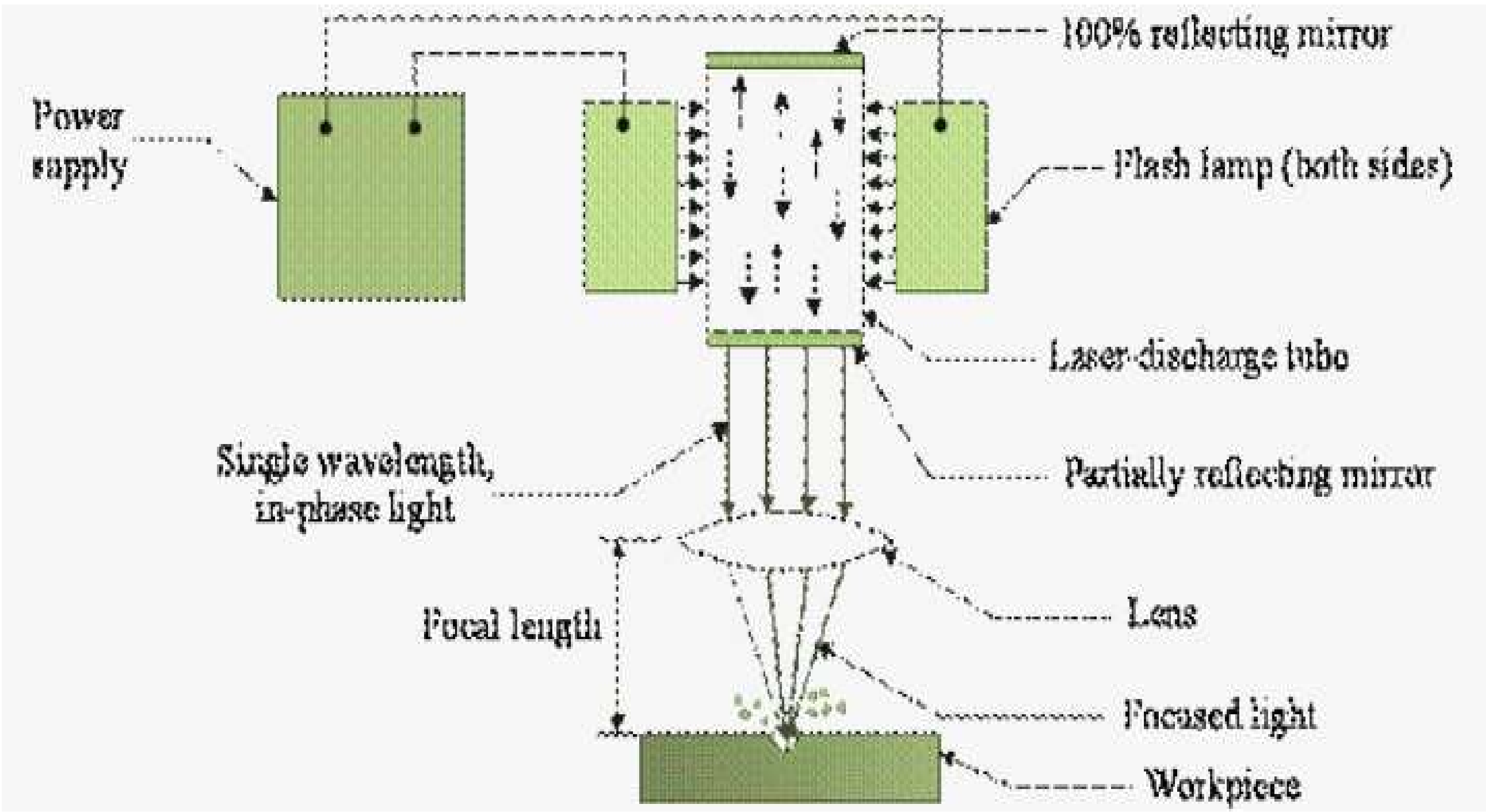
Disadvantages of MECM

- High energy consumption.
- Non conducting material cannot be machined.
- Corrosion and rust of ECM machine can be hazardous but preventive measures can help in this regard.

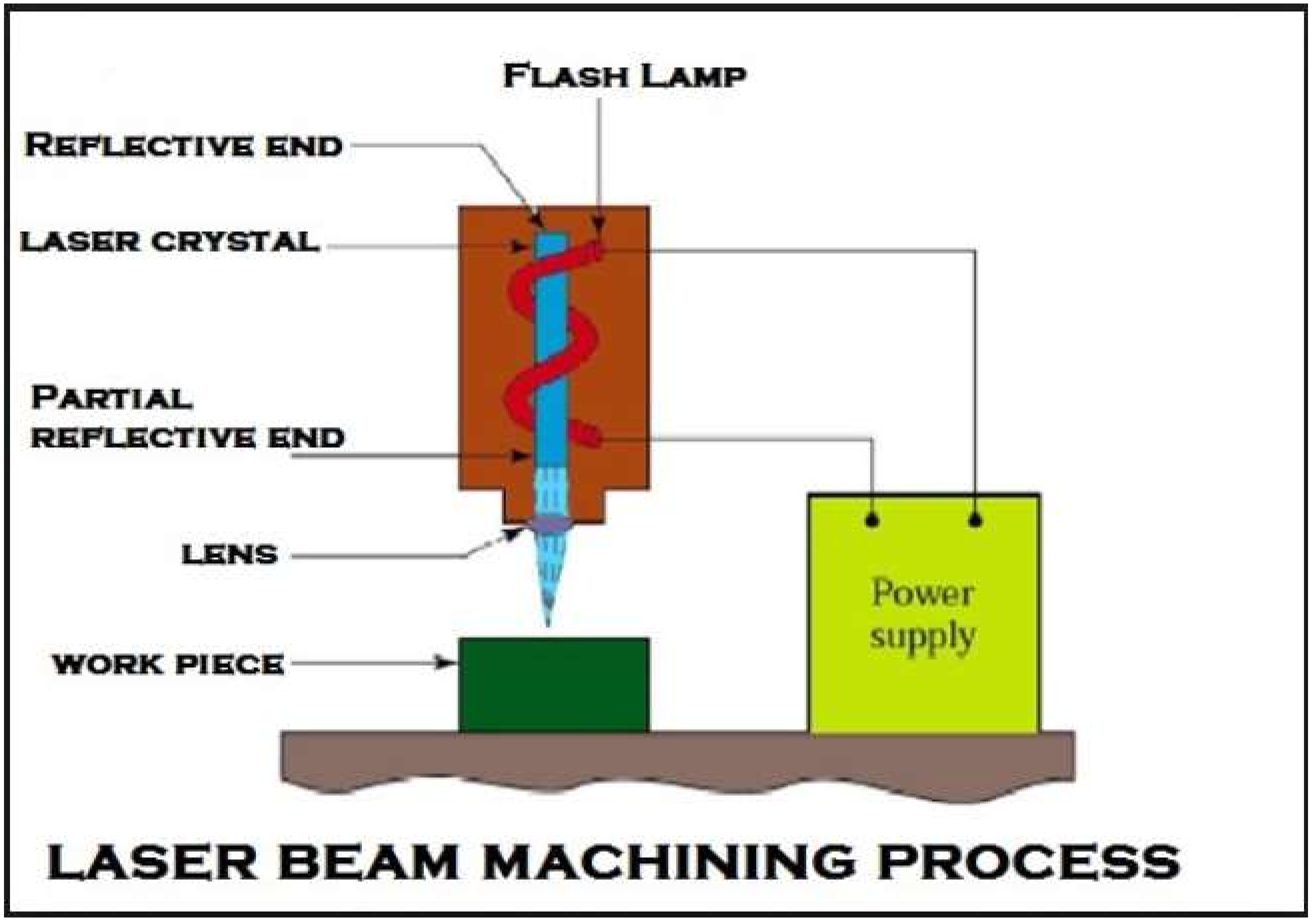
MICRO LASER BEAM MACHINING

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro Laser Beam Machining (MLBM)



MLBM


FLASH LAMP
REFLECTIVE END
LASER CRYSTAL
PARTIAL REFLECTIVE END
LENS
WORK PIECE
Power supply
LASER BEAM MACHINING PROCESS

Why Laser…?

1. **Directional** - This refers to light divergence over long distances. A laser is collimated and will travel long distances without the beam spreading .

2. **Monochromatic** - Monochromatic means single colour - Lasers emits light that consists of a very narrow spectral range.

3. **Coherent** - All of the light waves emitted by a laser are in phase with each other. All the peaks and valleys are perfectly in line with each other.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Laser Material Interaction

- Energy absorbed by the workpiece, I

$$I = (1\text{-}R)\, I_0\, e^{(-\alpha z)}$$

- Where R = Reflectivity of the material,
- 1-R = Absorptivity of the material (A),
- I_0 = Incident intensity,
- α = Absorption coefficient,
- z = Depth of machining.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Laser Material Interaction

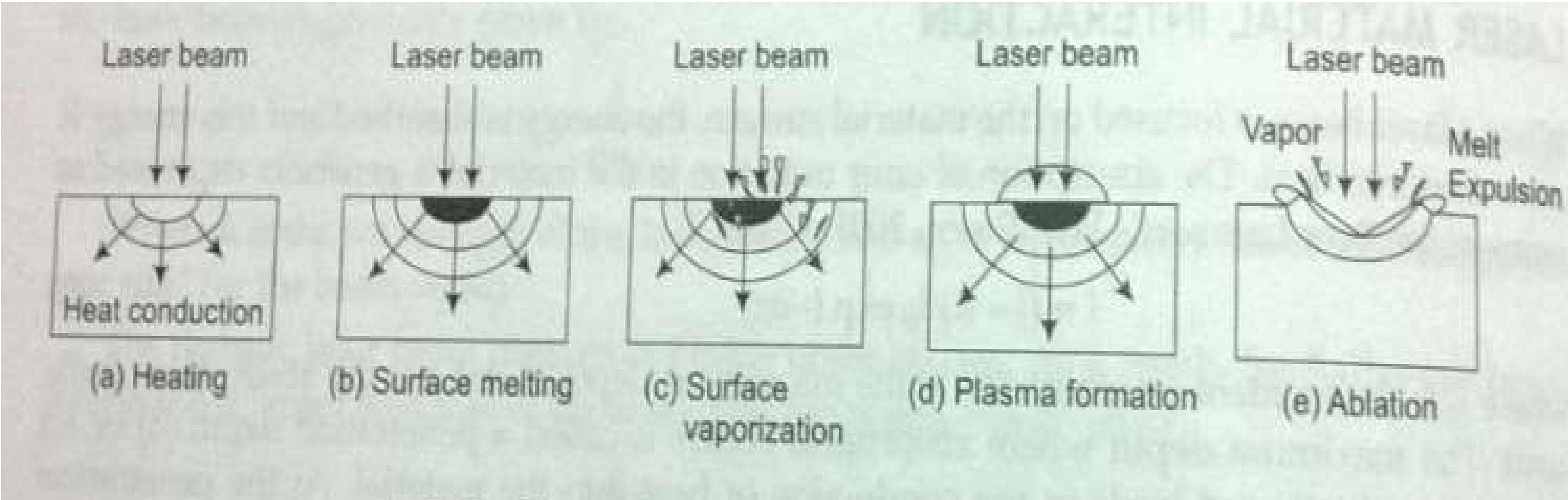


FIG. 2 Schematic of laser and material interaction.

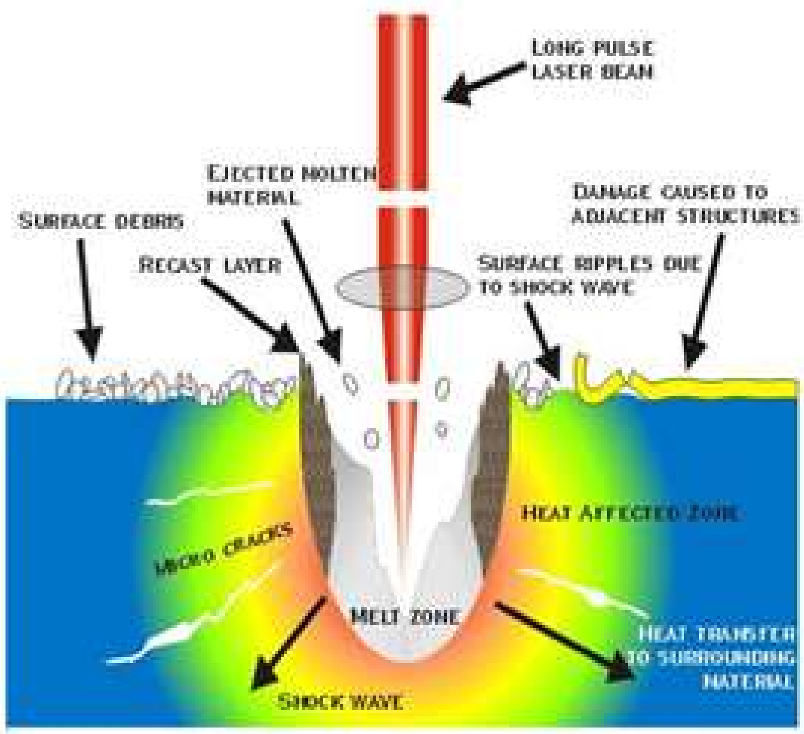
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters of LBM

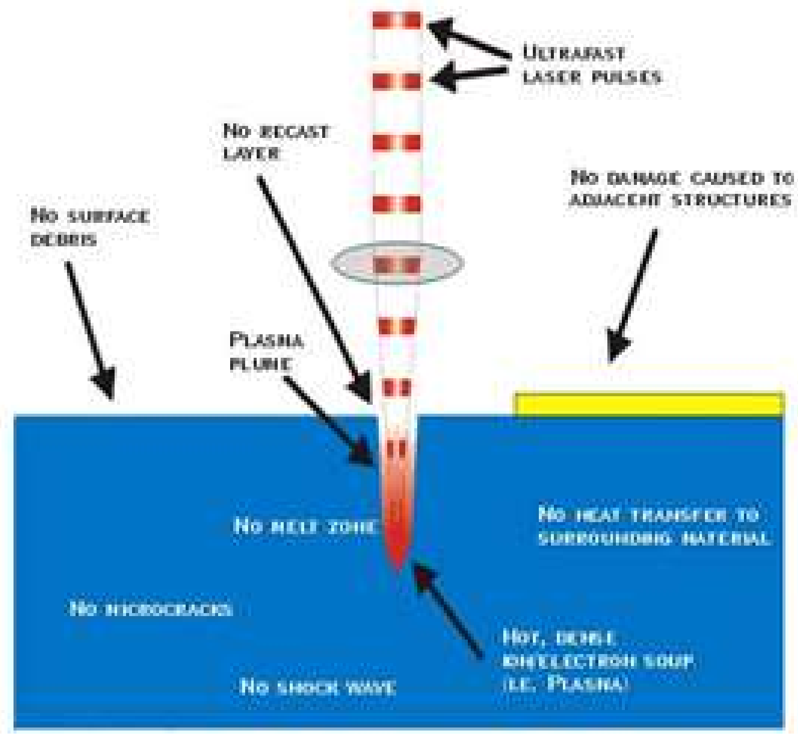
Process Parameters	Effect
1. Wave length / Focal length of lens	Feature size, Ablation rate
2. Beam shape (Gaussian/Square Wave)	Feature shape, Uniformity of the process
3. Beam energy, Pulse width	Size of HAZ
4. Pulse repetition range	Depth of material removal
5. Depth of focus	Aspect ratio
6. Vacuum / Inert gas environment	Accuracy of the process

Long Vs Short Pulse Laser Machining

Long pulse



Short pulse



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Short Pulse Laser Machining

Unit	Size	Notes
attosecond	10^{-18} s	shortest time now measurable by scientists
femtosecond	10^{-15} s	pulse width on world's fastest lasers
picosecond	10^{-12} s	switching time of the world's fastest transistor
nanosecond	10^{-9} s	time for molecules to fluoresce
microsecond	10^{-6} s	length of time of a high-speed, strobe light flash
millisecond	0.001 s	time for a housefly's wing flap

Short Pulse Laser Machining

1. Nanosecond Pulse Micromachining

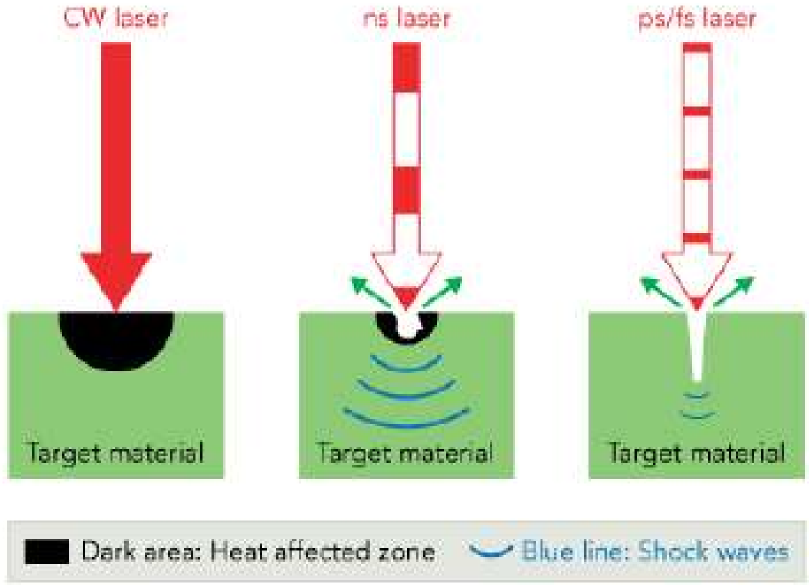
Pulse duration: 1-10 ns (1 ns = 10^{-9} Sec.)

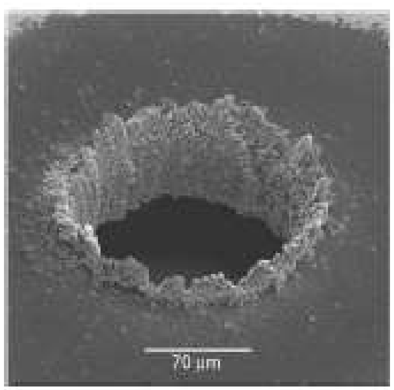
2. Picosecond Pulse Micromachining

Pulse duration: 1-10 ps (1 ps = 10^{-12} Sec.)

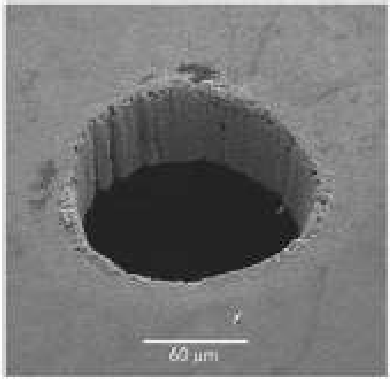
3. Femtosecond Pulse Micromachining

Pulse duration: 1-10 fs (1 fs = 10^{-15} Sec.)

