ADVANCED MACHINING PROCESSES: AN INTRODUCTION

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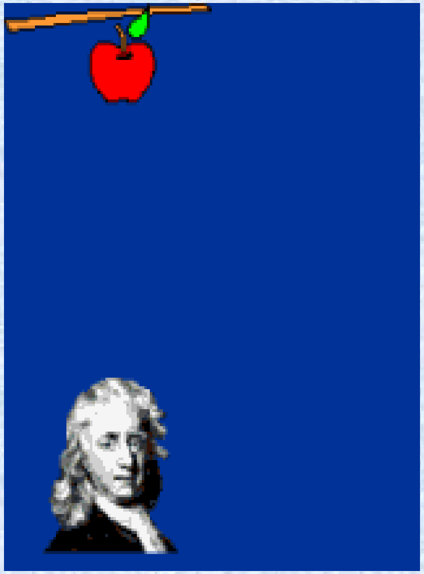
* BE KEEN OBSERVER

EXAMPLES OF SOME SCIENTISTS

SIR ISSAC NEWTON

KEEN OBSERVATIONS HAD LED TO BIG INVENTIONS



WHY IT FELL DOWNWARD?
WHY DID IT NOT GO UP?

↓

THEORY OF GRAVITATION

DR. C. V. RAMAN

OBSERVING THE WAVES IN SEA WHILE GOING ABROAD

WHY THE WATER OF SEA LOOKS BLUE IN COLOUR?

LED TO THE INVENTION OF "*RAMAN EFFECTS*"

NOBLE PRI ZE WINNER

IS IT NECESSARY FOR THE TOOL TO BE HARDER THAN WORKPIECE ?

HOW A ROPE CAN WEAR THE PULLEY ?

WORN OUT PULLEY BY A ROPE

INTRODUCTION

ENGINEERING MATERIALS

METALS AND ALLOYS

PLASTICS AND COMPOSITES

CERAMICS

- GETTING MORE POPULARITY
- DEFINITE ADVANTAGES OVER OTHERS

HOW TO MACHINE THEM ?

SOLUTION

ADVANCED MACHINING PROCESSES

PRESENT DAY DEMAND TRENDS IN INDUSTRIES
(AEROSPACE , MISSILES , AUTOMOBILES, NUCLEAR REACTORS, ETC.)

ENGG. MATERIALS HAVING MUCH SUPERIOR PROPERTIES

→ ULTRA HIGH STRENGTH , HARDNESS

→ VERY HIGH TEMPTURE RESISTANCE

→ DIFFICULT TO MACHINE BY CONVENVENTIONAL MACHINING METHODS

→ **WORK PIECE MATERIAL HARDNESS >> TOOL MATERIAL HARDNESS**

HOW TO SOLVE THE PROBLEM ?

↓

ADVANCED MACHINING PROCESSES

WORKPIECE HARDNESS DOES NOT MATTER IN AMPs

WHY DO YOU NEED ADVANCED MACHINING PROCESSES

(AMPs)

?

- **LIMITATIONS OF CONVENTIONAL MACHINING METHODS**

  (WORKPIECE HARDNESS, SURFACE ROUGHNESS, 3-D PARTS, COMPLEX GEOMETRIES)

- **INCREASED WORKPIECE HARDNESS → DECREASED ECONOMIC CUTTING SPEED → LOWER PRODUCTIVITY**

- **RAPID IMPROVEMENTS IN THE PROPERTIES OF MATERIALS (WORKPIECE→HARDNESS, STRENGTH, ETC.)**

- **METALS & NON – METALS : STAINLESS STEEL , HIGH STRENGTH TEMPERATURE RESISTANT (HSRT) SUPER ALLOYS: STELLITE, ETC.**

- **TOOL MATERIAL HARDNESS >> WORKPIECE HARDNESS**

- REQUIRES MUCH SUPERIOR QUALITY OF TOOL MATERIALS

WHY DO YOU NEED ADVANCED MACHINING PROCESSES (AMPs)

?

PRODUCT REQUIREMENTS

- COMPLEX SHAPES
- MACHINING IN INACCESSIBLE AREAS
- LOW TOLERANCES (SAY, 10 µm)
- BETTER SURFACE INTEGRITY (NO SURFACE DEFECTS, ETC.)
- HIGH SURFACE FINISH (NANO LEVEL Ra VALUE =>nm)
- MINIATURIZATION OF PRODUCTS (EXAMPLES: LANDLINE PHONE & MOBILE, OLD COMPUTERS & LAP TOP, ETC.)
- HIGH MRR

WHY DO YOU NEED ADVANCED MACHINING PROCESSES

?

HIGH PRODUCTION RATE WHILE PROCESSING DIFFICULT –TO-MACHINE MATERIALS

LOW COST OF PRODUCTION

PRECISION AND ULTRAPRECISION MACHINING

(NANO-METER MACHINING)

REQUIRES MATERIAL REMOVAL IN THE FORM OF ATOMS AND / OR MOLECULES

ADVANCED MACHINING PROCESSES

(AMPs)

WHY DO YOU NEED ADVANCED MACHINING PROCESSES ?

some examples

Fabrication

Building of machines, structures, or process equipment by cutting, shaping and assembling components made from raw materials.

Fabrication

IGNORING MESO AND NANO FABRICATION

Meso / Macro fabrication	Micro fabrication
Process of fabrication of structures that are measurable and observable.	Process of fabrication of miniature structures / features of µm sizes
Visible by naked eye	Need microscopic equipments
Dimensions >= 1mm	999 nm <=Dimensions <= 999 µm

- CLASSIFICATION BASED ON THE KIND OF ENERGY USED : MACHANICAL, THERMOELECTRIC, ELECTROCHEMICAL & CHEMICAL, BIOCHEMICAL

MECHANICAL

MACHINING

ABRASIVE JET MACHINING (AJM)

ULTRASONIC MACHINING (USM)

WATER JET MACHINING (WJM)

ABRASIVE WATER JET MACHINING (A WJM)

FINISHING

ABRASIVE FLOW FINISHING (AFM)

MAGNETIC ABRASIVE FINISHING (MAF)

MAGNETORHEOLOGICAL FINISHING (MRF)

THERMOELECTRIC

PLASMA ARC MACHINING (PAM)

LASER BEAM MACHINING (LBM)

ELECTRON BEAM MACHINING (EBM)

ELECTRIC DISCHARRGE MACHINING (EDM)