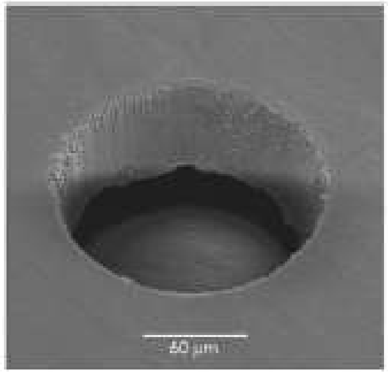




nanosecond Pulse



picosecond Pulse



Femtosecond Pulse

Laser material interaction basic for different types of lasers

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Advantages & Disadvantages of LBM

- **Advantages**

1. No limit to cutting path as the laser point can move in any path.
2. The process is stress less, allowing very fragile materials to be laser cut without any support.
3. Very hard and abrasive material can be machined.
4. It is a cost effective and flexible process.
5. Non metals like plastic & rubber can be also machined.
6. No cutting lubricants required
7. No tool wear
8. Narrow heat affected zone

- **Disadvantages**

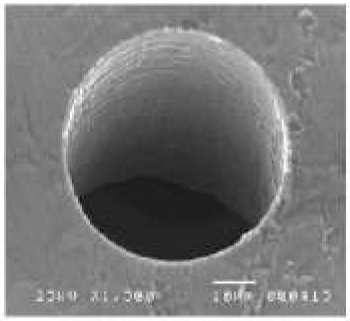
1. Skilled labour & expert CNC programmer is required
2. Limitations on thickness due to taper
3. High capital cost & maintenance cost
4. Safety precautions are required

Applications of LBM

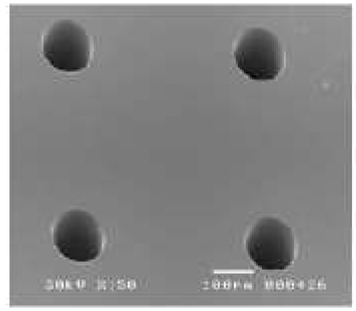
1. Machining of small/ micro holes
2. Cutting complex profiles on thin & hard materials.
3. Partial cutting and engraving,
4. Sheet metal trimming,
5. Blanking
6. Precise aerospace applications,
7. Making cellular phone parts, Ink jet heads, surgical equipments, medical devices…

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

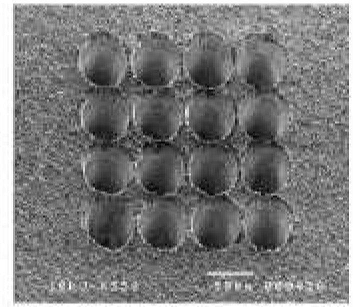
Applications of LBM



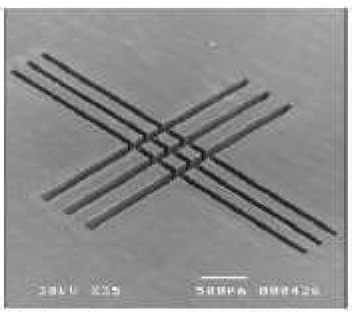
40 μm diameter hole drilled through stainless steel using 511nm copper vapor laser (CVL)



Laser trepanned holes in silicon using high laser intensity (15 GW/cm^2) at 355nm

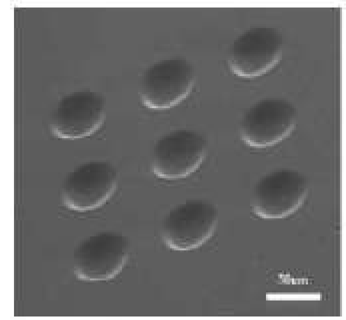


Array of 40 μm diameter holes drilled in 250 mm thick alumina using a 511nm CVL



Blind channels cut into polyimide using a 355nm laser

SEM image of parallel grooved microstructure on glass ablated by ArF laser at a fluence of 1.7 J/cm^2 with 250 shots



Array of 50 μm microlens manufactured on polymer material

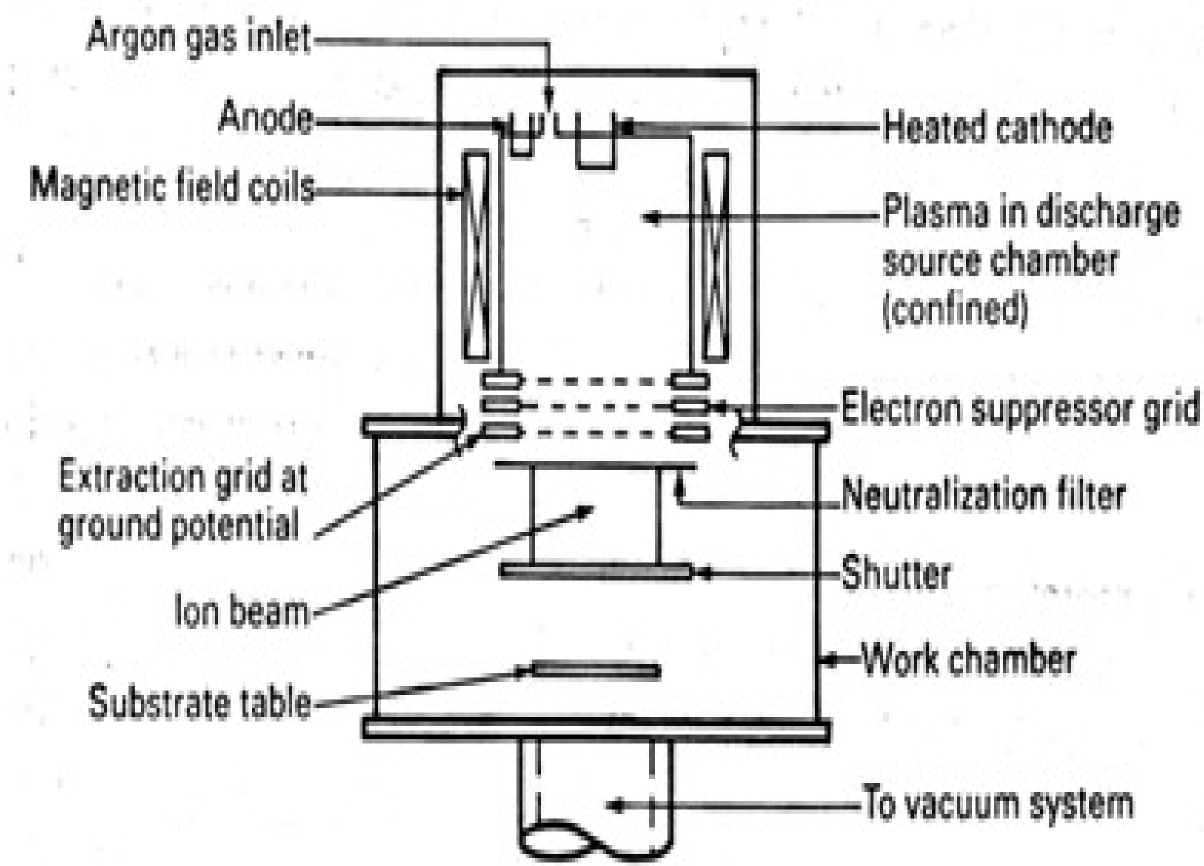
Courtesy: Oxford Lasers, Laser Micromachining, Tseng et al., Optics and Lasers in Engg., 2007

Focused Ion Beam Machining (FIB)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Focused Ion Beam Machining (FIB)

Equipment



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Plasma Source in IBM

- A heated element usually tungsten acts as cathode, from which electrons are accelerated by means of high voltage (above 1 kv) towards anode.
- During the passage of electrons from the cathode to the anode, they interact with argon atoms and the following reaction takes place.

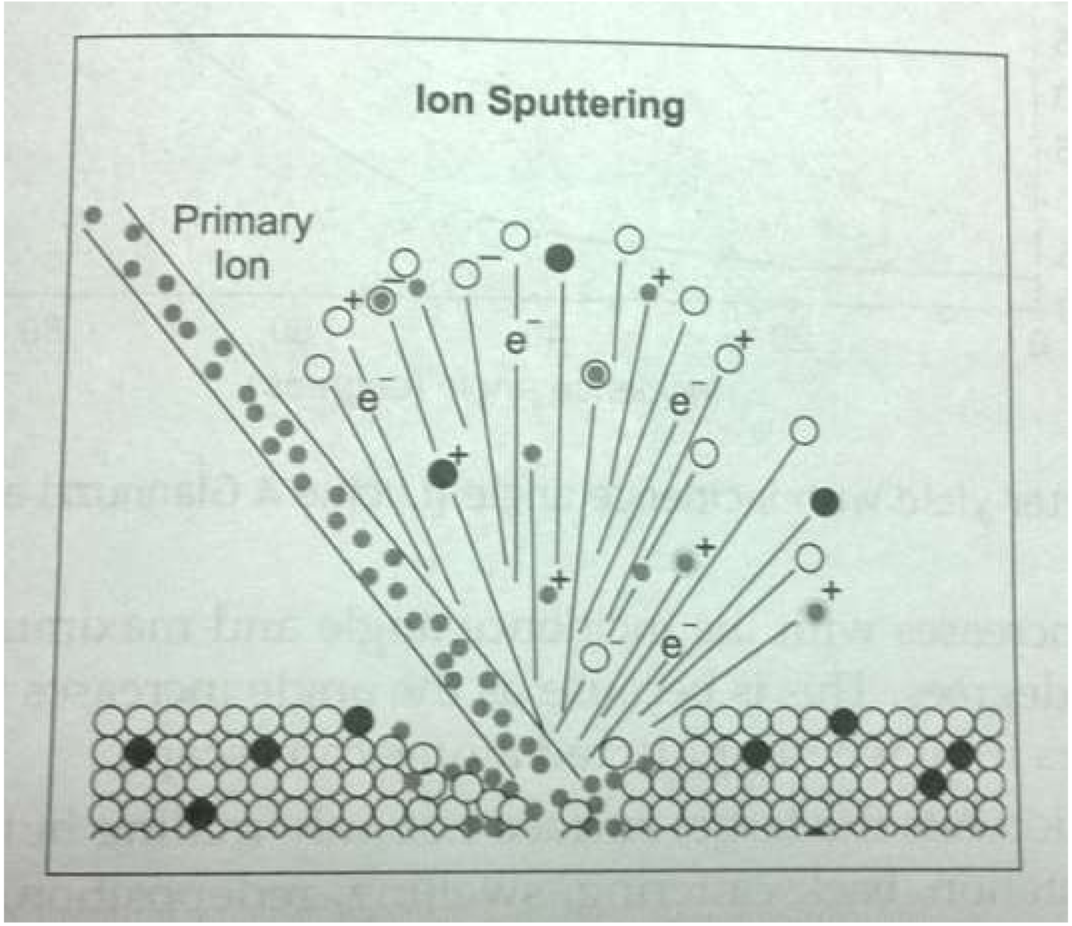
$$Ar + e^{-} = Ar^{+} + 2e^{-}$$ (Argon ions produced)

- A magnetic field, obtained from an electromagnetic coil or a permanent magnet, is applied between the anode and cathode.
- It make electron spiral which increases the path length of the electrons and ionization.

Interaction of ion with substrate

- Compared to electrons, ions are 20 times larger in size & 130 times heavier in mass.
- Due to this, ions removes material more effectively.
- The removal of atoms from the work piece by the accelerated ions is a physical sputtering process.
- Atoms will be removed from the work piece when the energy transferred from the ions is more than the binding energy of atoms.
- The sputtering yield (No. of atoms ejected / ion) is in the range of 1-50.

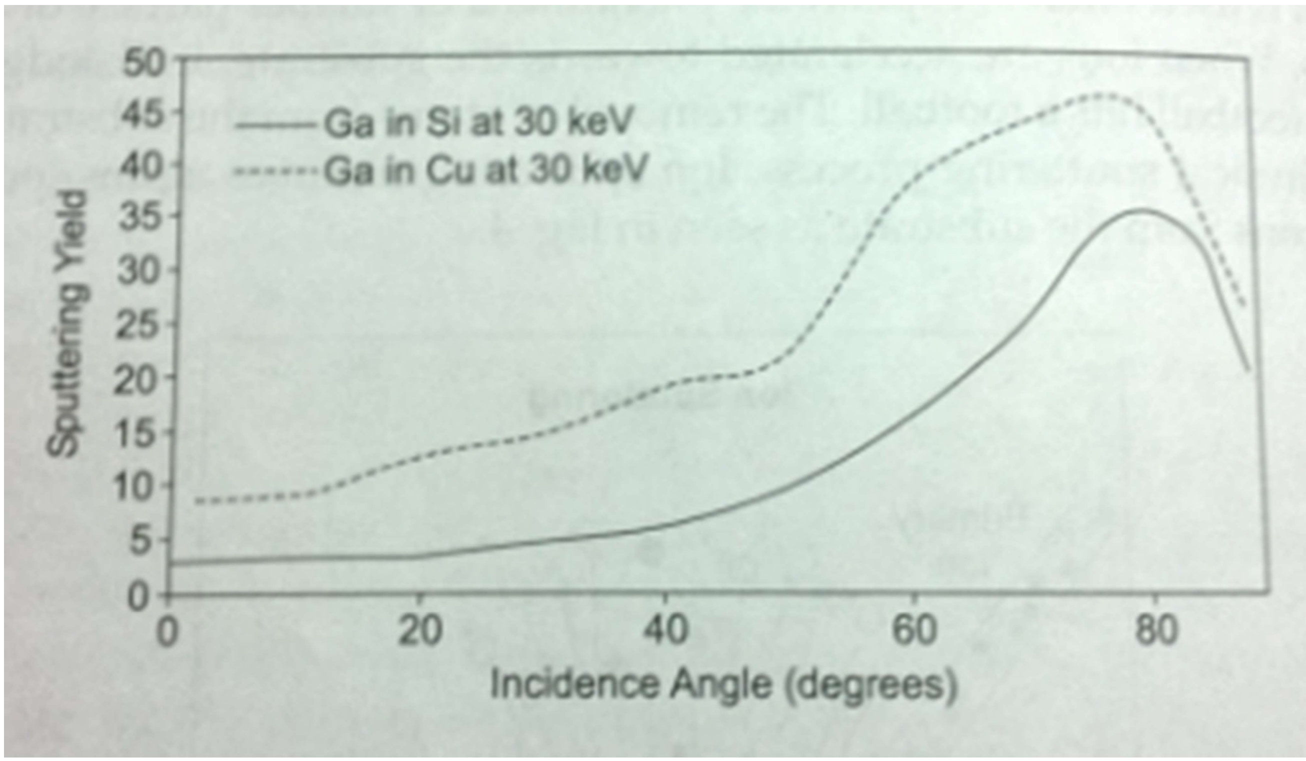
Ion Sputtering



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Sputtering Yield Vs Incidence Angle

- Sputtering Yield is maximum when Incident Angle is 60-90 Deg



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

FIB Milling

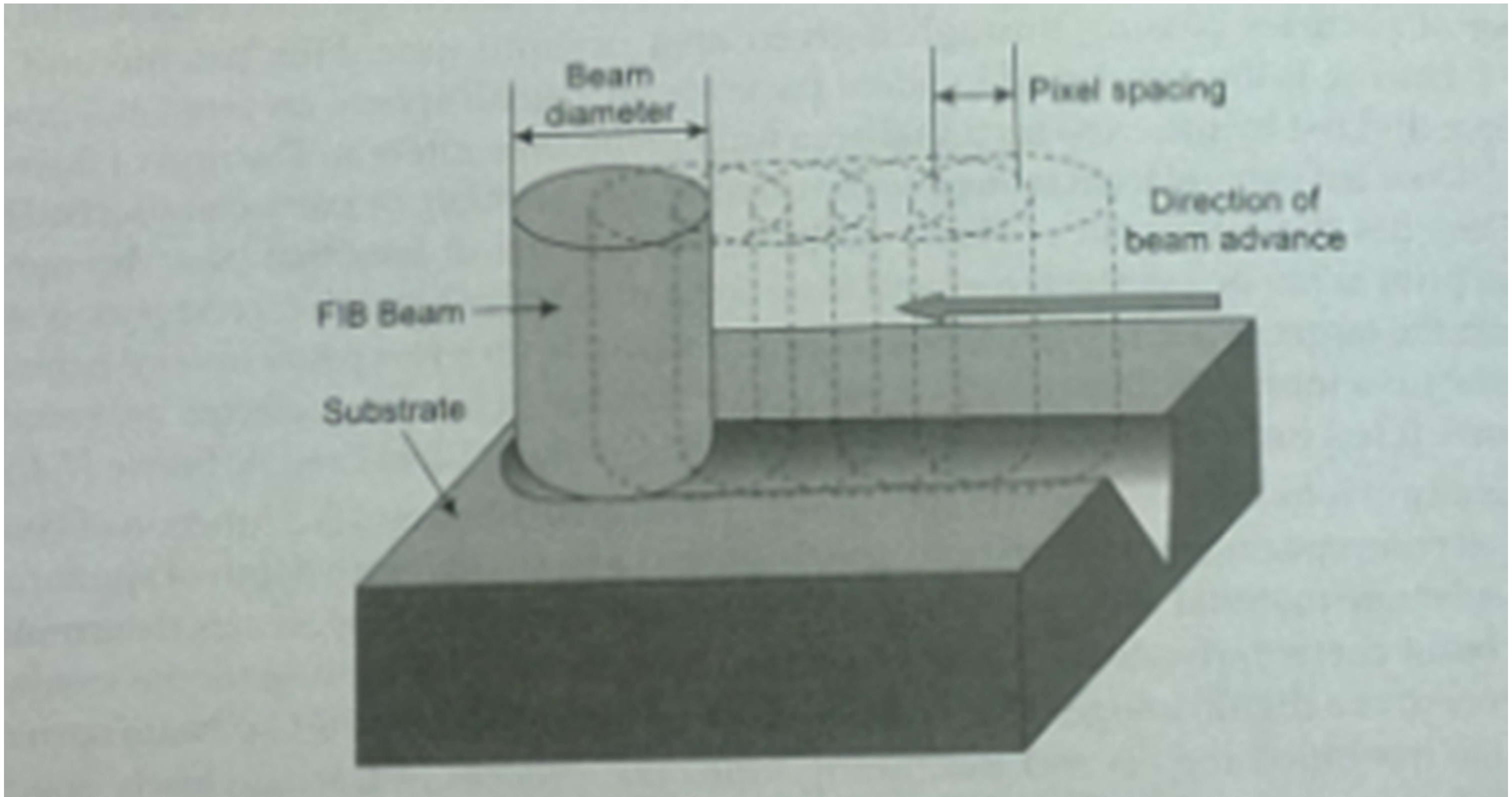


FIG. 7 FIB milling [Ampere A Tseng (2004)]

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

FIB Milling – Process Parameters

1. Scan rate – As speed increases, MRR reduces.
2. Beam spot size
3. Dwell time (Duration for which beam rests on each pixel)
4. Degree of overlap

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Rectangular Raster Scan Vs Line Scan

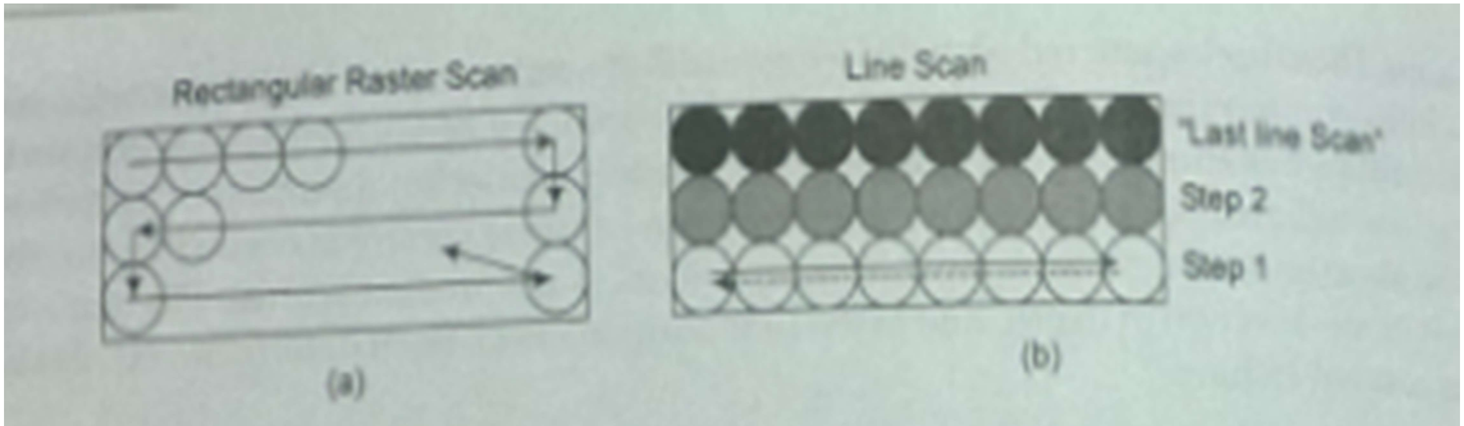


FIG. 6 Scanning of a rectangular pattern

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Gas assisted FIB processing

- Gases are used for enhanced milling and deposition of metals.
- Precursor gas containing the element to be deposited is passed through a capillary gas feeding nozzle towards the substrate.

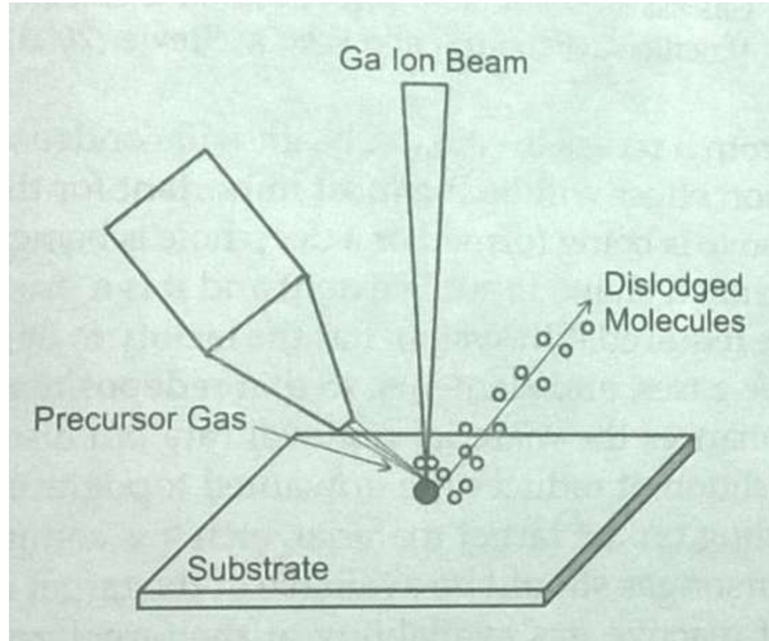


FIG. 9 Gas assisted FIB deposition

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Precursor gases used for FIB deposition

Element to be deposited	Precursor gas used
Carbon	Phenanthrene
Platinum	Tri methyl cyclo penta dienyl platinum
Tungsten	Tungsten hexa carbonyl
SiO_2	Oxygen + Tetra methoxysilane
Aluminium	Trimethylamine alane

Applications of FIB Machining

1. Fabrication of lathe tools for nano machining,
2. End mill cutters for micro machining,
3. Micro surgical tools,
4. Fabrication of diamond micro indenters,
5. Tools and dies for micro forming,
6. Tools and dies for Micro EDM,
7. Diamond and silicon nitride mould for nano patterns.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Applications of FIB Machining

- **Smoothing** – Smoothing of mirrors and for modifying the thickness of thin films without affecting surface finish.
- **Ion Beam Texturing** – For texturing surfaces of the materials like nickel, copper, stainless steel, silver, gold etc.
- **Ion beam cleaning** – Used for cleaning surfaces which are produced by EBM, EDM etc.
- **Shaping, Polishing and Thinning** – Argon ions has been used to enhance polishing, macroscopic thinning and shaping of thin materials
- **Ion Milling** – Ion milling is useful for the accurate production of shallow grooves by milling through masks to produce regular arrays of pits with widths 5 – 200 μm and depths upto 1mm. Some researchers reported that ion milling is an alternative for chemical etching of devices of fine geometry.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

End of Module 3

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MODULE 4

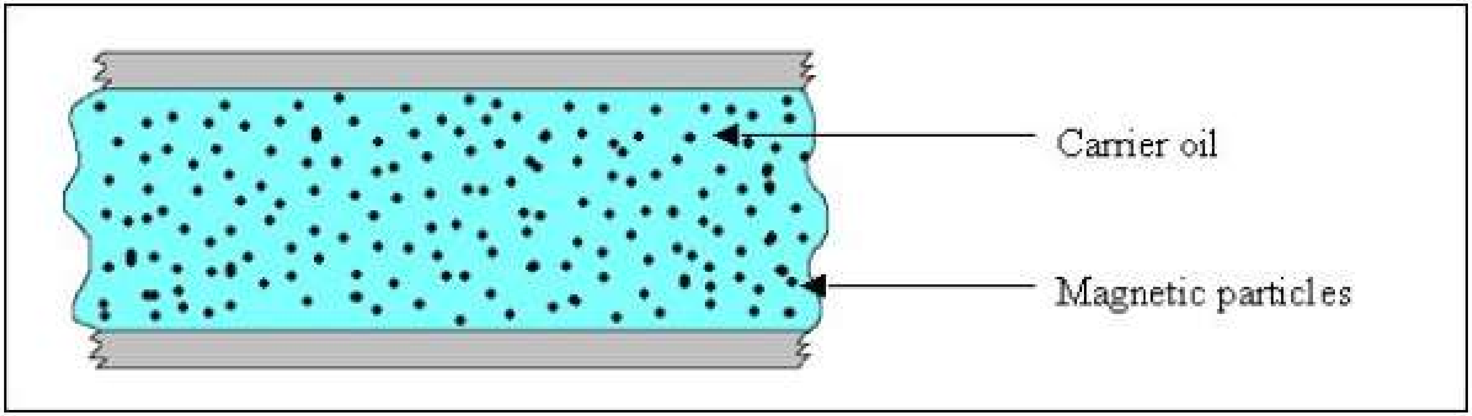
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Magneto Rheological (MR) Fluid

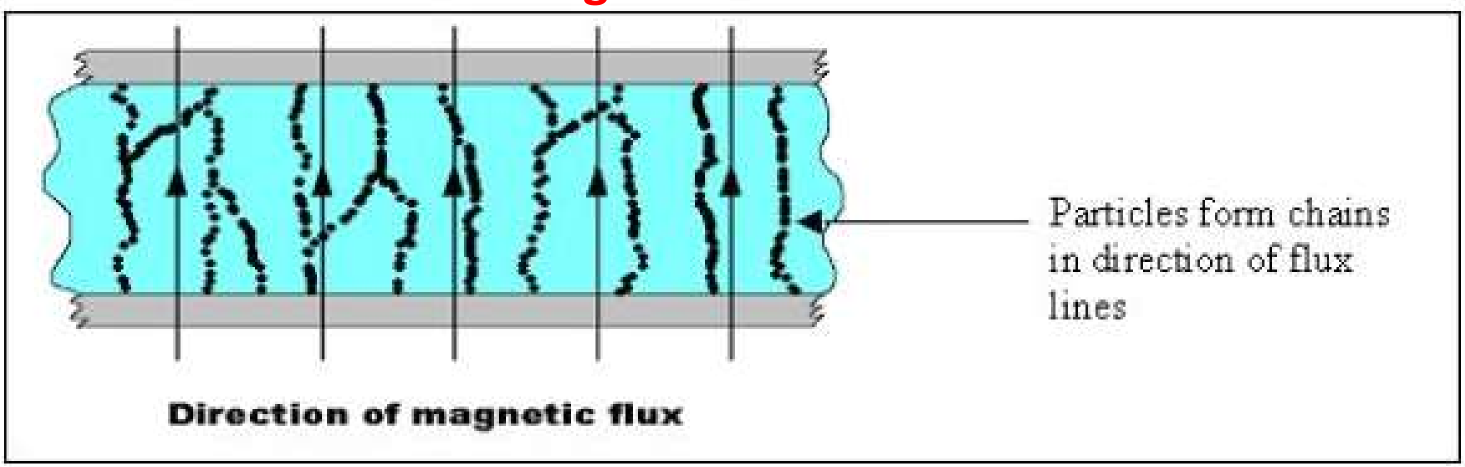
- **Magneto rheological fluid** (MR fluid) is a type of smart fluid in which abrasive particles are carried in a carrier medium. (Usually mineral oil/organic or aqueous liquids).
- When subjected to a magnetic field, the abrasive particles become active and the fluid greatly increases its apparent viscosity, to the point of becoming a viscoelastic solid.

Rheological Properties of MR Fluid

Magnetic Field "OFF"

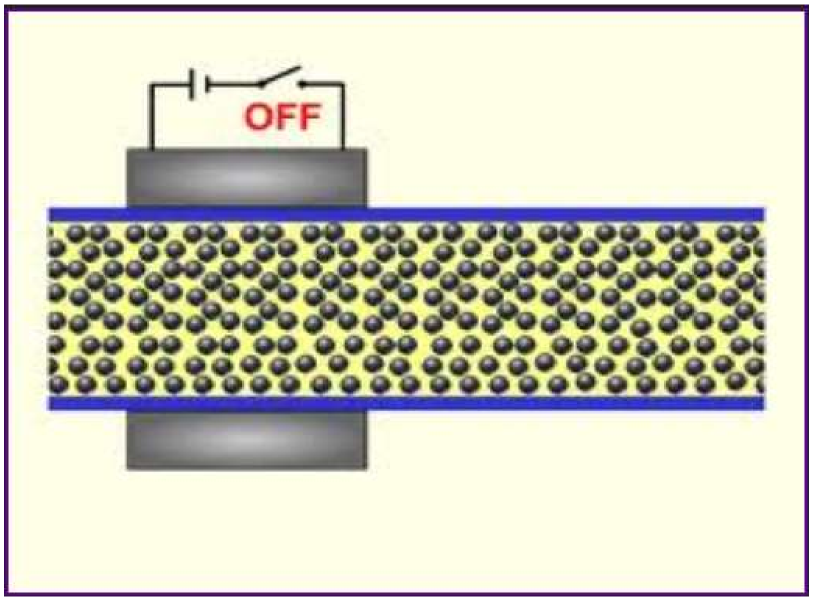


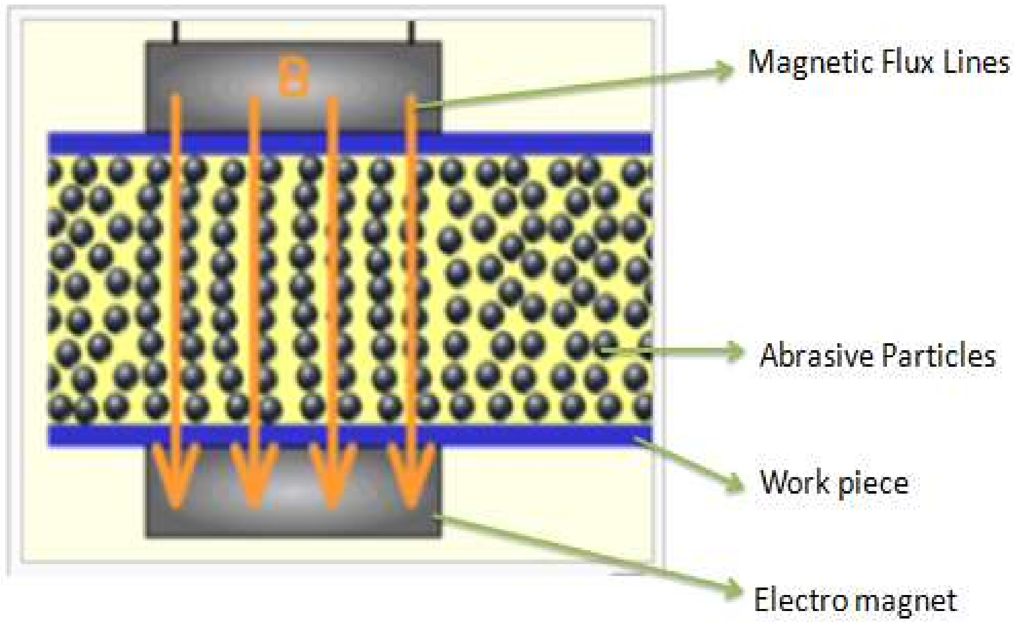
Magnetic Field "ON"



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MR Abrasive Flow Finishing Process (MRAFF)





Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Material Removal Mechanism

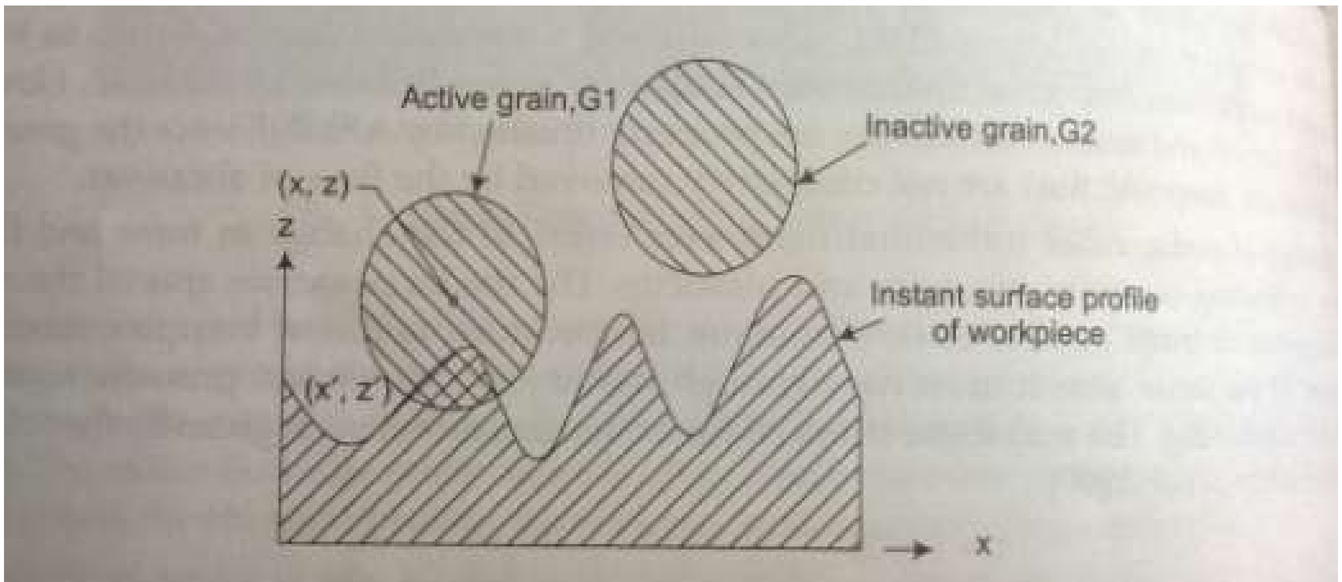


FIG. 6 Schematic of action of abrasive particle during AFMNF (Jain et al. 1999)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Magneto Rheological (MR) Fluid

- Apparent Viscosity of MR fluid increases by several times within few milliseconds, when magnetic field is applied. The process reverses as magnetic field is turned OFF.
- Abrasive particle size ranges from 0.5 – 100µm
- E.g. of ferrous abrasives – Iron, ferrites & other ferromagnetic particles.
- E.g. of non ferrous abrasives – (Diamond, Silica, Barium titanate) + Carbonyl Iron Particles (CIPs)
- Excitation is done by Electromagnets / Permanent magnets.

Carbonyl Iron Particles (CIPs)

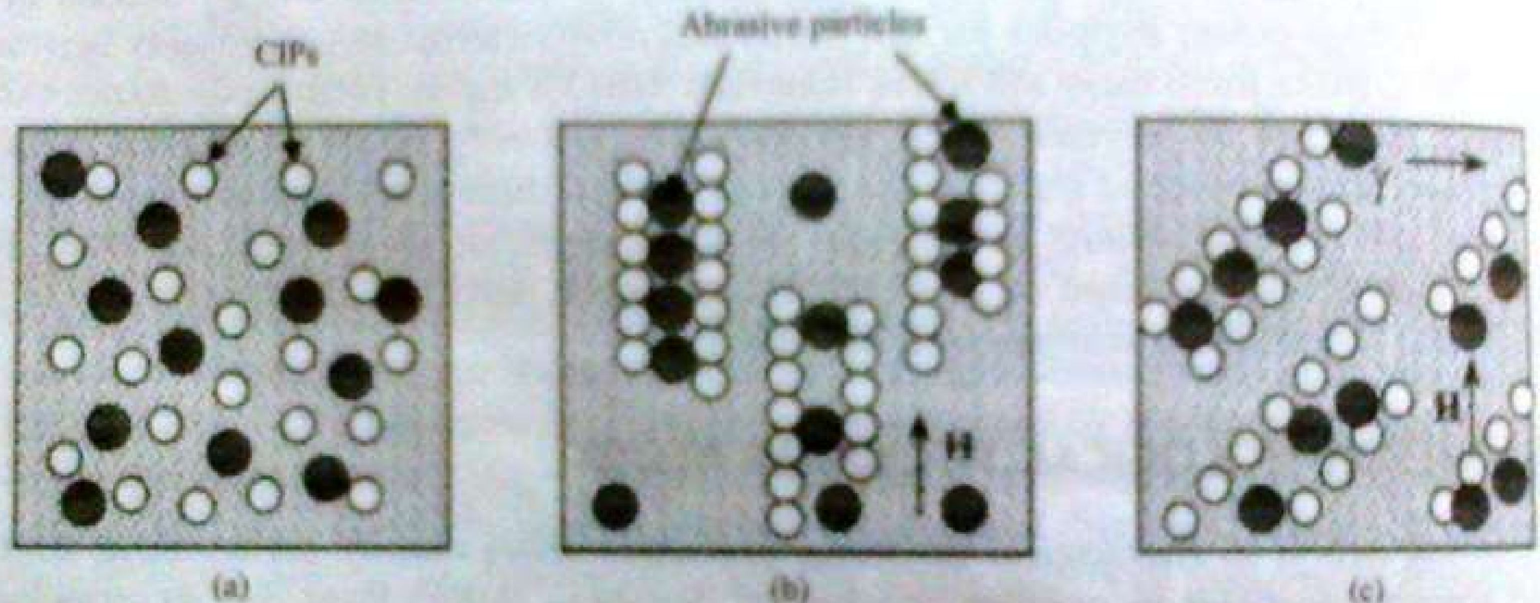


FIG. 2 A schematic diagram to illustrate magnetorheological effect in polishing fluid. (a) No magnetic field, (b) At magnetic field strength H, (c) At magnetic field H & applied shear strain

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MR Polishing Fluid Nomenclature

MRPF 20 CS 20 SiC 800

- **800** → **Abrasive mesh size**
- **SiC** → **Abrasive type**
- **20** → **% Vol. of abrasives**
- **CS** → **Carbonyl Iron grade**
- **20** → **% Vol. of CIPs**
- **MRPF** → **Magneto Rheological Polishing Fluid**