ION BEAM MACHINING(IBM)

ELECTROCHEMICAL & CHEMICAL

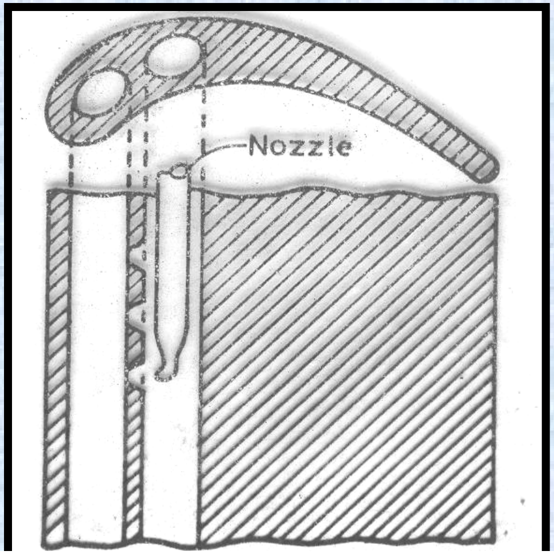
ELECTROCHEMICAL MACHINING (ECM)

CHEMICAL MACHINING (CHM)

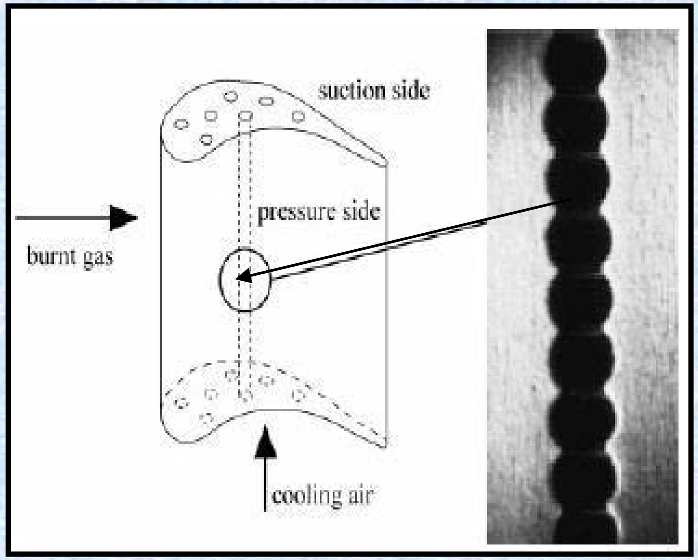
BIOCHEMICAL MACHINING (BM)

MACHINING OF COMPLEX SHAPED WORKPIECES?

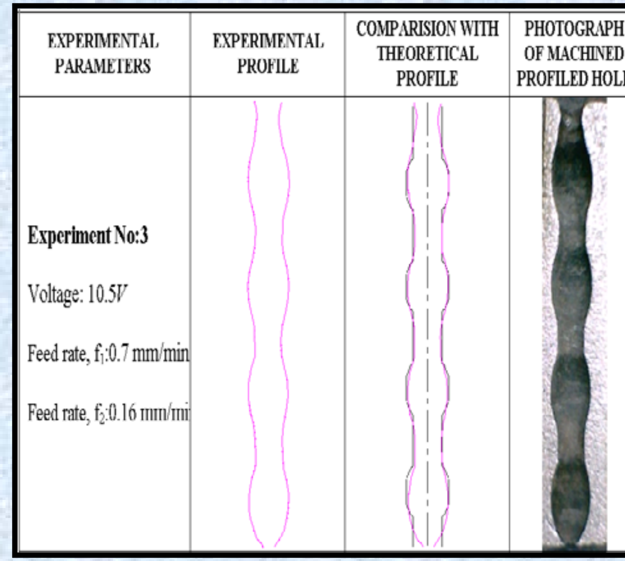
ELECTROCHEMICAL MACHINING



HOLE NORMAL TO THE WALL

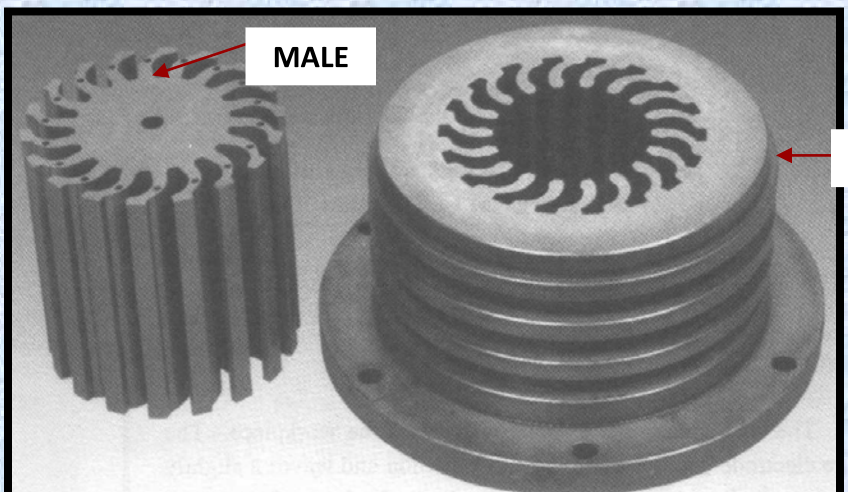


Turbine Blade with cooling Holes



EXPERIMENTAL PARAMETERS	EXPERIMENTAL PROFILE	COMPARISION WITH THEORETICAL PROFILE	PHOTOGRAPH OF MACHINED PROFILED HOLE
Experiment No:3 Voltage: 10.5V Feed rate, f_1:0.7 mm/min Feed rate, f_2:0.16 mm/mi			

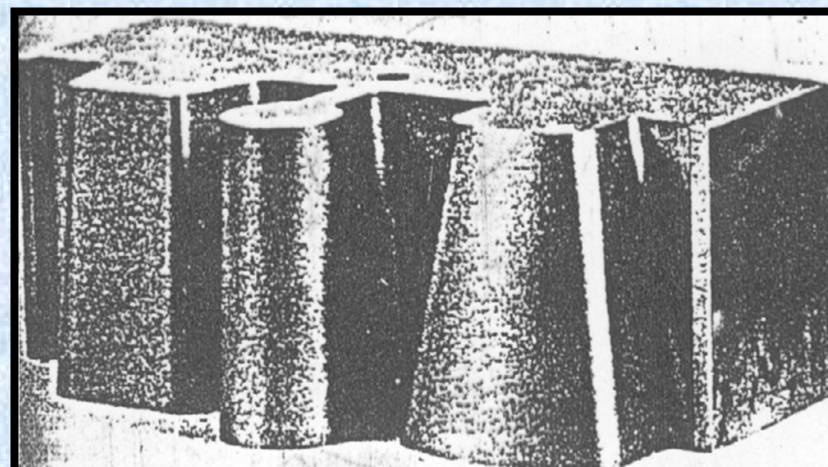
Contoured Hole Drilled In Inconel Using ECM



MALE

FEMALE

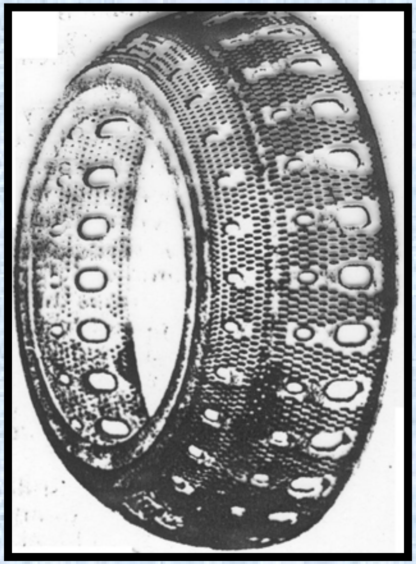
PRECISION WIRE EDM



TAPER 3-D CUTTING USING TRAVELING WIRE- EDM

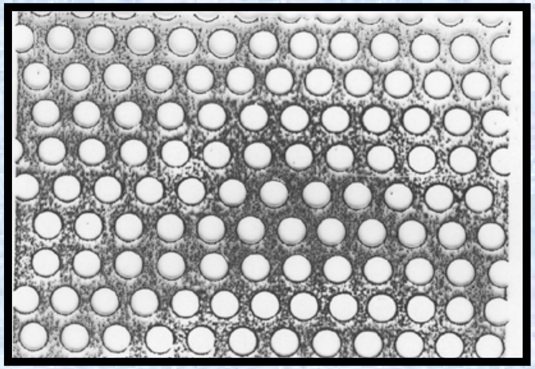
PATTERN OF HOLES DRILLED BY EBM

PART OF A HELICOPTER TURBINE " HOLES DRILLED BY EBM"



HOLE=0.09 mmϕ HOLES DENSITY = 4000/cm^2
WORKPIECE- S.S.;

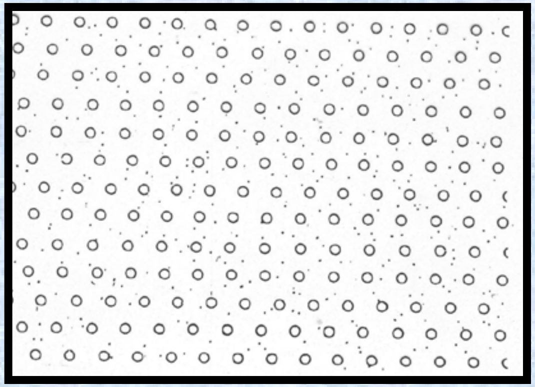
THICK = 0.2 MM; TIME = 10 μS/HOLE



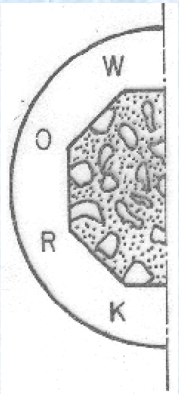
HOLE ϕ =0.006 mm (6 μm);

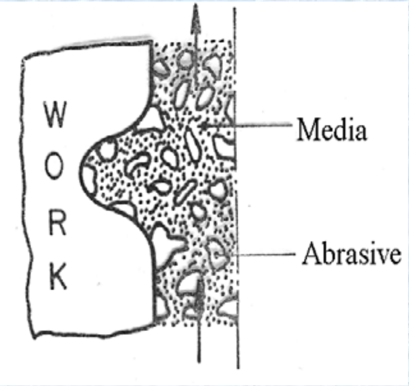
HOLES DENSITY = 200,000 / cm^2 ;