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

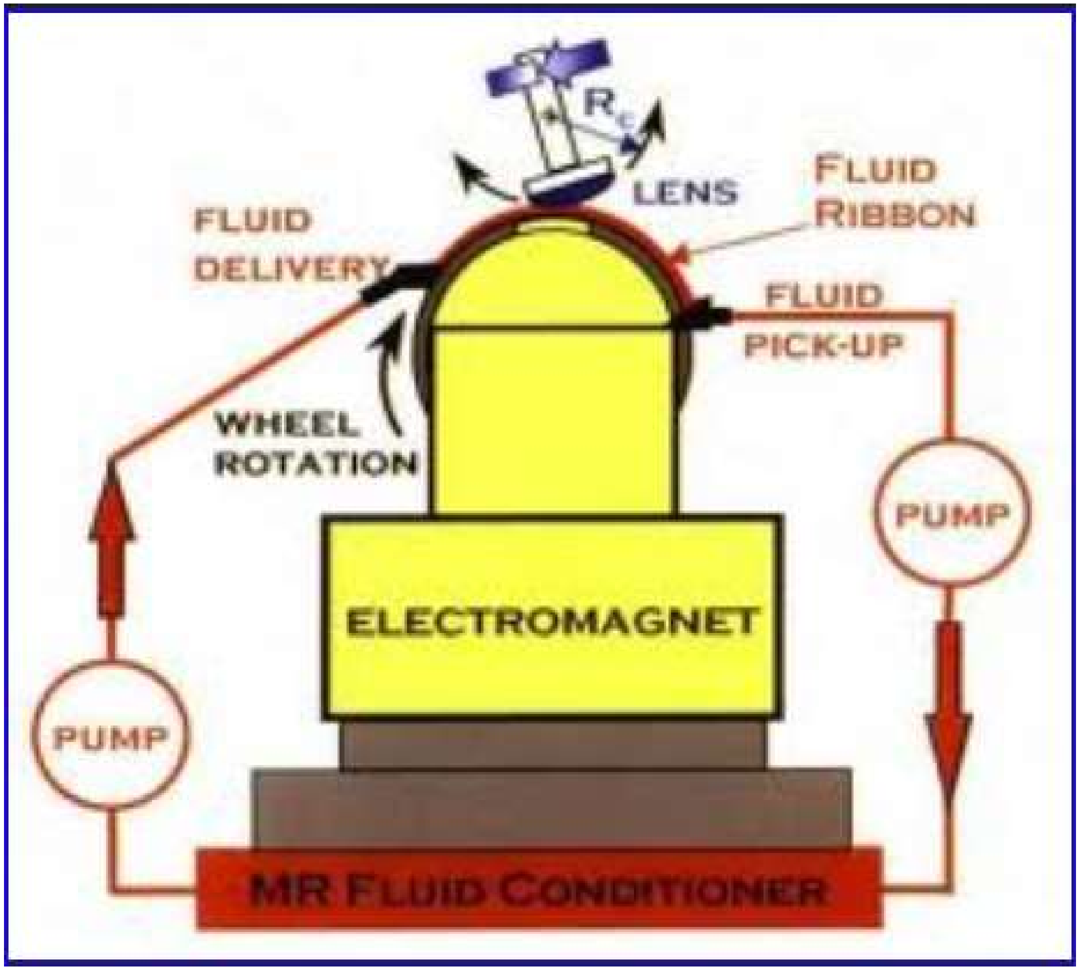
Performance Analysis of MRAFF Process

- Specimen: Flat stainless steel plate (35x5x2 mm)
- Initial Ra value of specimen: 280 nm
- Apparatus used: Atomic Force Microscope
- MR Fluids used: 1) MRPF 20 CS 20 SiC 800
  2) Diamond abrasives.
- Fluid pressure: 3.75 M Pa

Performance Analysis - Result

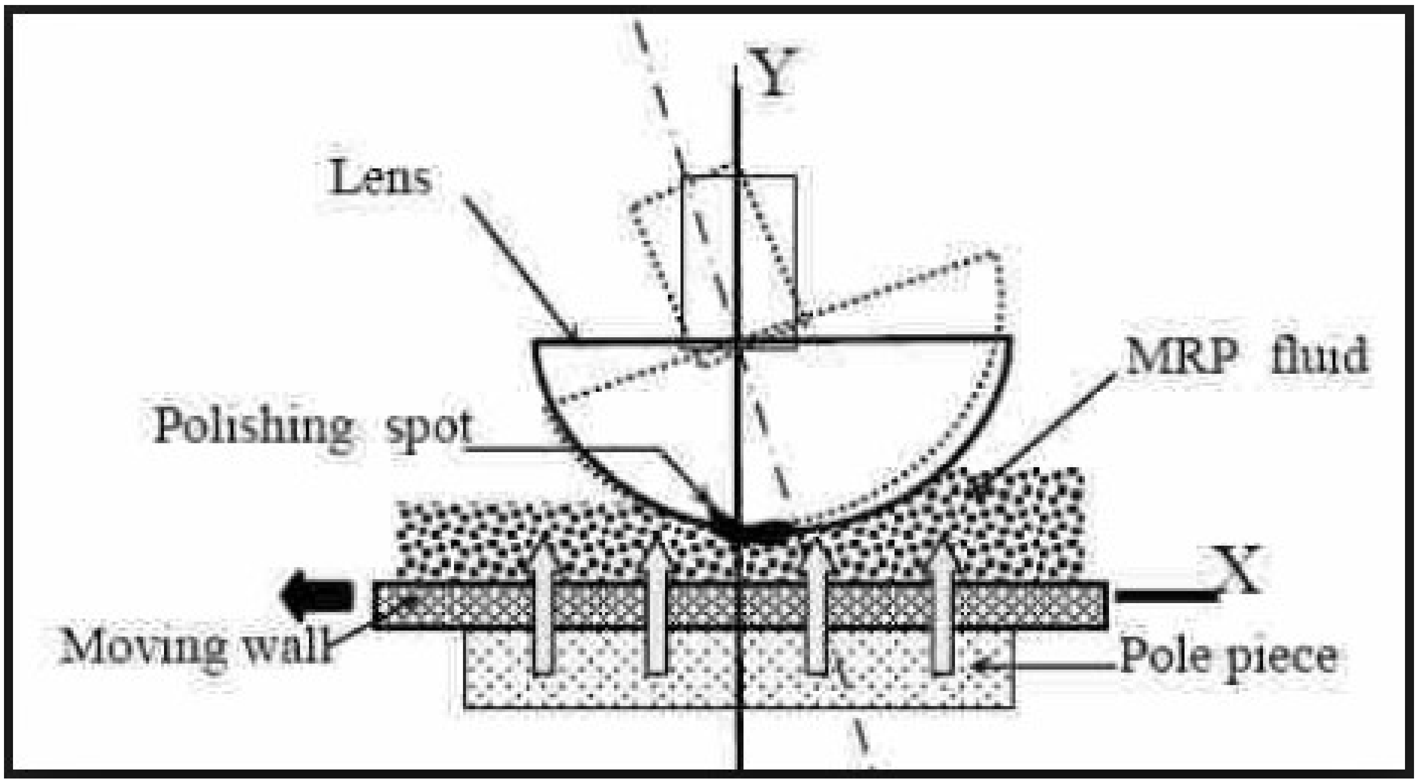
- Initial Ra value of specimen = 280 nm
- Ra value after 2000 cycles with SiC abrasives = 100 nm
- Ra value after 3500 cycles with diamond abrasives = 100 nm

MR Finishing Process – Machining of Contact Lens



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MR Finishing Process – Machining of Contact Lens



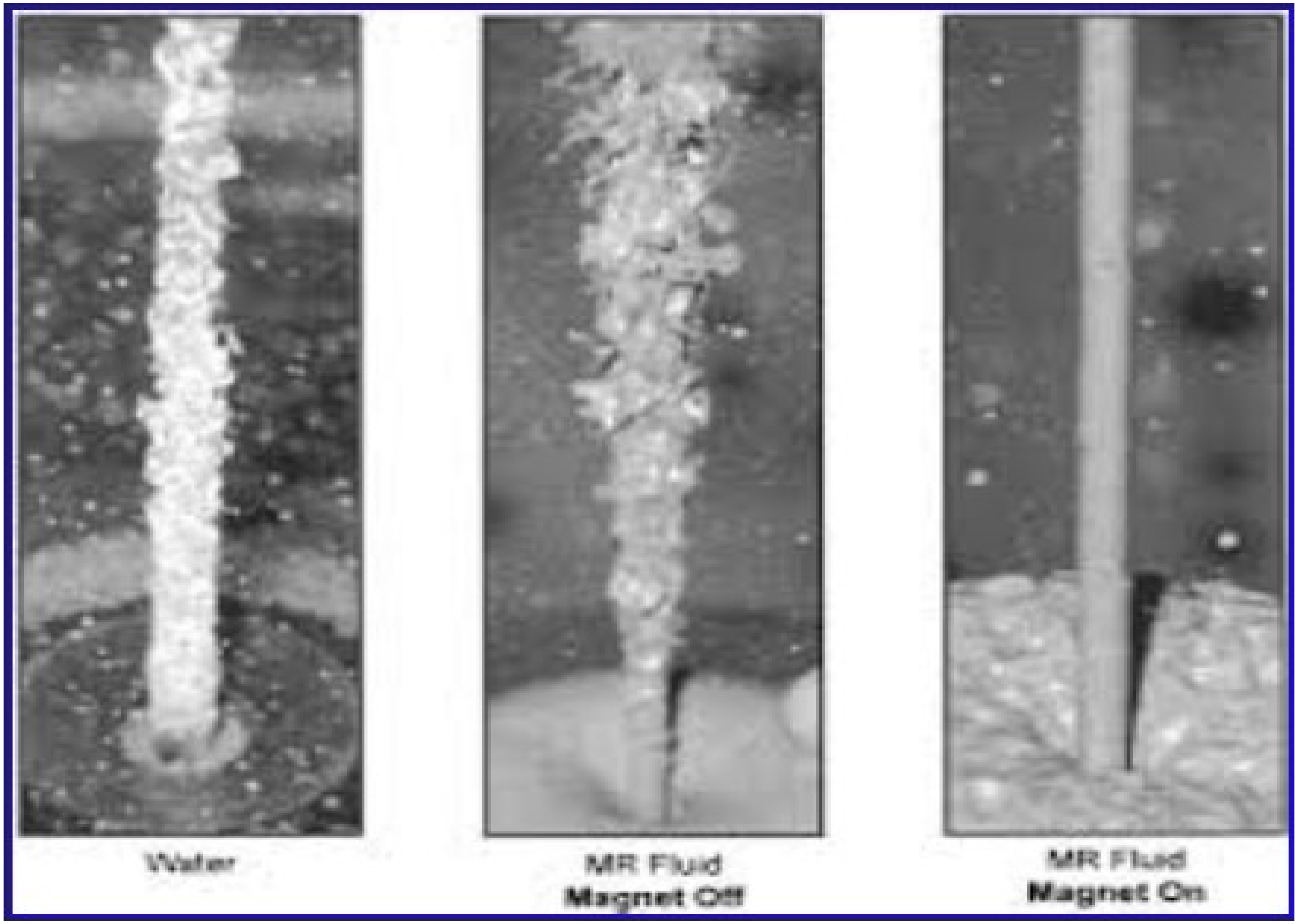
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Advantages of MR Finishing over Conventional Grinding Process

1. Can vary the machining rate by varying magnetic field intensity, abrasive flow rate & abrasive type.
2. Carries heat & debris away from the polishing zone.
3. Does not load the work piece like a grinding wheel.
4. It does not lose its shape during the process as it is self deformable.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MR Jet Finishing Process



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Working Principle of MR Jet Finishing Process

- Material removal is governed by Kinetic Energy of impacting abrasive particles.
- Surface stresses developed due to the flow of abrasive slurry results in material removal required for polishing.
- Jet stabilization is achieved by magnetizing the tip of nozzle.
- MR fluid jet remain coherent for distance more than 200 times the diameter of the nozzle.

MR Jet Finishing Machine

- A computer code (micro processor) generates machine control programs for polishing.
- Inputs to this code are 1) Material removal spot, 2) Initial surface details.
- Outputs of the machine are machine program instructions in the form of 1) Velocity schedule 2) Prediction of final surface figure.
- The micro processor based software uses series of complex algorithms to derive an operating program for CNC machine.
- The code specifies angles, velocity, no. of cycles required and total estimated processing time.
- The CNC jet finishing machine then executes this program instructions to obtain required surface finish.

Jet Finishing Polishing Performance Analysis

- Specimen used: Concave glass inserts placed in aluminium shell.
- Specimen is rotated on its axis & swept around its centre of curvature.
- Jet is kept normal to the optical surface.
- Initial peak-valley error: 470 nm
- Final peak-valley error: Less than 50 nm

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Process Parameters of MR Finishing

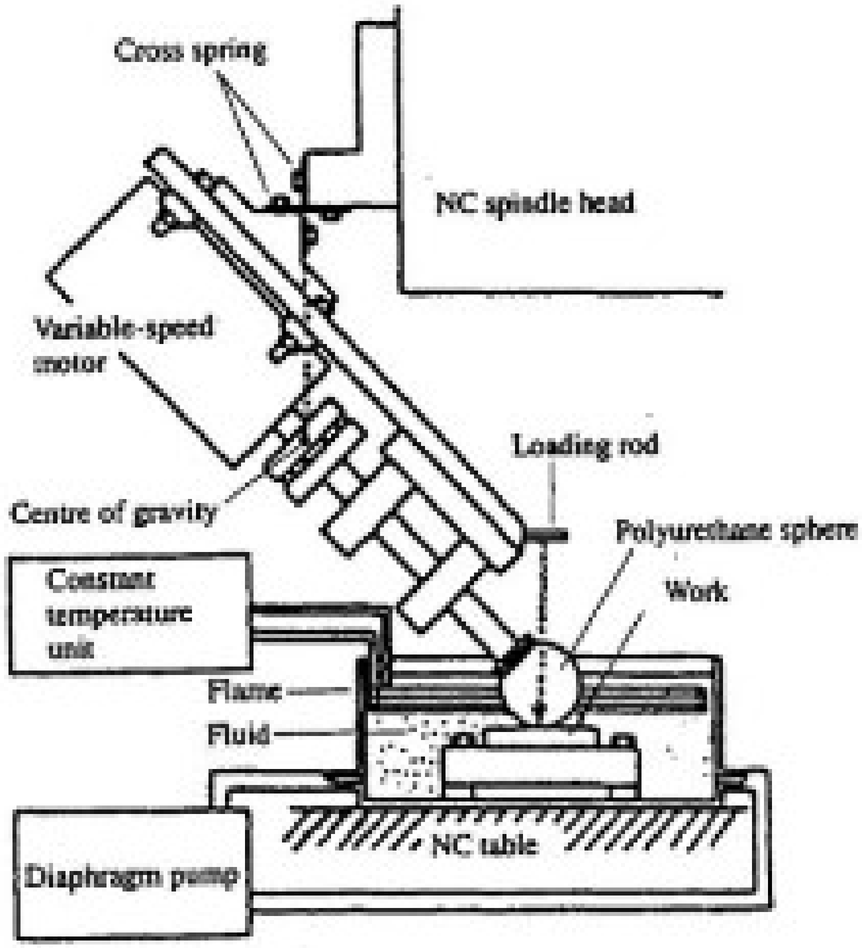
1. Flow rate of abrasives : As flow rate increases, MRR also increases.
2. Magnetic field: As magnetic flux intensity increases, Viscosity of MR fluid increases & MRR also increases.
3. Abrasive Particles:

   1) As abrasive particles becomes finer, surface finish increases.

   2) As grain size & hardness of abrasive particles increases, MRR increases.
4. Viscosity of MR fluid: As viscosity increases, MRR also increases.

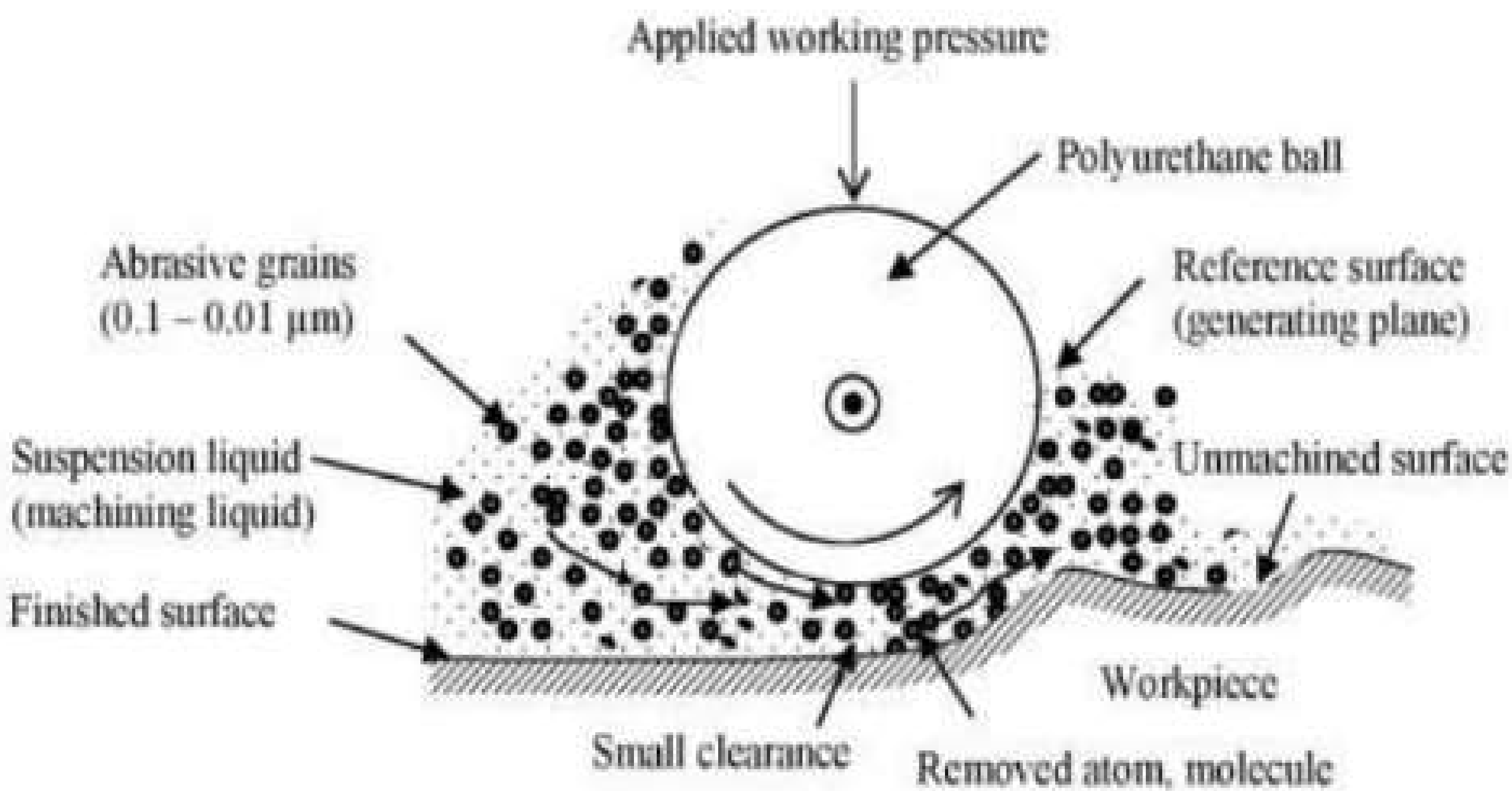
Elastic Emission Machining (EEM)