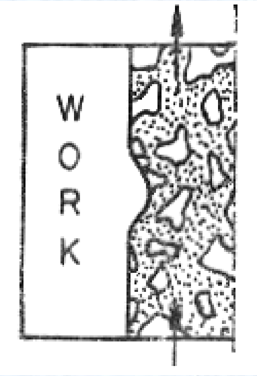
THICKNESS = 0.12 mm; TIME= 2μs / HOLE



AFF MEDIA ACTS AS A SELF-DEFORMABLE STONE







SOME IMPORTANT CHARACTERISTICS OF AMPs & MACHINE TOOLS

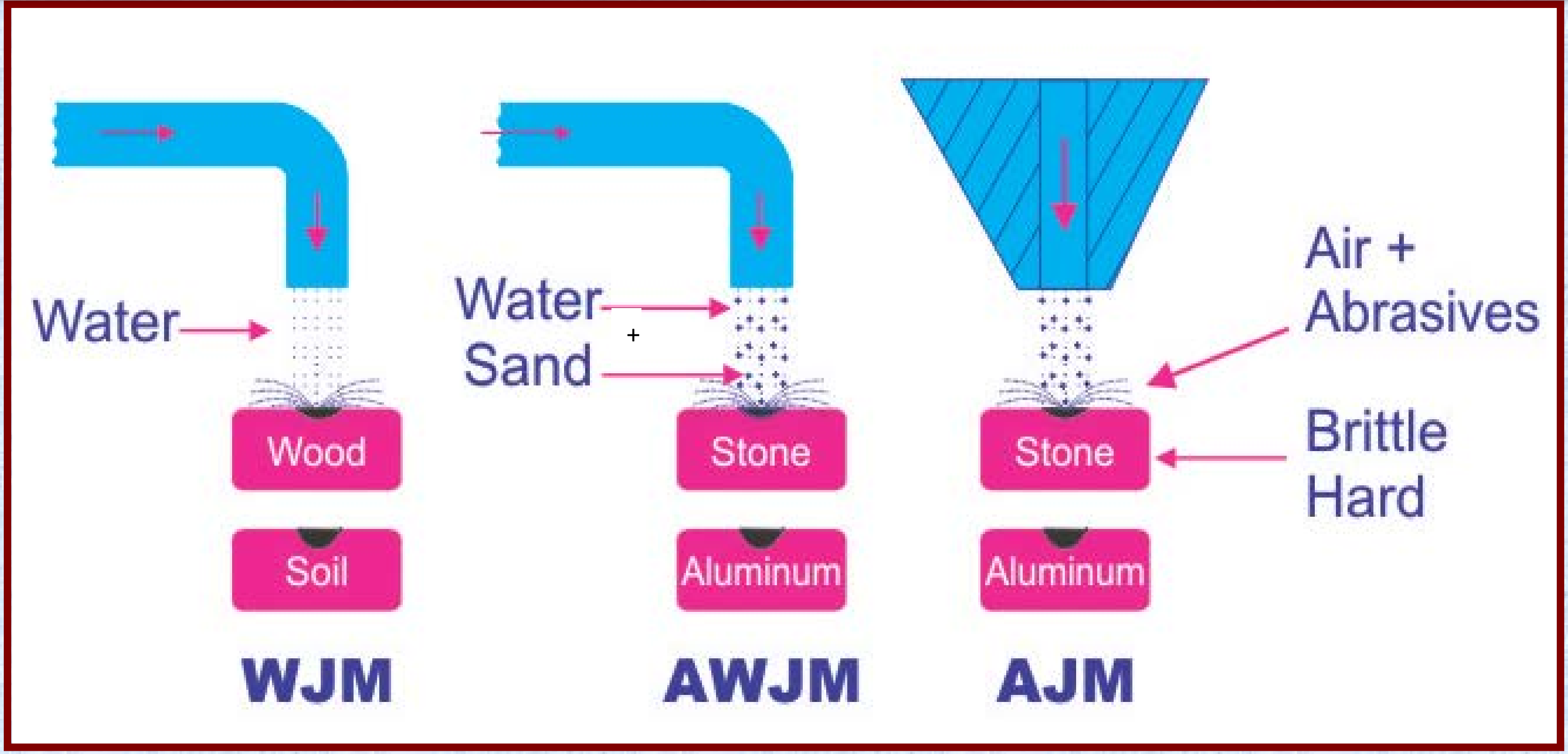
- PERFORMANCE IS INDEPENDENT OF STRENGTH BARRIER.
- PERFORMANCE DEPENDS ON THERMAL, ELECTRICAL, MAGNETIC OR / AND CHEMICAL PROPERTIES OF WORKPIECE MATERIALS.
- USE DIFFERENT KINDS OF ENERGY IN DIRECT FORM.
- IN GENERAL, LOW MRR BUT BETTER QUALITY PRODUCTS.
- COMPARATIVELY HIGH INITIAL INVESTEMENT COST OF MACHINE TOOLS AND HIGH – OPERATING COST .

ADVANCED MACHINING PROCESSES

CAN WATER CUT THE METALS ?

YES. BUT HOW?

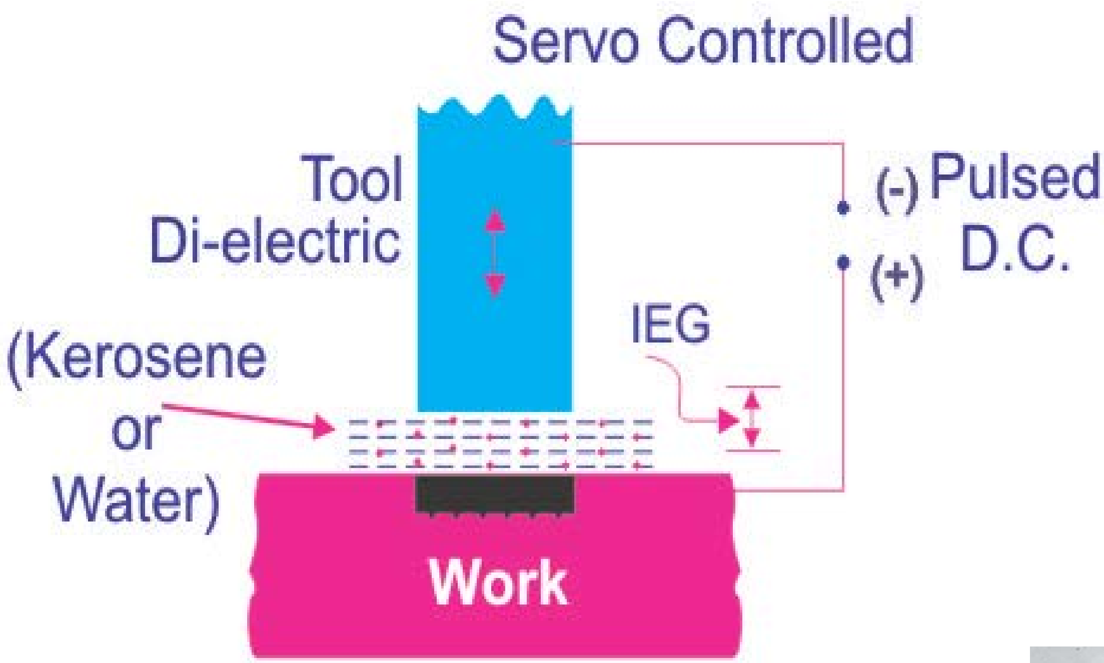
WATER JET MACHINING (WJM), ABRASIVE WATER JET MACHINING (AWJM) , ABRASIVE JET MACHINING (AJM)



HOW DOES IT WORK? K.E. of WATER AND / OR ABRASIVE PARTICLES MAKES IT TO HAPPEN.

VELOCITY OF THE ABRASIVE WATER JET ➔ AS HIGH AS 900 m/s.