Elastic Emission Machining



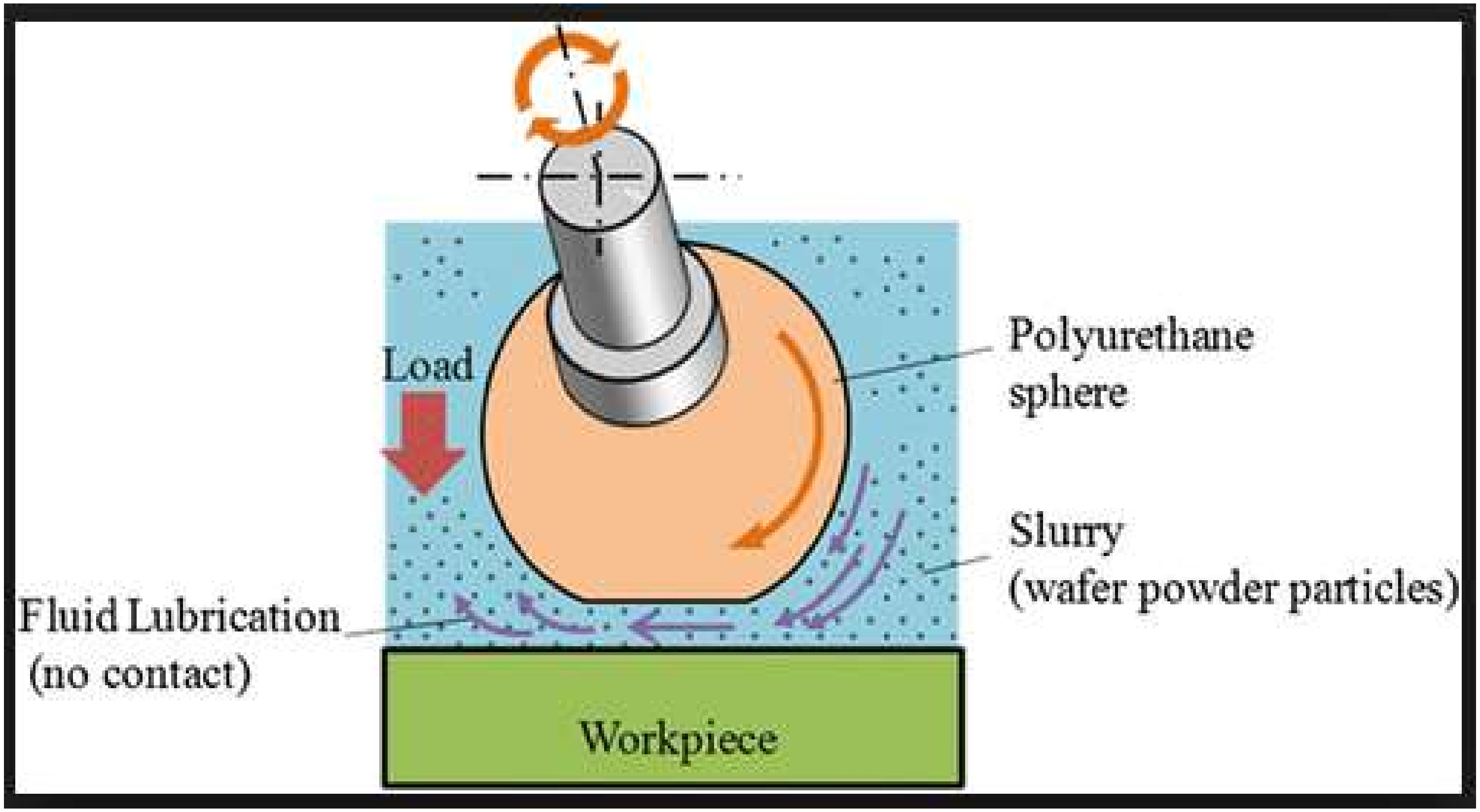
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

EEM – Working Mechanism



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

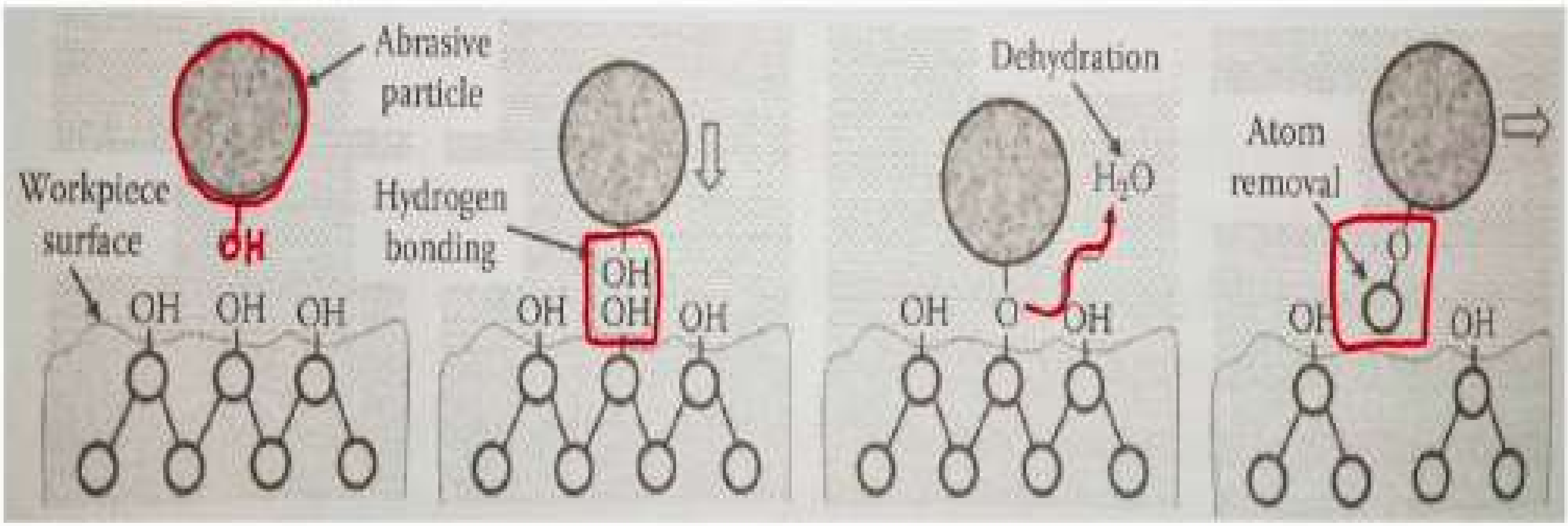
EEM



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Mechanism of Material Removal in EEM Process

Chemical Reaction between abrasive particle and workpiece surface



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Elastic Emission Machining

- Uses **ultra fine particles** to collide with workpiece surface.
- Finish surface by atomic scale **elastic fracture** & **directly** by **removing atoms** & molecules from surface without plastic deformation.
- Workpiece is submerged in slurry of **abrasive particles** (ZrO_2 or Al_2O_3) **and water.**
- **Polyurethane ball**(56 mm dia) mounted on shaft, driven by motor, is used to apply working pressure.
- Material removed by **erosion of surface atoms** by bombardment of abrasive particles.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

EEM – Process Parameters

1. Applied working pressure

- As working pressure increases MRR also increases.

2. Traverse speed / No. of cycles of operation

- As traverse speed increases, surface finish increases.

3. Fineness and hardness of abrasive particles

- As abrasive fineness increases, surface finish increases.
- Hard abrasives removes material more effectively.

EEM Applications

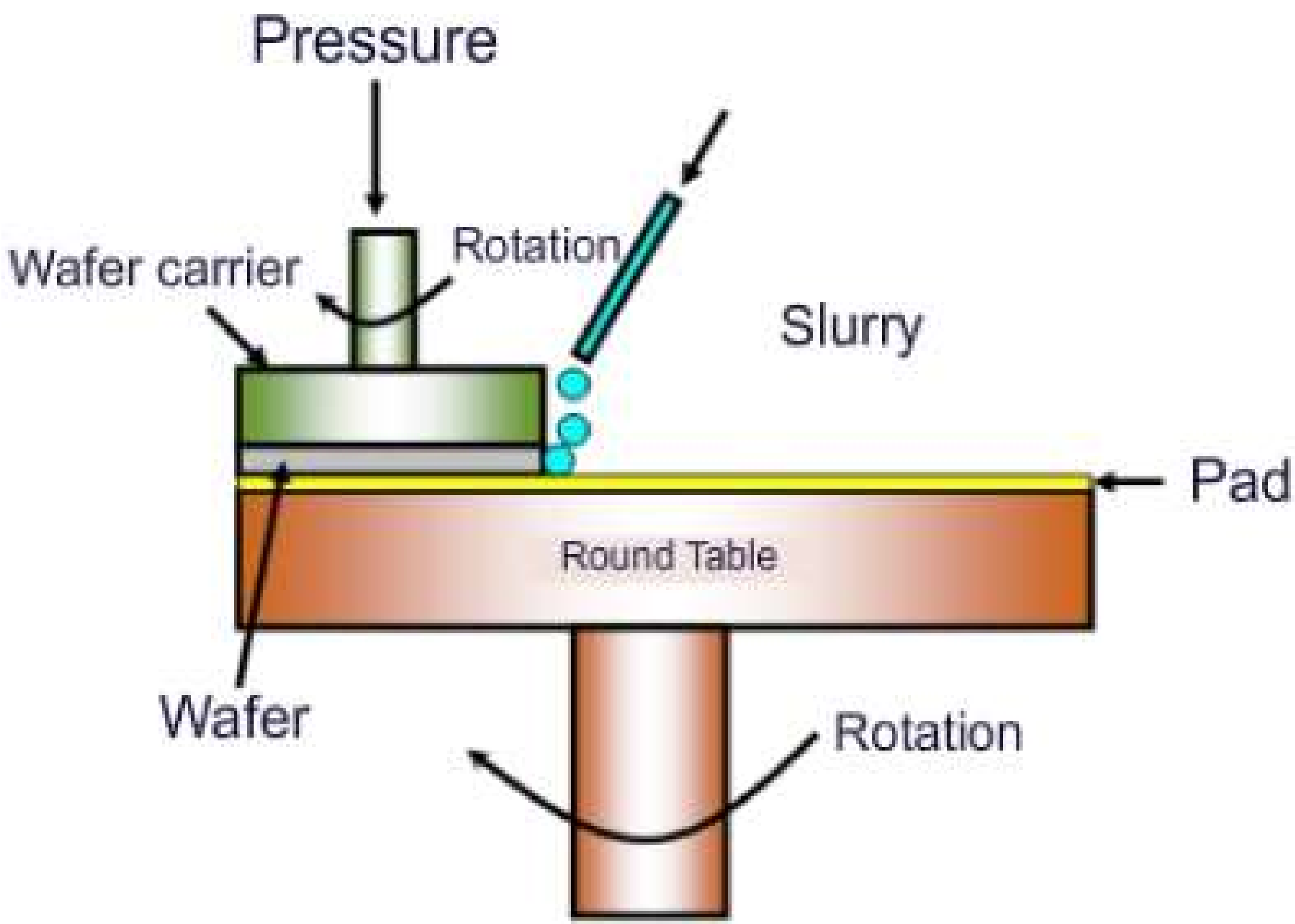
- Used for the fabrication of smooth and stress free surfaces of optical devices.
- For finishing ellipsoidal and focusing mirrors.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Chemical Mechanical Polishing (CMP)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Chemical Mechanical Polishing (CMP)



Chemical Mechanical Polishing (CMP)

- **Chemical mechanical polishing/ planarization** is a process of smoothing surfaces with the combination of chemical reaction and mechanical force.
- CMP is considered as a hybrid combination of chemical etching and abrasive polishing.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

CMP – Working principle

- The process uses an abrasive and corrosive chemical slurry (commonly known as colloid) in combination with a polishing pad.
- The corroded thin surface layer on the work piece is removed during the abrasive action.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

CMP Applications

- Fabrication of semi conductor devices.
- Micro fabrication of patterns for precise medical and aerospace applications.
- For making surgical equipments.
- Widely used in electronics industry for nano finishing of components.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

MODULE 5

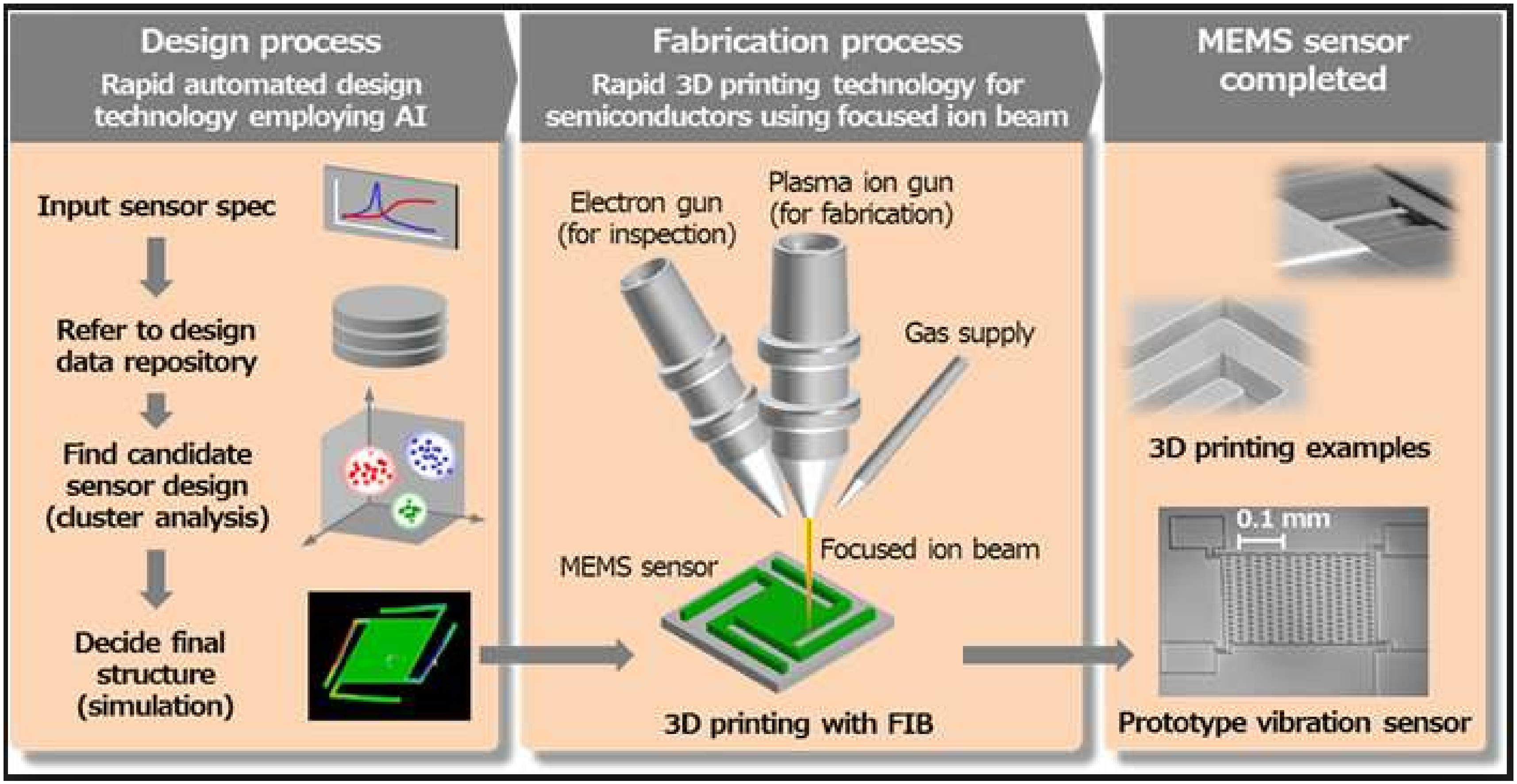
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro fabrication

- **Micro fabrication** is the process of fabricating miniature structures of micro meter scales and smaller.
- Eg. Integrated circuit board fabrication, semiconductor manufacturing & micro electro mechanical systems (MEMS) fabrication.

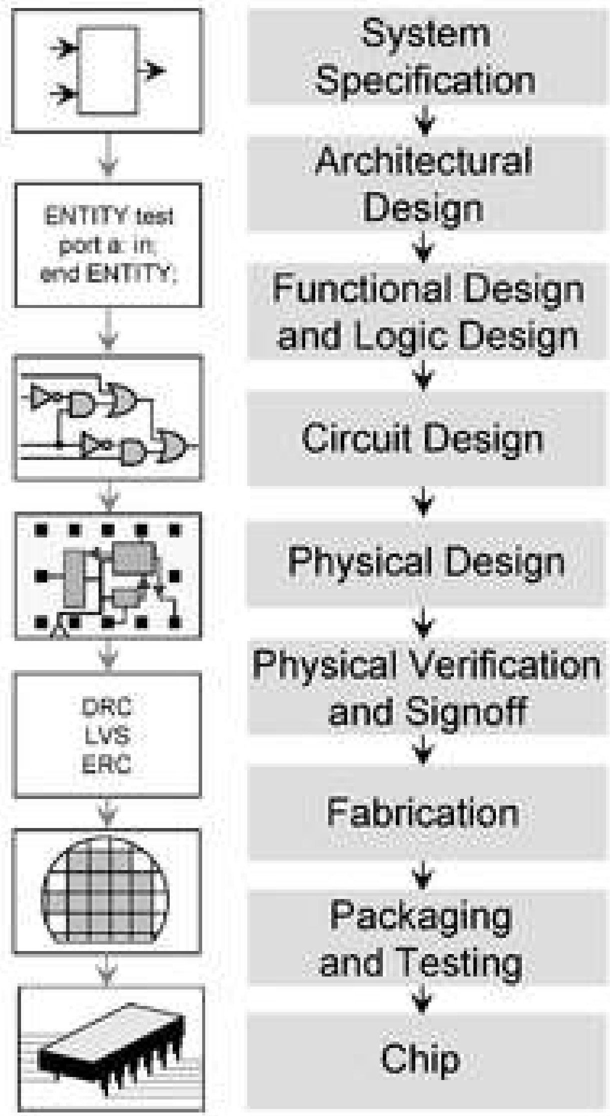
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Micro fabrication of MEMS – flow chart



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Chip making process



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Nano fabrication

- Nanofabrication refers to the design and manufacturing process of nano materials and devices that are measured in nanometers.
- It is a cost-effective method whereby large-scale production of components are achieved.