ELETRIC DISCHARGE MACHINING



ELECTRICALLY CONDUCTIVE

EDM

Sparking In a Switch

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Metal Removal From Both Points

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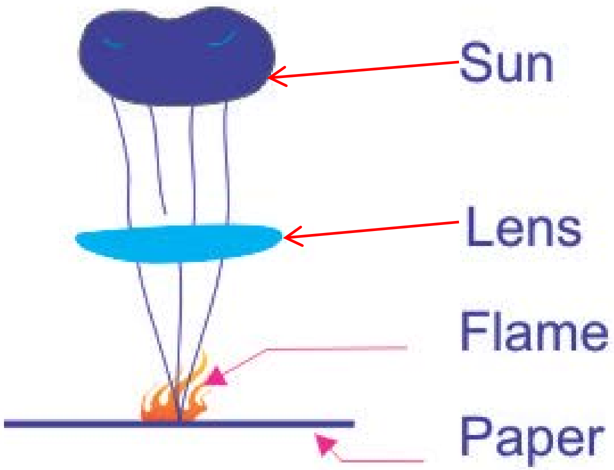
Evolution of EDM By USSR scientists

LAZERANKO

Brothers

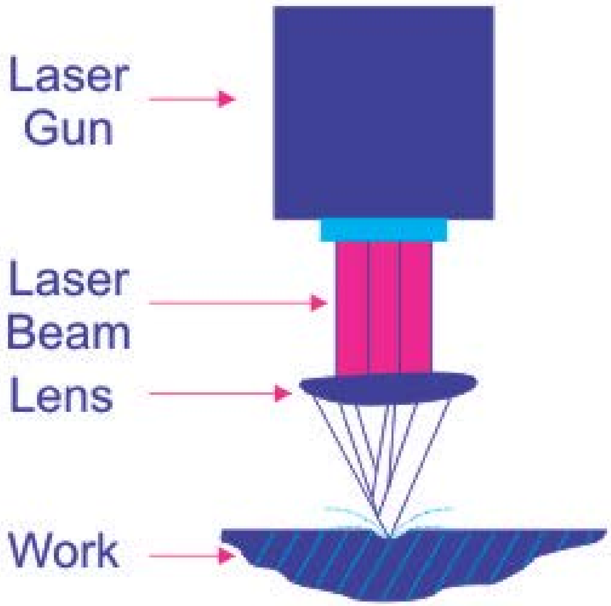
WORN OUT MARKS

LASER BEAM MACHINING (LBM)



BURNING OF A PIECE OF PAPER
BY CONCENTRATING.
SUN RAYS

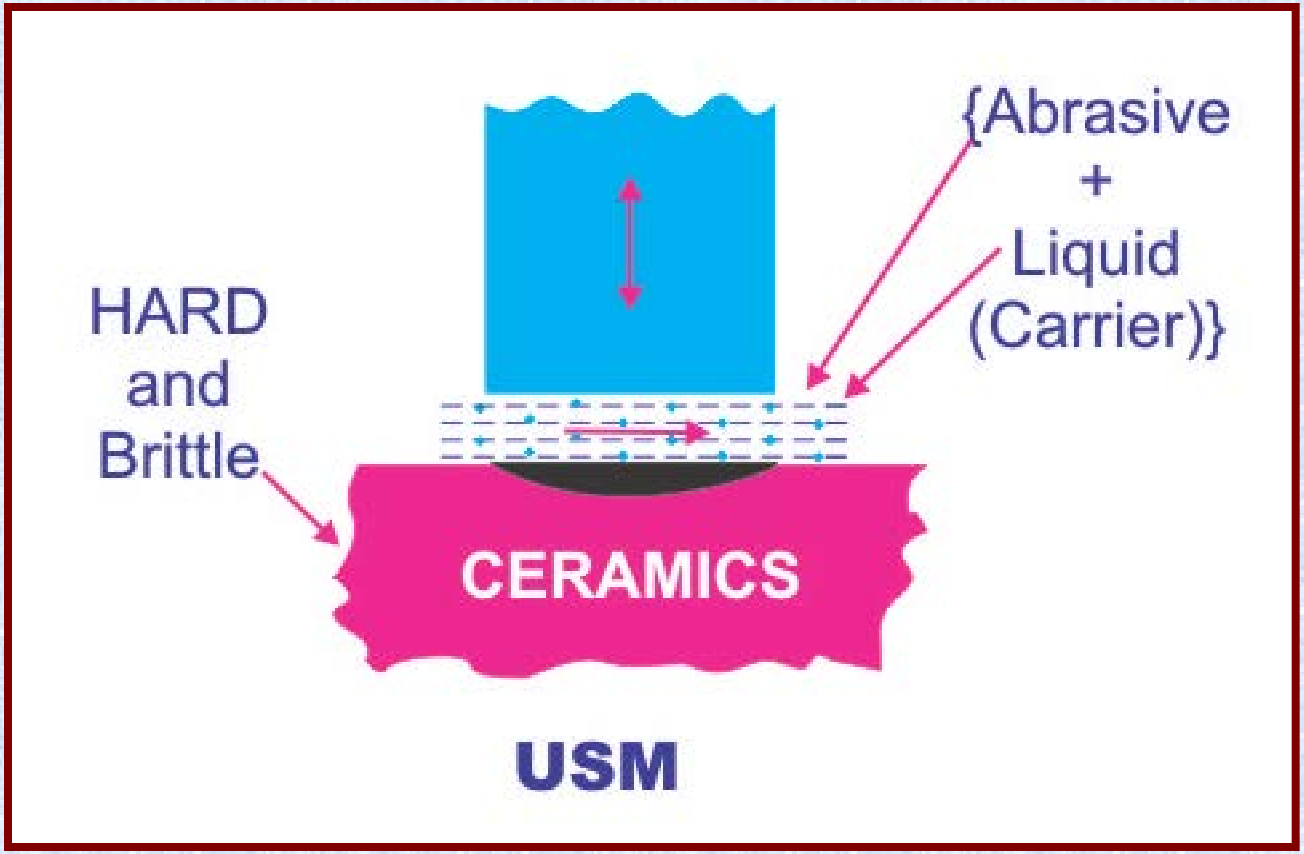
LASER BEAM MACHINING (LBM)