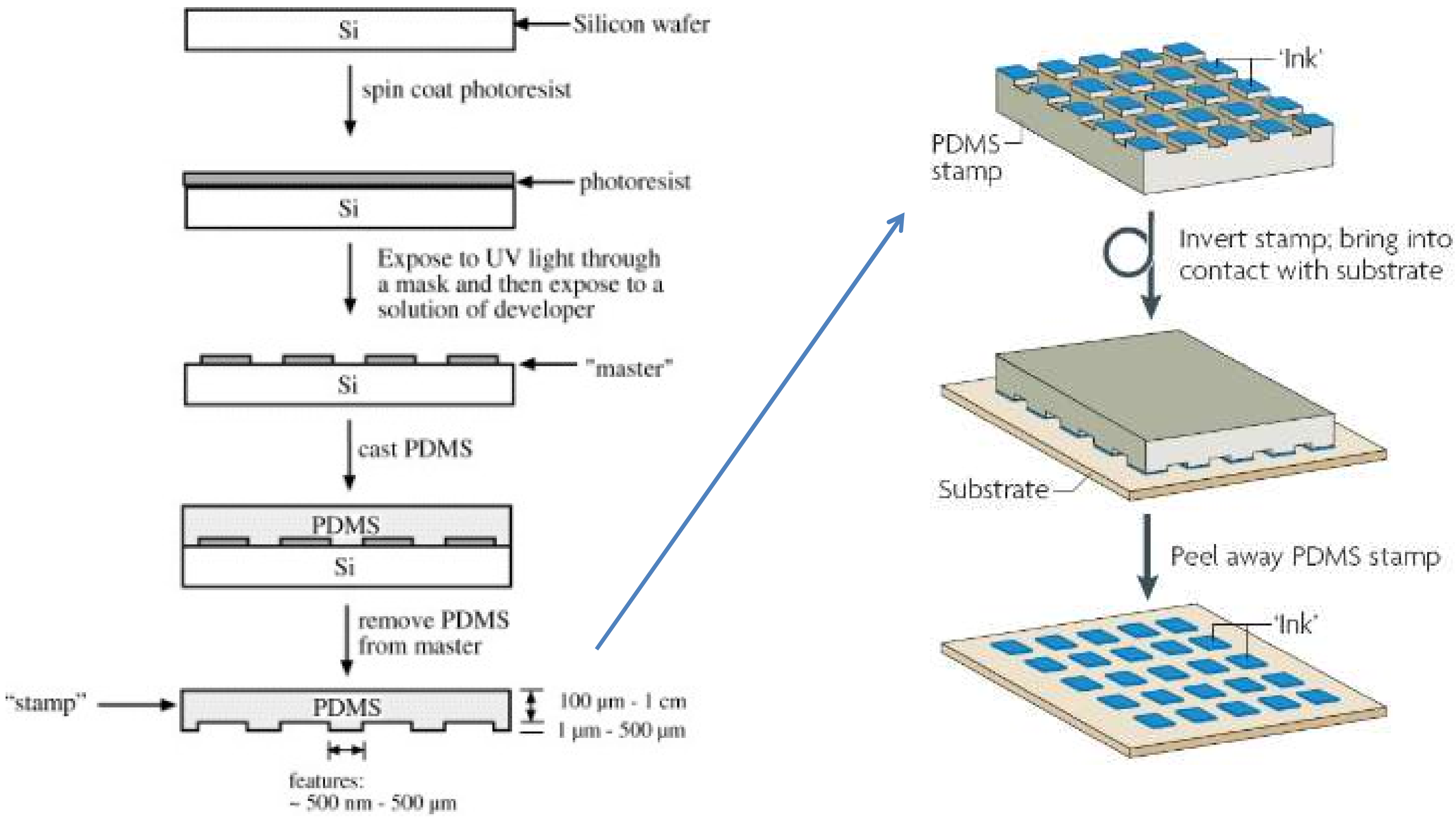
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Soft Lithography

- Soft lithography is a technique for fabricating or replicating structures using elastomeric stamps, molds and conformable photo masks.
- It is called "soft" because it uses elastomeric materials, most commonly Poly di methyl siloxane (PDMS)

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Soft Lithography



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

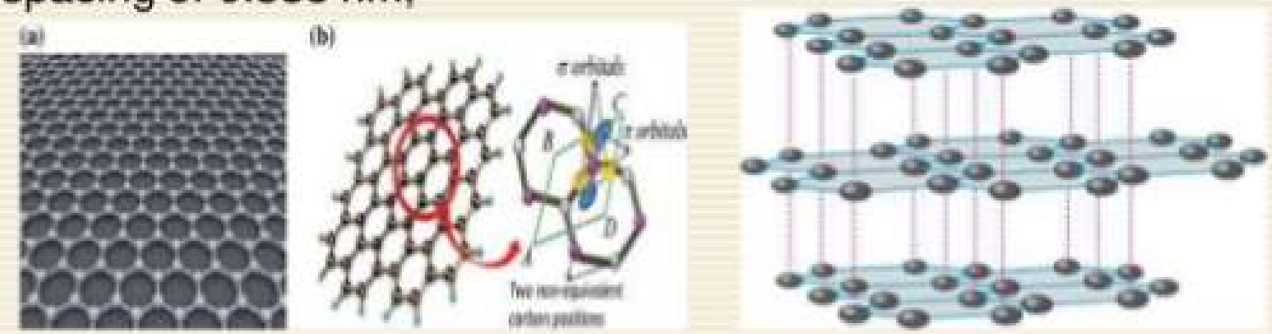
Carbon Nano Tubes (CNTs)

- Carbon nanotubes (CNTs) are allotrope of Carbon with a cylindrical nanostructure.
- Carbon nanotubes (CNTs) are best described as a seamless cylindrical hollow fibers, comprised of a single sheet of pure graphite (Graphene), having a diameter of 0.7 to 50 nanometers with lengths generally in the range of 10-100 of microns.
- Carbon nanotubes (CNTs) are made by rolling up of sheet of GRAPHENE into a cylinder.

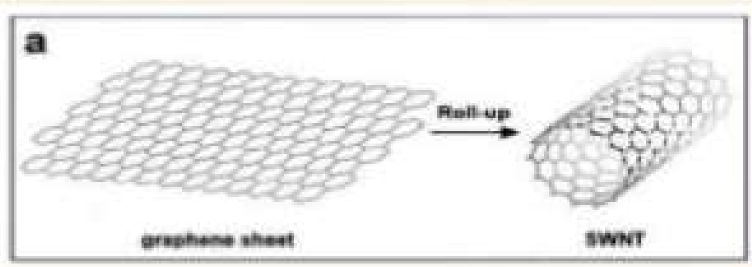
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Graphene

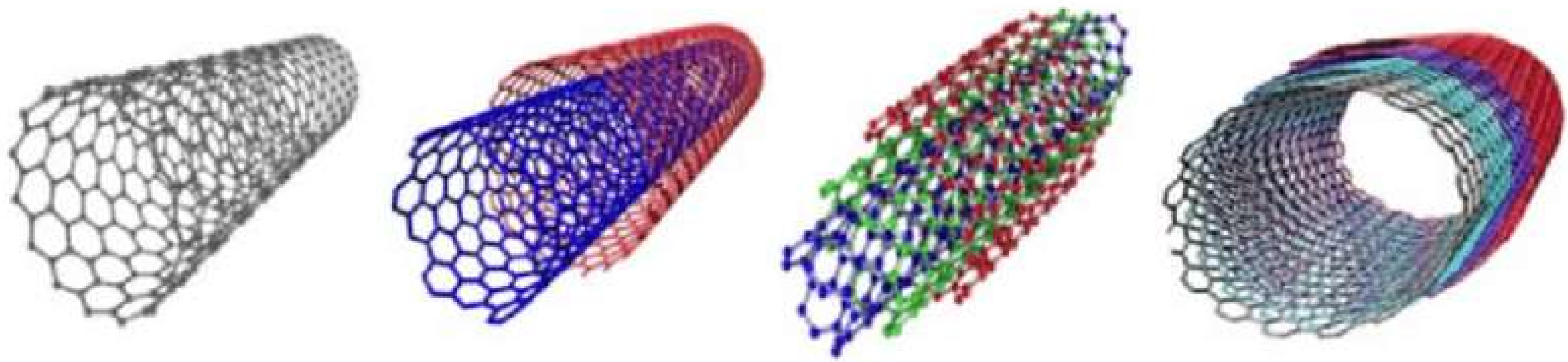
- Graphene is basically a 2D single layer of graphite.
- Graphene is stronger and stiffer than diamond. It, however, can be stretched like rubber.
- The C–C bond($sp2$) length in graphene is ~0.142 nm. The graphene sheets stack to form graphite with an inter planar spacing of 0.335 nm,



- Roll-up Graphene ⟹ Carbon Nano Tubes



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.



SWCNTs
Length = 20-1000 nm
Diameter = 0.4-2.5 nm

DWCNTs
Length = 50μm
Diameter = Less than 2 nm

TWCNTs
Length = 100 mm
Diameter = 3-5nm

MWCNTs
Length = 1-50 μm
Diameter = 1.4-100 nm

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

CNTs

Mechanical and Physical Properties

- Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively.
- This strength results from the covalent sp2 bonds formed between the individual carbon atoms which are stronger than 3D diamond bonds.

Comparison of Mechanical Properties

Materials	Young's modulus (TPa)	Tensile strength (GPa	Elongation at break (%)
SWCNTs	~1 (from 1 to 5)	13–53	16
Armchair SWNT	0.94	126.2	23.1
Zigzag SWCNT	0.94	94.5	15.6–17.5
Chiral SWCNT	.92		
MWNT	0.2 - 0.9	63 - 150	
Stainless Steel	0.183 – 0.264	0.38 – 1.55	15 - 50
Kevlar	0.06 – 0.18	3.6 – 3.8	~2

CNT Applications

1. **Electronic applications**
- Conductive composites
- Electron emitters
- Nano probes
2. **Sensors** for automotive industry, biomedical industry, food industry & environment monitoring
3. **Medical Applications**
- Artificial and damaged hearts
- Artificial limbs
- Prosthetic devices
4. **CNT based composites**

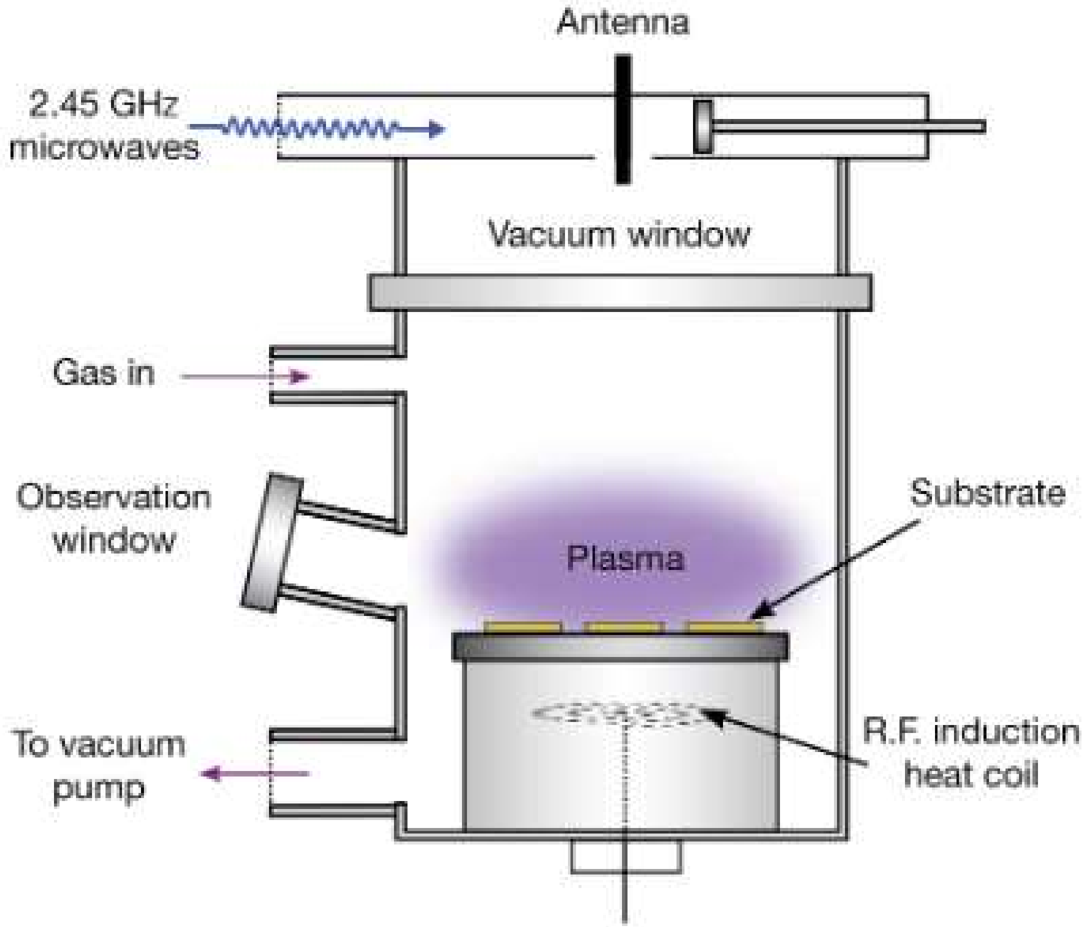
Synthetic diamond

- A synthetic diamond is produced by a controlled process, as contrasted with a natural diamond
- It is created by geological processes or an imitation diamond made of non-diamond material that appears similar to a real diamond.

CVD diamond technology

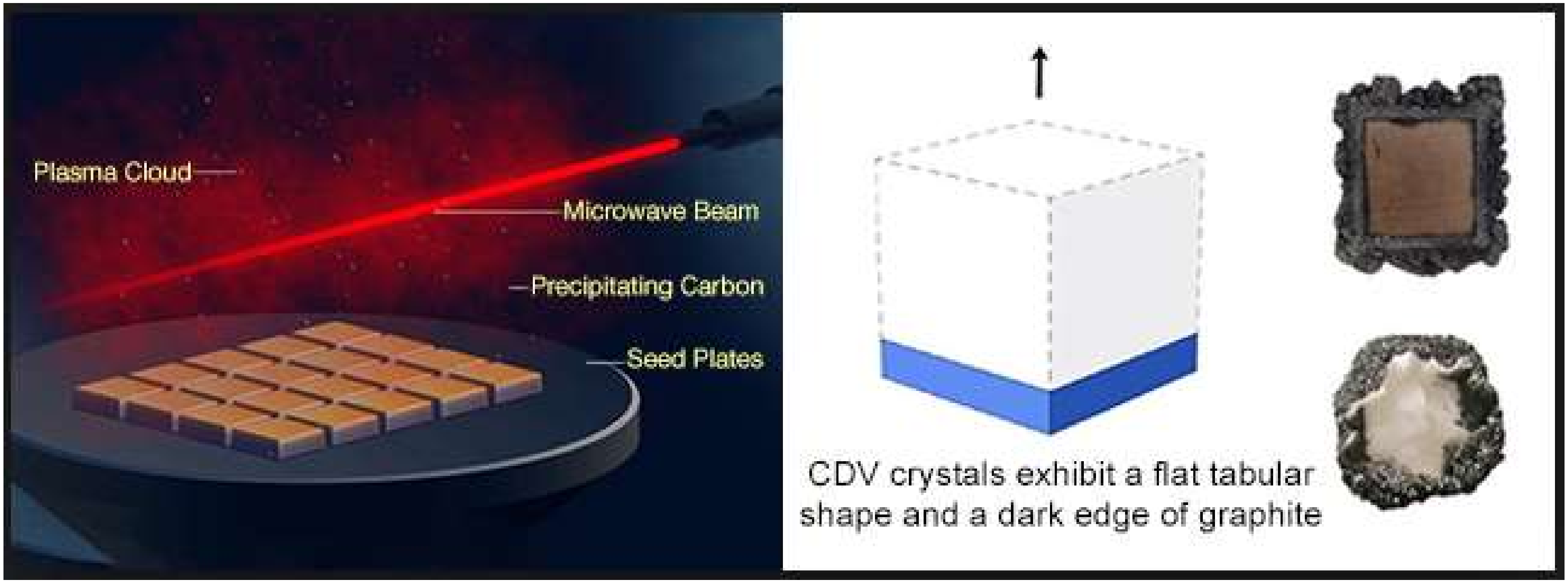
- This technology makes use of controlled chemical vapor deposition (CVD) of carbon particles for manufacturing synthetic diamonds.

CVD diamond technology - Setup



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

CVD diamond technology - Process

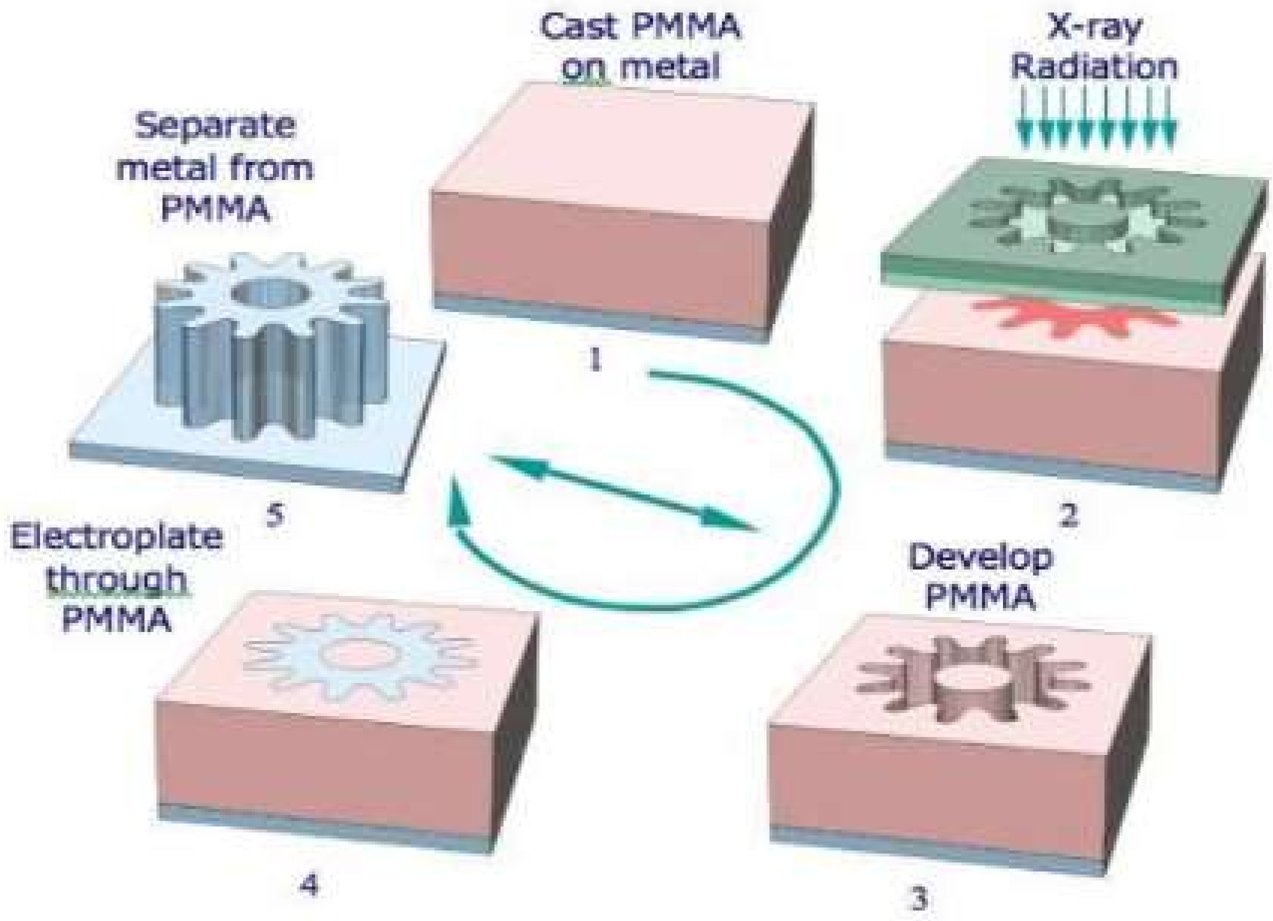


LIGA Process

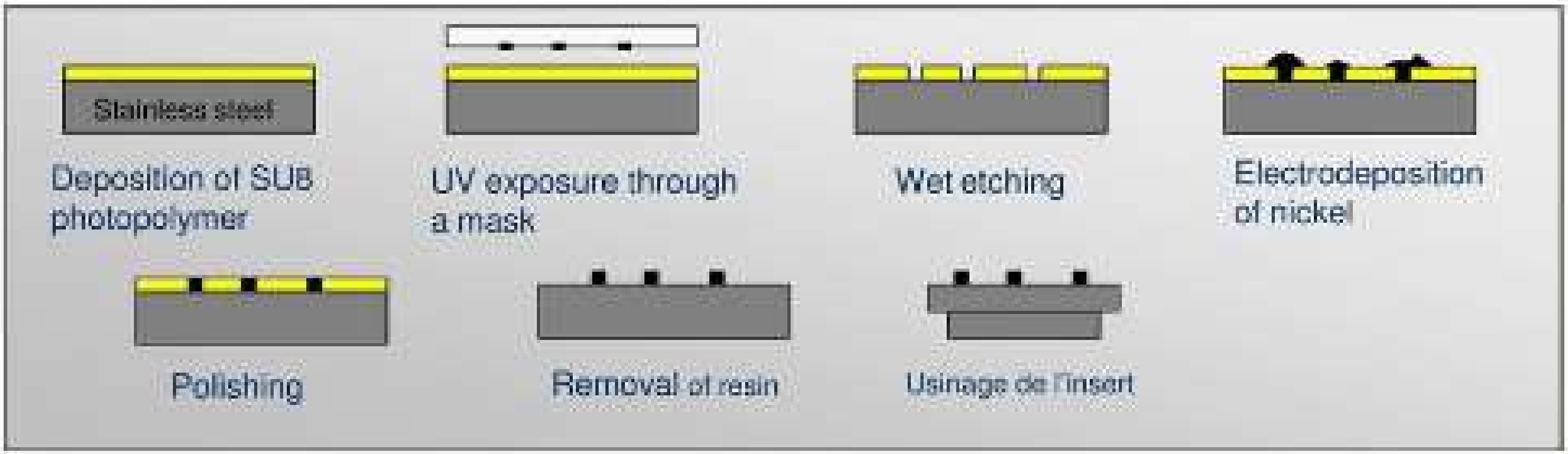
- LIGA process is used to manufacture micro structures by deep X-ray or UV lithography.
- LIGA is the german acronym for lithography, electroplating and moulding (**Li**thographie, **G**alvanik und **A**bformung).