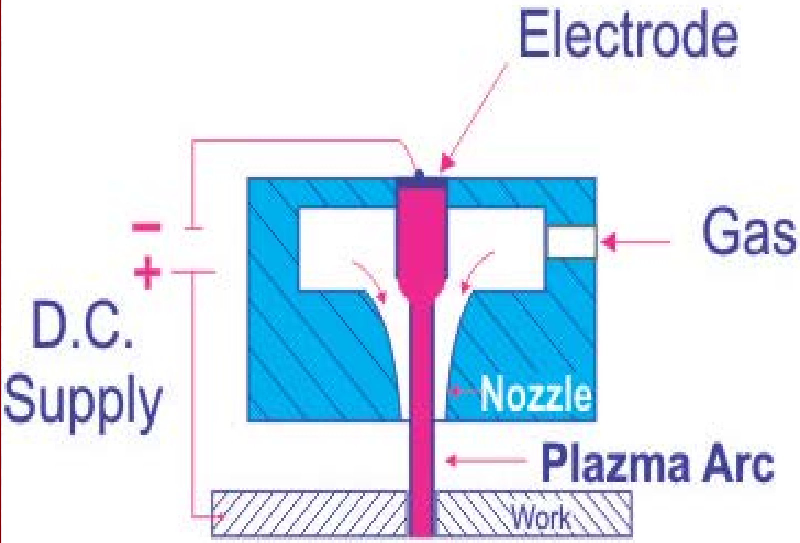
LBM

- Mechanism of material removal.
  ↓
  Melting & vaporization
- For Difficult to machine materials High thermal conductivity.
  ↓
  High Reflectivity
  ↓
  Al, Cu
- Very low machining efficiency 1≤%

ULTRASONIC MACHINING



PLASMA ARC MACHINING (PAM)



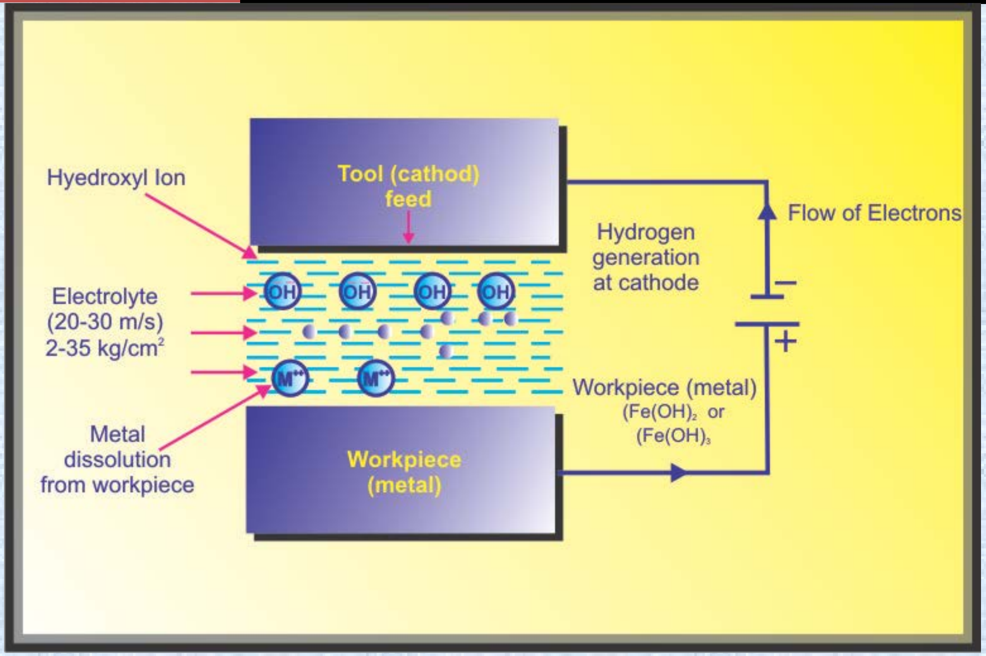
PAM

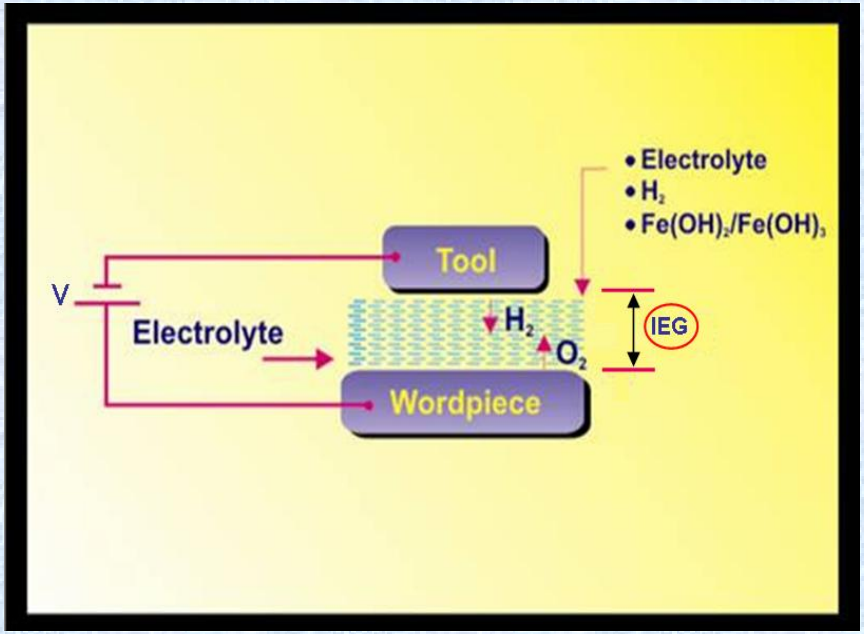
ALSO FOR SOFTENING OF WORK PIECE BY HEATING USING PLASMA ARC, THEN MACHINING

OVERVIEW OF ADVANCED MACHINING PROCESSES

ELECTROCHEMICAL MACHINING (ECM)

ELECTRICHEMICAL MACHINING (ECM)





ECM PROCESS IS ALSO KNOWN AS A CONTACTLESS ELECTROCHEMICAL FORMING PROCESS

ELECTROCHEMICAL ENERGY DETACHES METAL FROM ANODE ATOM BY ATOM

ELECTROCHEMICAL REACTIONS

TYPES OF ELECTROLYTES USED IN ECM

ACIDIC | **ALKALINE** | **NEUTRAL**

$$2\,H_2O + 2e^- \rightarrow H_2\uparrow + 2OH^{--}$$

$$2Fe - 2e^- \rightarrow 2Fe^{++}$$

$$Fe^{++} + 2OH^{--} \rightarrow Fe(OH)_2$$

$$2Fe + 4\,H_2O \rightarrow Fe(OH)_3 + H_2\uparrow + \tfrac{1}{2}O_2\uparrow$$

$Fe(OH)_2$, $Fe(OH)_3$ → INSOLUBLE IN WATER

POSITIVE IONS CONVERT AS HYDROXIDES (FERROUS OR FERRIC HYDROXIDE IN CASE OF IRON AS ANODE/ WORK MATERIAL)

IEG < 1 mm, VOLTAGE ➔ 8-20

NO ELECTROLYTE IS BEING CONSUMED IN THE PROCESS

WORKING PRINCIPLE OF ECM

FARADAY' S LAWS OF ELECTROLYSIS

m α itE

MASS OF DISSOLVED METAL

GRAM CHEMICAL EQUIVALENT = A / Z

CURENT

TIME

A➔ATOMIC MASS OF ANODE, Z ➔ VALENCY OF DISSOLUTION OF ANODE

MATERIAL REMOVAL IN ECM

MATERIAL REMOVAL (m) IN ECM *FOLLOWS FARADAY'S LAWS* OF ELECTROLYSIS:

$$m = \frac{ItE}{F}$$ ....(1)

MATERIAL RAMOVAL RATE (MRR) CAN BE OBTAINED AS

$$\frac{m}{t} = \dot{m} = \frac{IE}{F}$$ ....(1a)

Where, 'm' is amount of material removed in grams, 'I' is current flowing through the IEG in Amperes, 't' Is time of current flow (or ECM), 'E' Is gram chemical equivalent of anode material, 'F' is Faraday's constant (Coulombs or A.s) or** constant of proportionality . **and $\dot{m}$ is material removal rate in g/s.

MATERIAL REMOVAL IN ECM

MRR CAN BE OBTAINED AS

$$\frac{\rho_a v_a}{t} = \frac{\rho_a A_a (y_a)}{(t)} = \frac{IE}{F}$$

WHERE, ρ_a = DENSITY OF ANODE, V_a = VOLUME OF MATERIAL REMOVED FROM THE ANODE IN TIME 't', A_a = X- SECTIONAL AREA ON THE ANODE FROM WHICH MATERIAL IS BEING REMOVED IN TIME 't', y_a IS THE THICKNNESS OF MATERIAL REMOVED IN TIME 't'. ΔV IS OVER POTENTIAL, k= ELECTROLYTE'S ELECTRICAL CONDUCTIVITY

FROM ABOVE EQUATION, WE CAN WRITE

$$\therefore MRR_l = \frac{(y_a)}{(t)} = \frac{IE}{F\rho_a A_a}$$

$$MRR_l = \frac{JE}{F\rho_a} \quad \text{.......(2)}$$

(J = CURRENT DENSITY = I/Aa)

ABOVE EQUATION CAN BE WRITTEN AS

$$MRR_l = \left(\frac{V-\Delta V}{A_a}\right)\left\{\frac{kA_a}{y}\right\}\frac{E}{F\rho_a}$$

J=I/Aa=V/R=V/(**ρ**l/A)

ρ =(1/k)

J=((V- Δ**V)/A) (kA/y)**
ρ=Resistance

Anode density

THERMAL MICROMACHINING PROCESSES

ELECTRIC DISCHARGE MICROMACHINIG

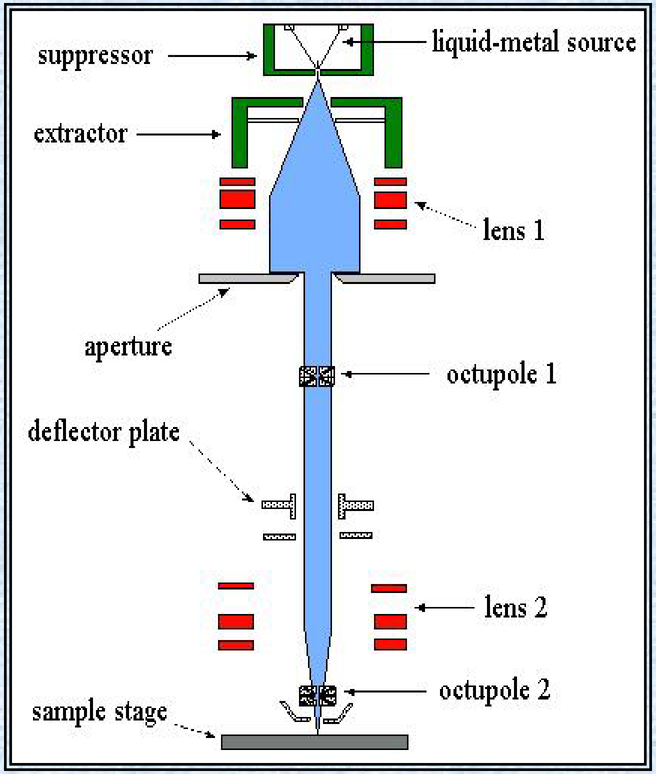
BEAM MICROMACHINING

⇩

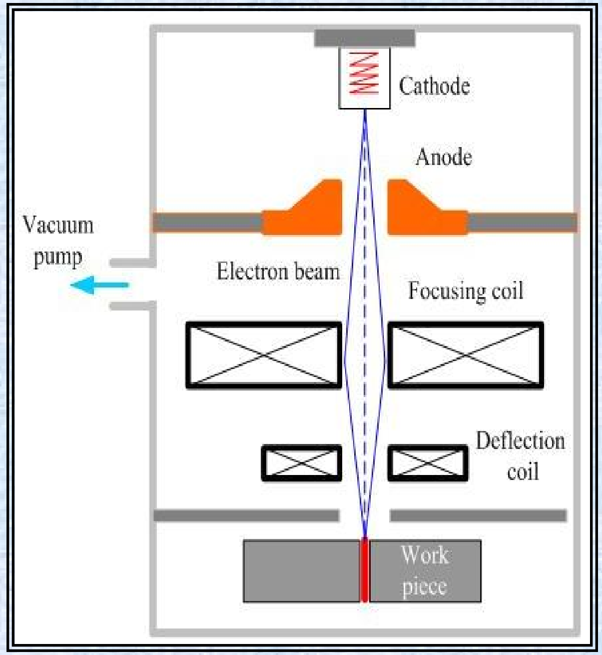
1. LASER BEAM MICROMACHINING
2. ELECTRON BEAM MICROMACHINING
3. ION BEAM MICROMACHINING
(NOT A THERMAL PROCESS)