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

LIGA Process



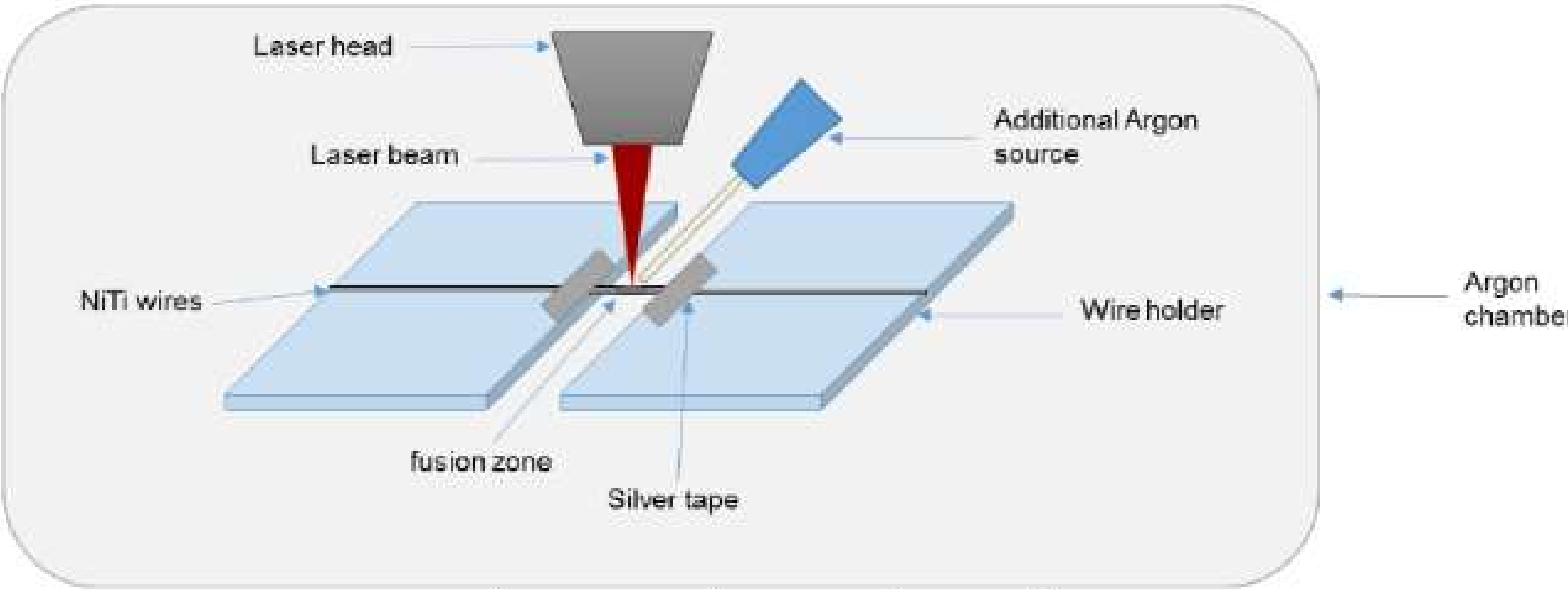
LIGA Process



End of Module 5

MODULE 6

Laser micro welding



Laser microwelding

- ✓ Fusion micro joining - at least one dimension of the part being processed is less than 100 µm.
- ✓ Non-contact nature and high intensity resulting from the ability to focus it to a small diameter. This property of laser makes it a very potent tool for processing micro scale jobs.
- ✓ Lasers can be used very efficiently to process a variety of materials - both metallic and non-metallic
- ✓ The general configuration of laser micro welding is similar to the conventional process.
- ✓ Pulse and continuous mode of laser microwelding
- ✓ Laser transmission welding where a combination of a transparent material and an absorbing material is used to fuse the transparent material.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Laser micro welding applications

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Laser micro welding

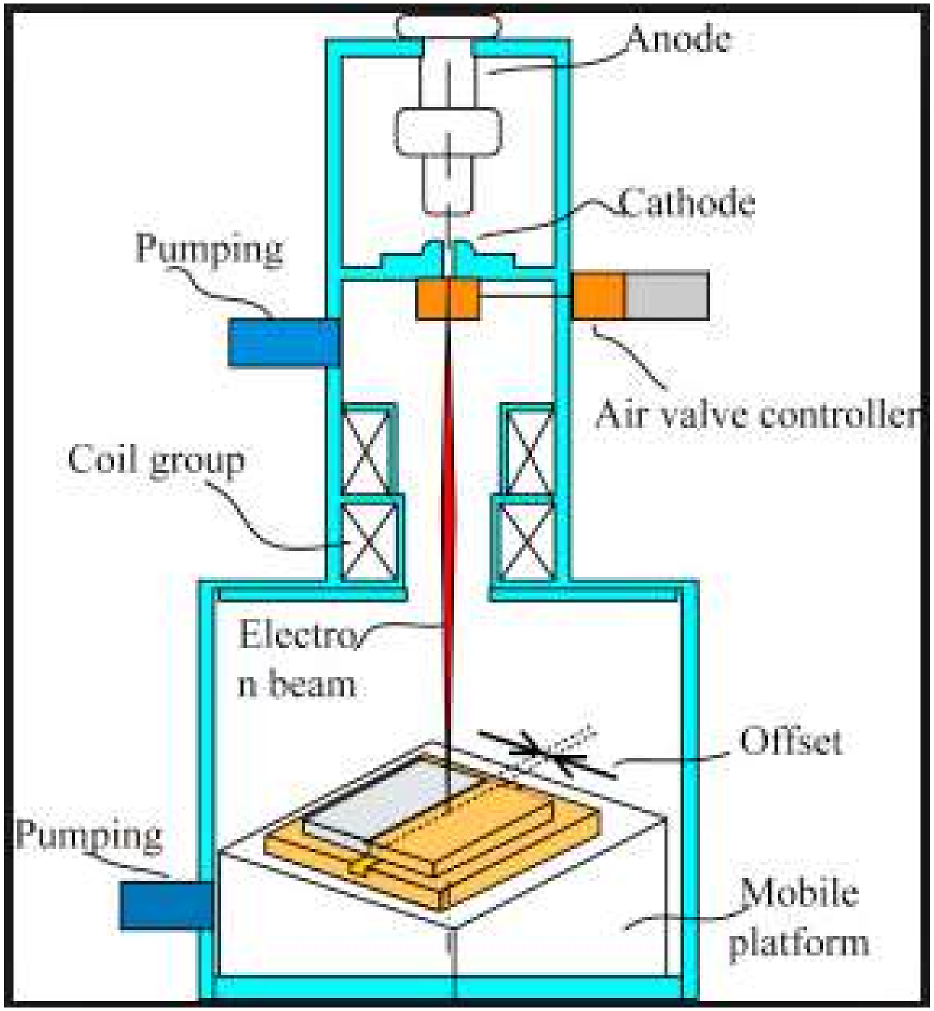
Advantages

- Precise location of small welds
- Low heat input
- Minimal distortion
- High speed
- Non-contact
- Can weld "shapes"

Disadvantages

- Laser cost $$
- Need line-of-sight access
- Requires good fit-up, tooling
- Heating starts on the surface
- Limited weld penetration especially on copper
- Makes fusion welds
- Welds very narrow
- Eye safety hazard

Electron beam micro welding



Electron beam micro welding applications

- Automotive industries
- Aircraft and space industries
- Mechanical engineering
- Tool construction
- Nuclear power industries
- Power plants
- Fine mechanics and electrical
- Industries
- Job shop

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

EBW Advantages / Disadvantages

Advantages:

- High-quality welds, deep and narrow profiles
- Limited heat affected zone, low thermal distortion
- High welding speeds
- No flux or shielding gases needed

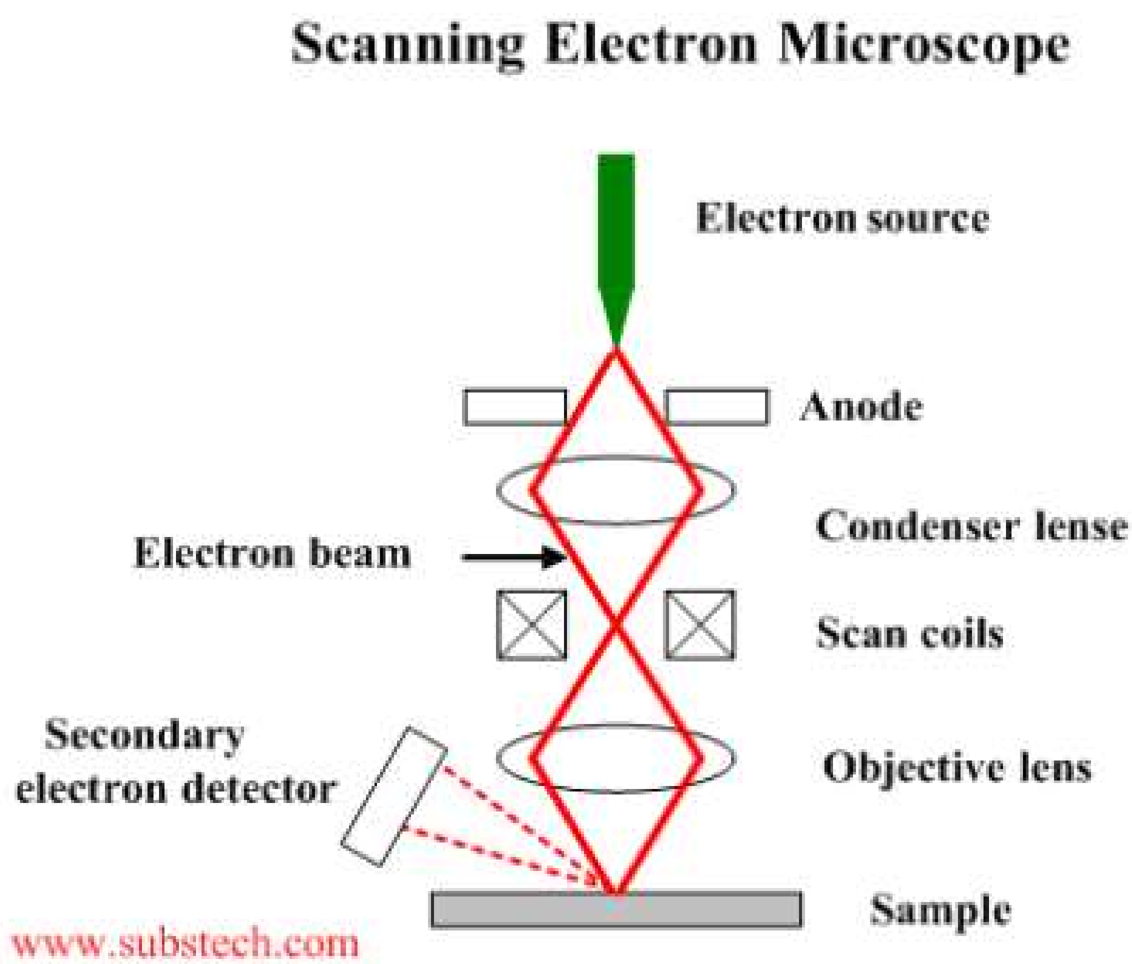
Disadvantages:

- High equipment cost
- Precise joint preparation & alignment required
- Vacuum chamber required
- Safety concern: EBW generates x-rays

Micro & nano measurement systems

1. Scanning electron microscopy (SEM)
2. Scanning white light interferometry (SWLI)
3. Optical microscopy
4. Scanning probe microscopy (SPM)
5. Scanning tunneling microscopy (STM)
6. Confocal microscopy

SEM

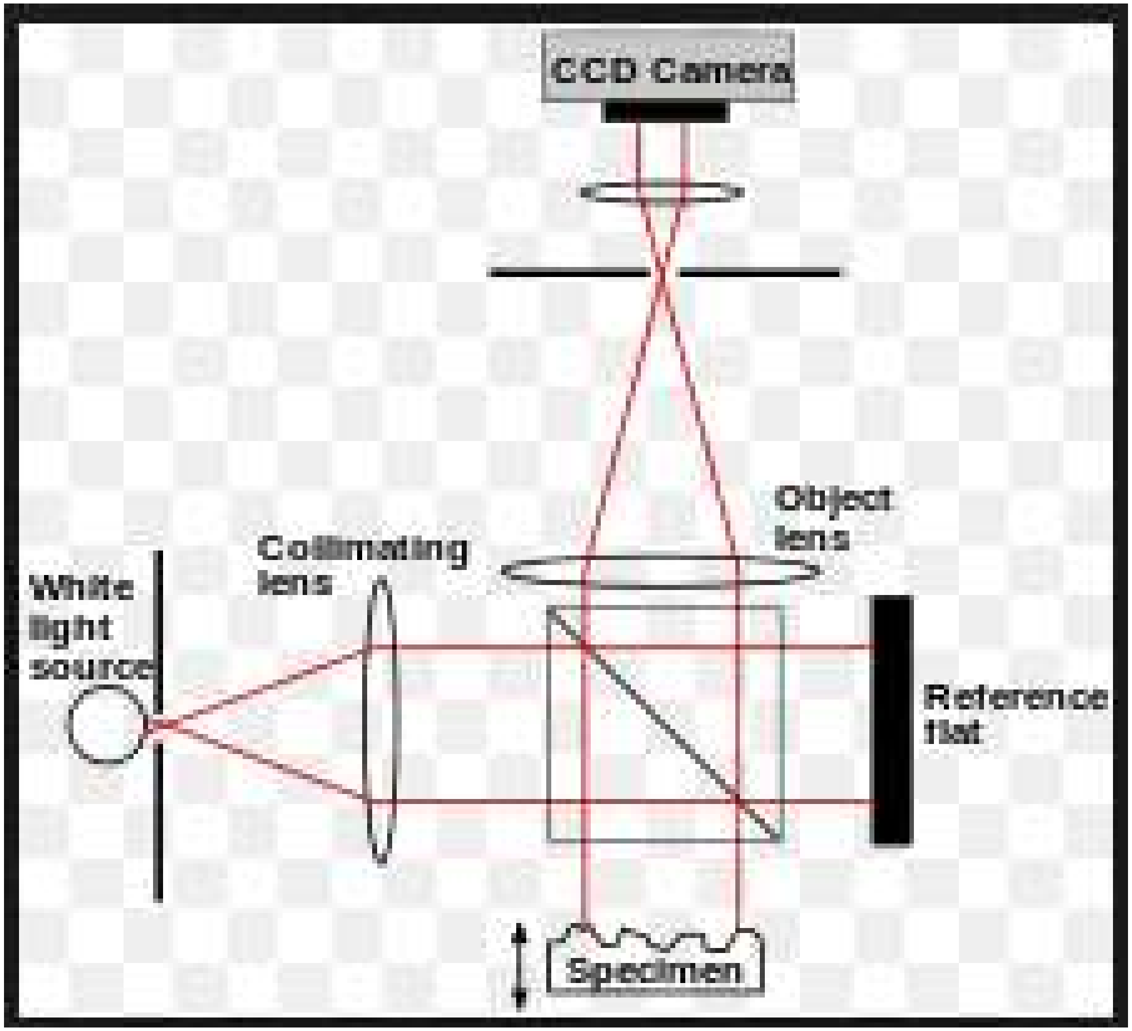


Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

SEM

- A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons.
- The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.

Scanning White Light Interferometry

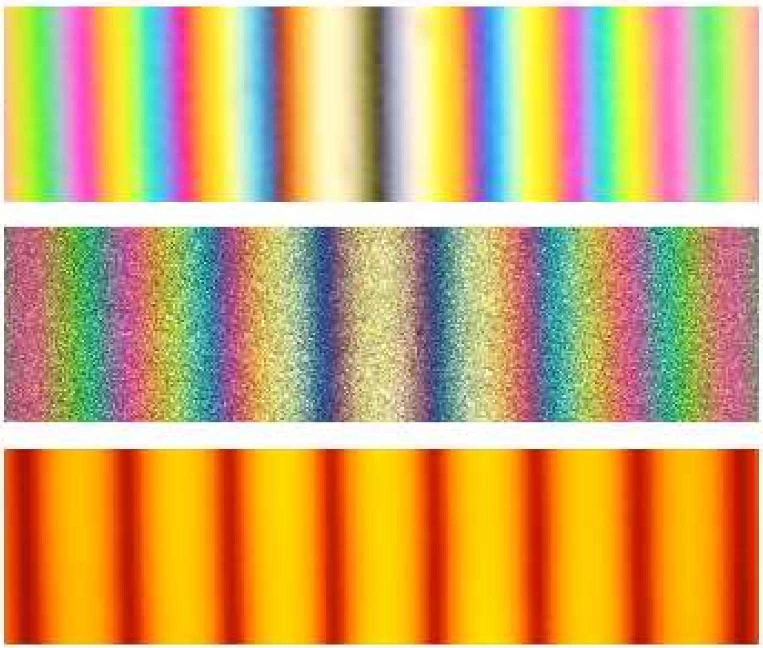


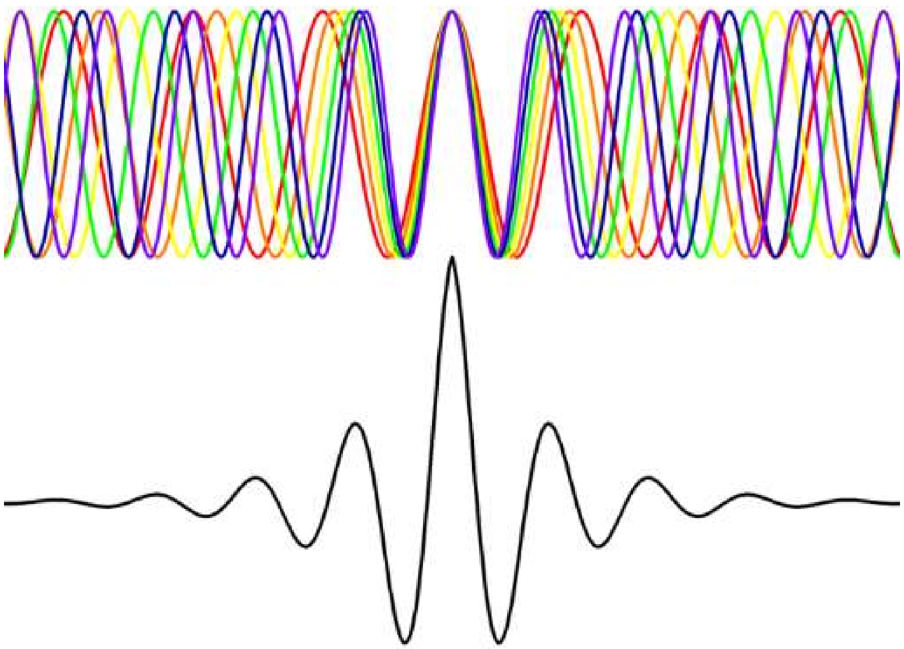
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Scanning White Light Interferometry (SWLI)

- SWLI uses a white light source to map surface topography of samples.
- Light from the source passes through a beam splitter to generate a measurement beam and reference beam.
- The reference beam travels along the reference beam path length and reflects from a mirror.
- The measurement beam reflects off of the sample and is recombined with the reference beam.
- The interferometer scans the intensity of reflected light captured by a CCD (charge coupled device) array or a HD camera.
- Used for measuring surface roughness, dimensions of micro holes and slots, depth of high aspect ratio holes…

SWLI – Light Fringes





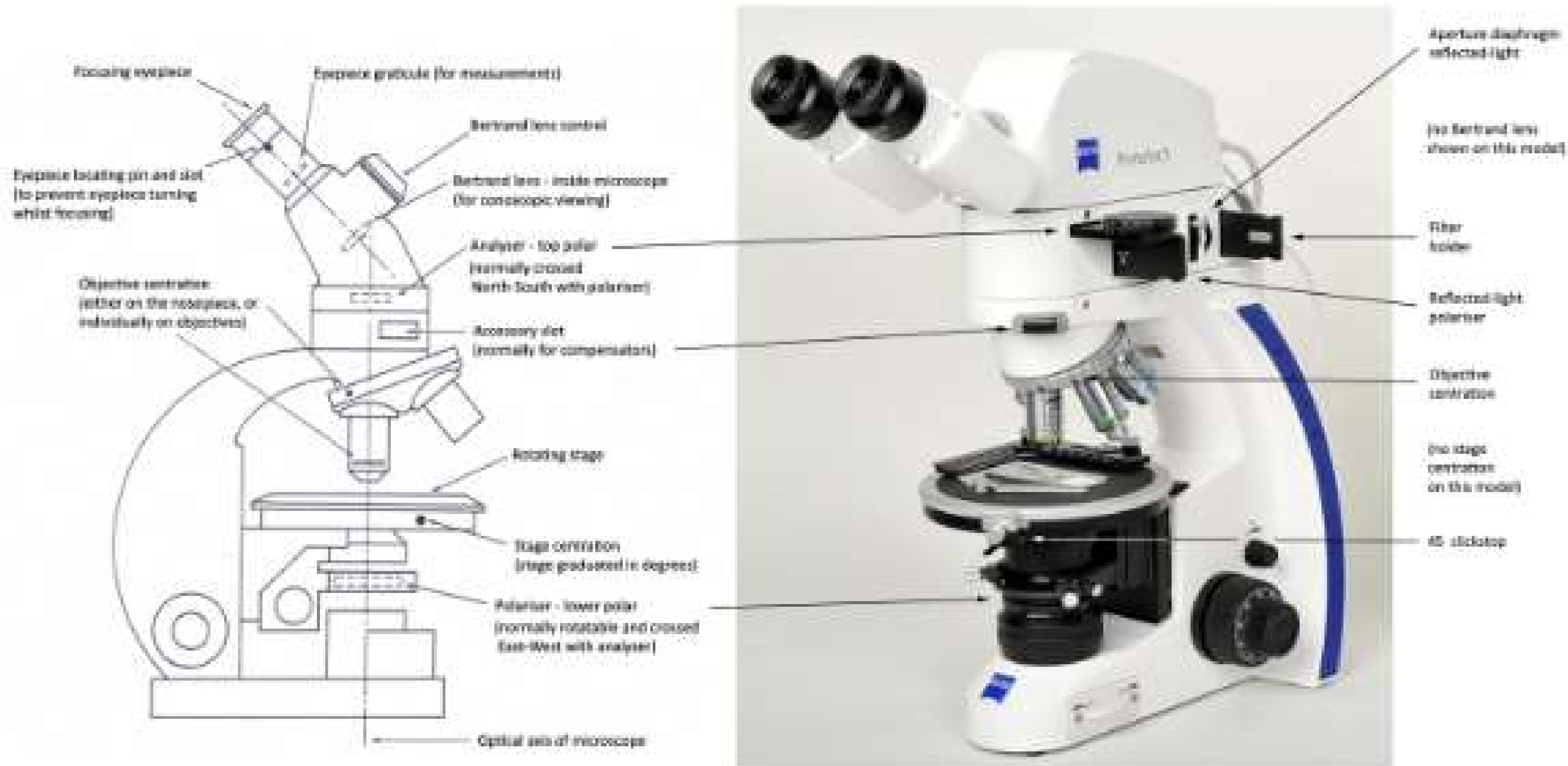
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Optical Microscopy

- An optical microscope, often referred to as the light microscope, is a type of microscope that commonly uses visible light and a system of lenses to magnify images of small objects.
- Optical microscopes are the oldest type of microscope.

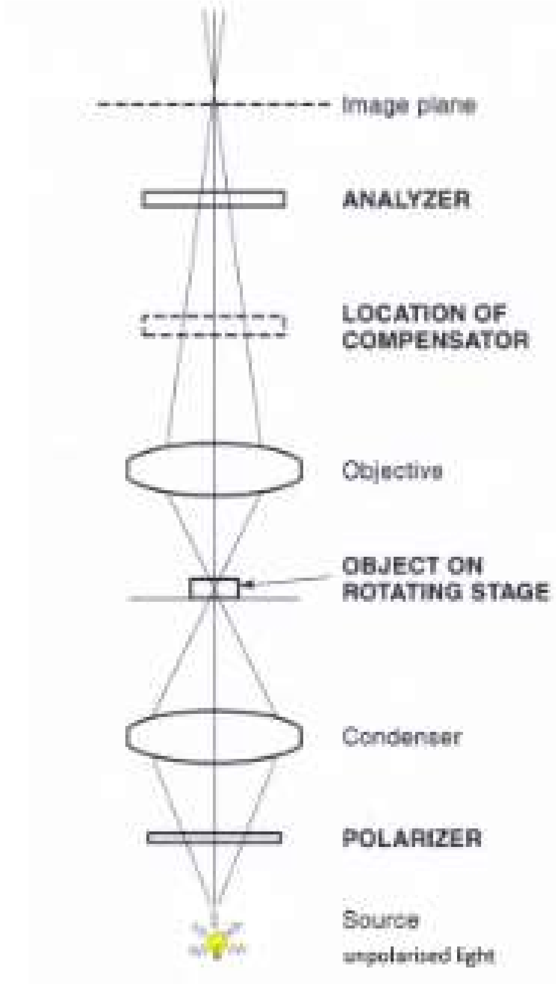
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Optical Microscope



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Optical Microscope



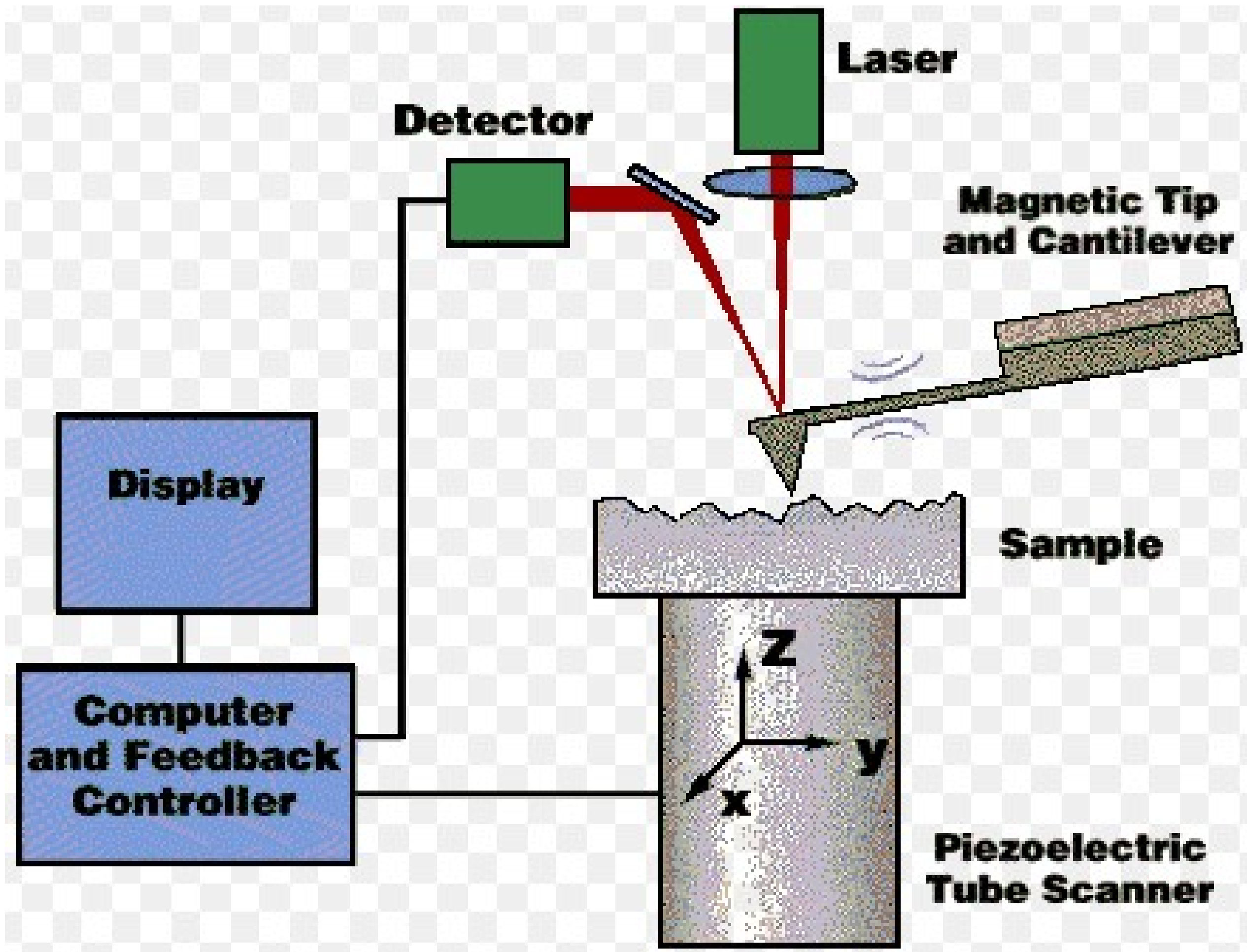
Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Applications

- **Optical microscopy**
  - phase identification, purity, and homogeneity
  - crystal defects : grain boundaries and dislocation
  - refractive index determination

- **Electron microscopy**
  - particle size and shape, texture, surface detail
  - crystal defects
  - precipitation and phase transitions
  - chemical analysis
  - structure determination

Scanning Probe Microscopy (SPM)



Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Scanning Probe Microscopy (SPM)

- Scanning probe microscopy (SPM) is a new branch of microscopy that forms images of surfaces using a physical probe that scans the specimen.
- An image of the surface is obtained by mechanically moving the probe in a raster scan of the specimen, line by line, and recording the probe-surface interaction as a function of position.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Applications of SPM

To resolve a wide range of **surface** properties on the **nanometer** scale including:

Topography, mechanical, magnetic, electric, thermal, and etc.

e.g., **Nano lithography**, inspecting defects of semiconductors, measuring physical and chemical properties of surface, DNA imaging, etc.

Advantages:

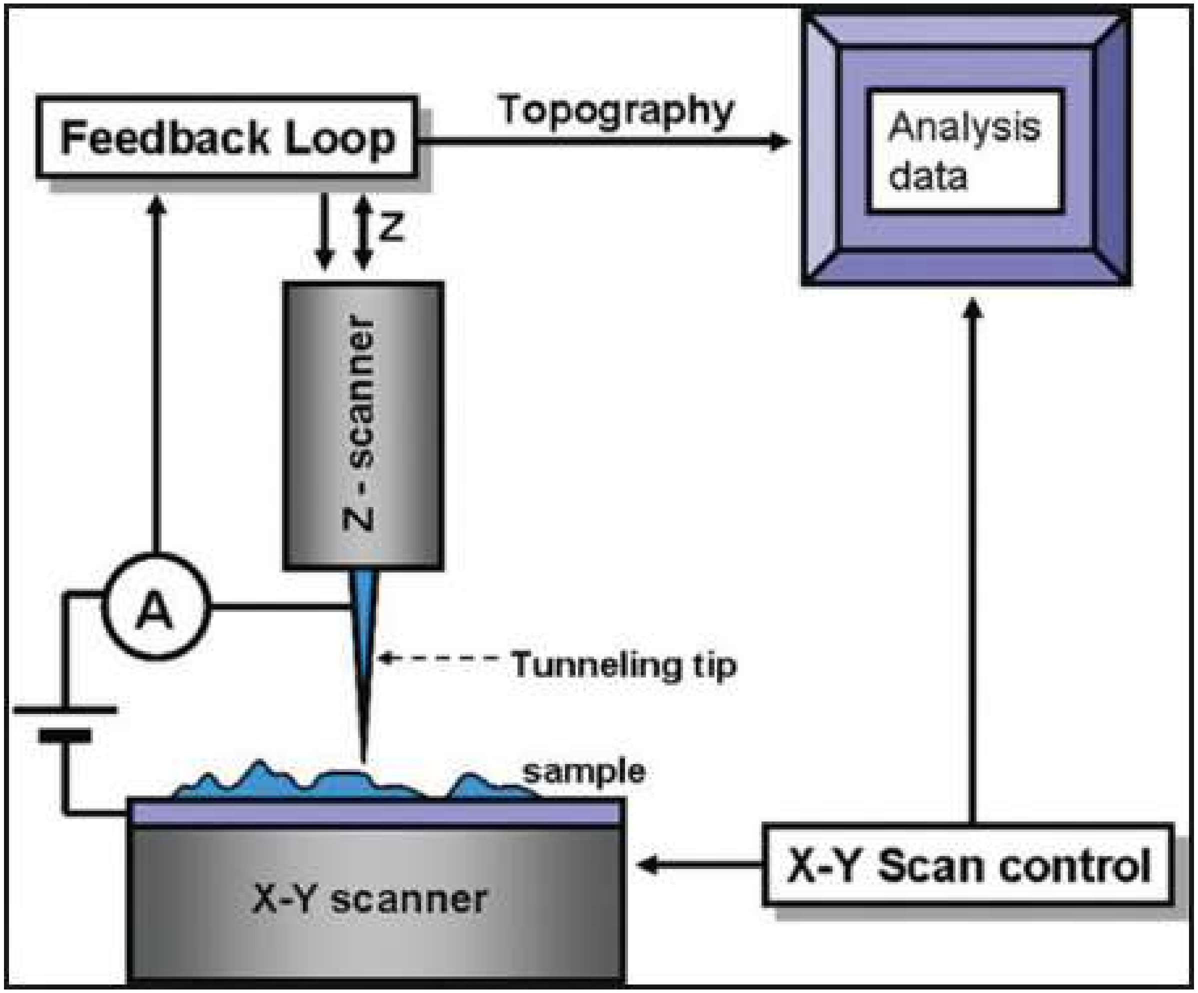
Superior resolution and versatility of scanning probes

Limitations:

Long imaging times due to slow scanning speed

The maximum imaging area is limited ($<mm^2$)

Scanning Tunneling Microscopy (STM)

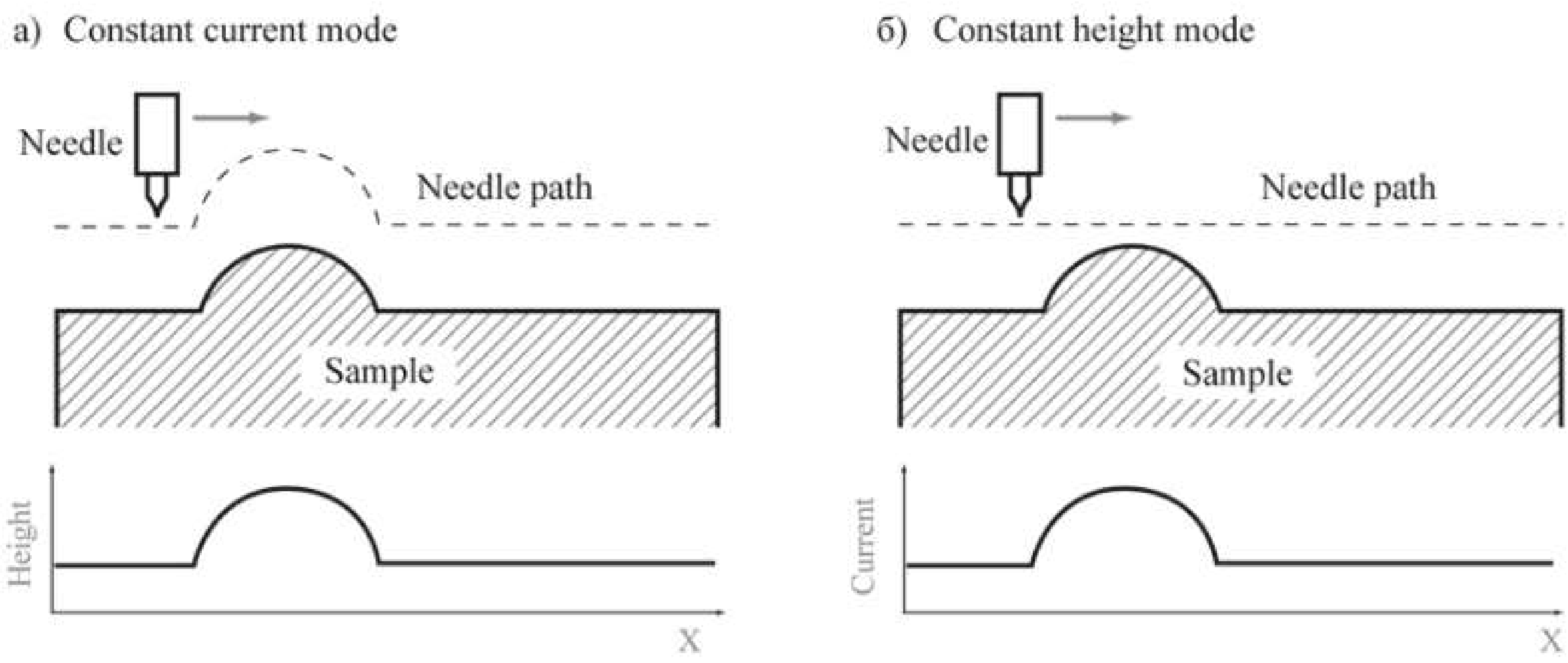


Scanning Tunneling Microscopy (STM)

- When a conducting tip is brought very near to the surface to be examined, a **bias** (voltage difference) applied between the two can allow electrons to tunnel through the vacuum between them.
- The resulting **tunneling current** is a function of tip position & applied voltage of the sample.
- Information is acquired by monitoring the current as the tip's position scans across the surface, and is usually displayed in image form.

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.

Scanning Tunneling Microscopy (STM)



STM

Advantages:

- STMs are versatile. They can be used in ultra high vacuum, air, water and other liquids and gasses.
- STMs give three dimensional profile of a surface, which allows researchers to examine a multitude of characteristics, including roughness, surface defects and molecule size.
- Lateral Resolution of 0.1 nm and 0.01 nm of resolution in depth can be achieved.

Disadvantages:

- It is very expensive.
- It need specific training to operate effectively.
- STM need very clean surface, excellent vibration control while operation, single atom tip.

Assignment # 2

(Submit on or before Friday 26.04.2019)

1. With neat sketches explain the working of a field effect transistor?
2. Explain a manipulative technique used in the area of nanofabrication.
3. With neat sketches explain the working of a carbon nano tube transistor.
4. With neat sketches explain the working principle of confocal microscopy. Also write few advantages, disadvantages & applications of the same.
5. Write short notes about on-machine metrology.

THANK YOU...

ALL THE BEST...

Kora T Sunny, Assistant Professor,
Department of Mechanical Engineering,
M A College of Engg., Kothamangalam.