BEAM TECHNOLOGY

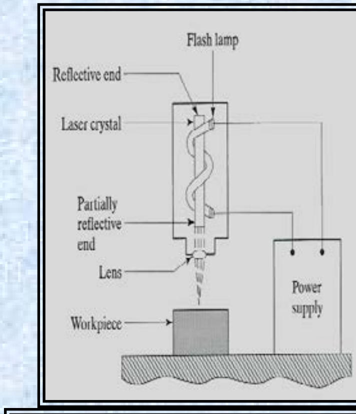
IBM

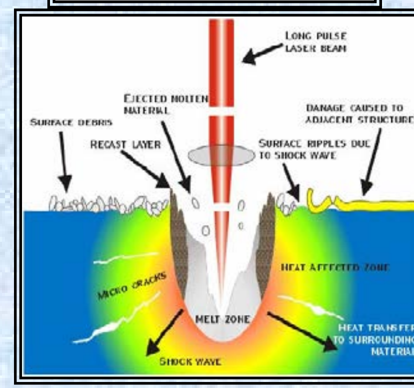


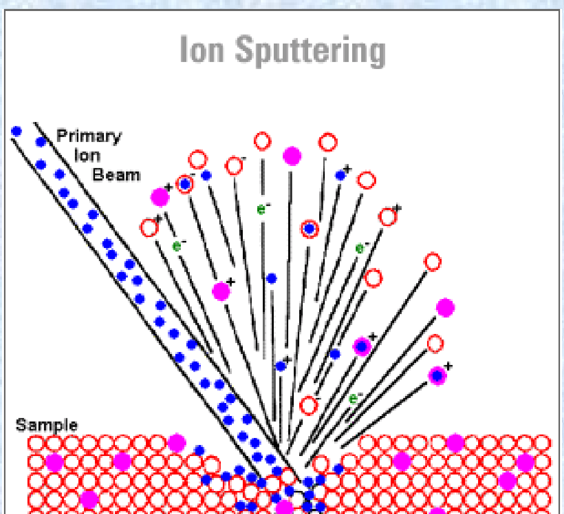
EBM



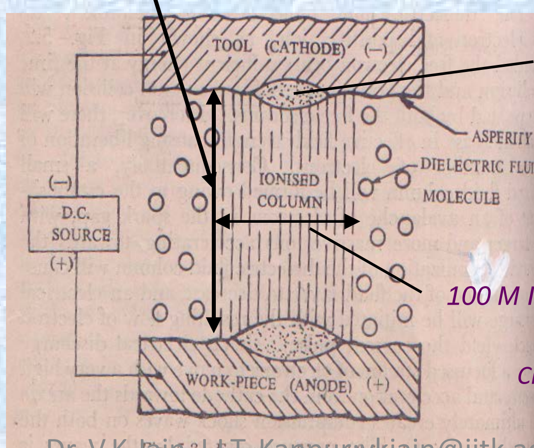
LBM







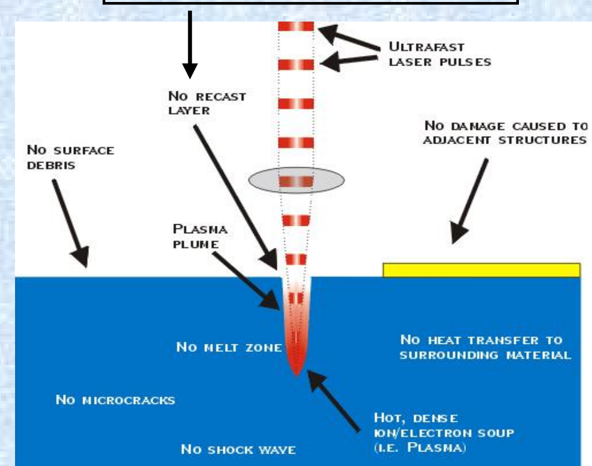
IEG = A FEW HUNDRED μm



CRATER

100 M ICRONS

CRATER



SHORT PULSE LASER MACHINING

ELECTRIC DISCHARGE MACHINING (EDM)

ELECTRIC DISCHARGE MACHINING

(EDM)

- *SPARKS* CREATED DELIBERATELY
- HEAT IN A LOCALIZED AREA

IEG = A FEW HUNDRED μm

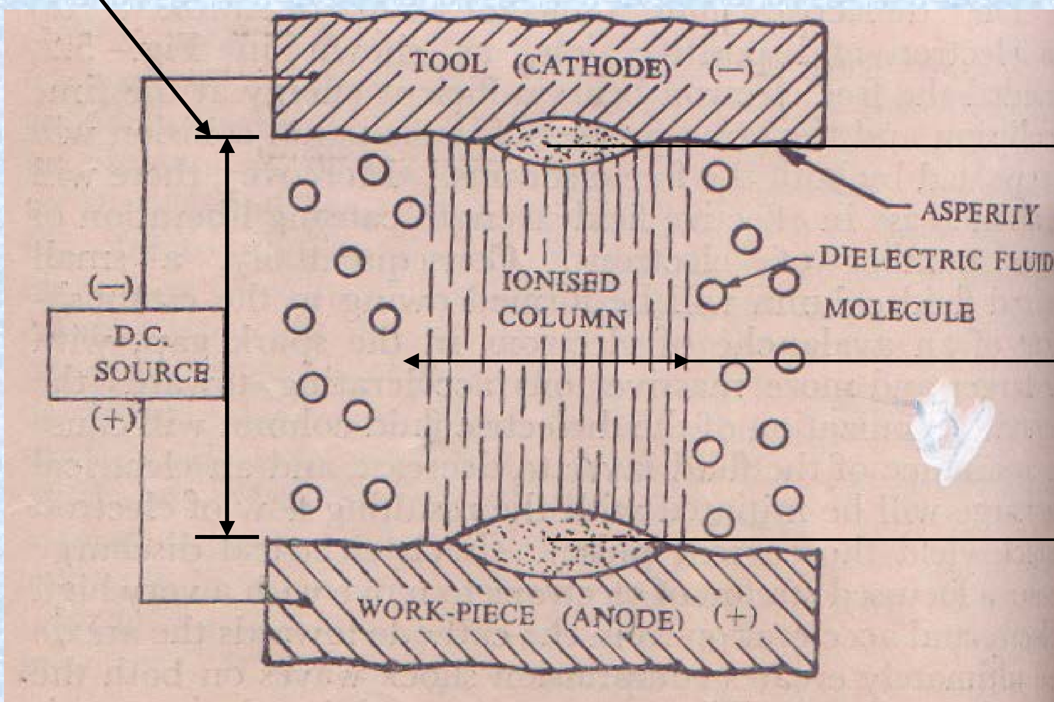


Fig. 5.3 Formation of ionised fluid colum

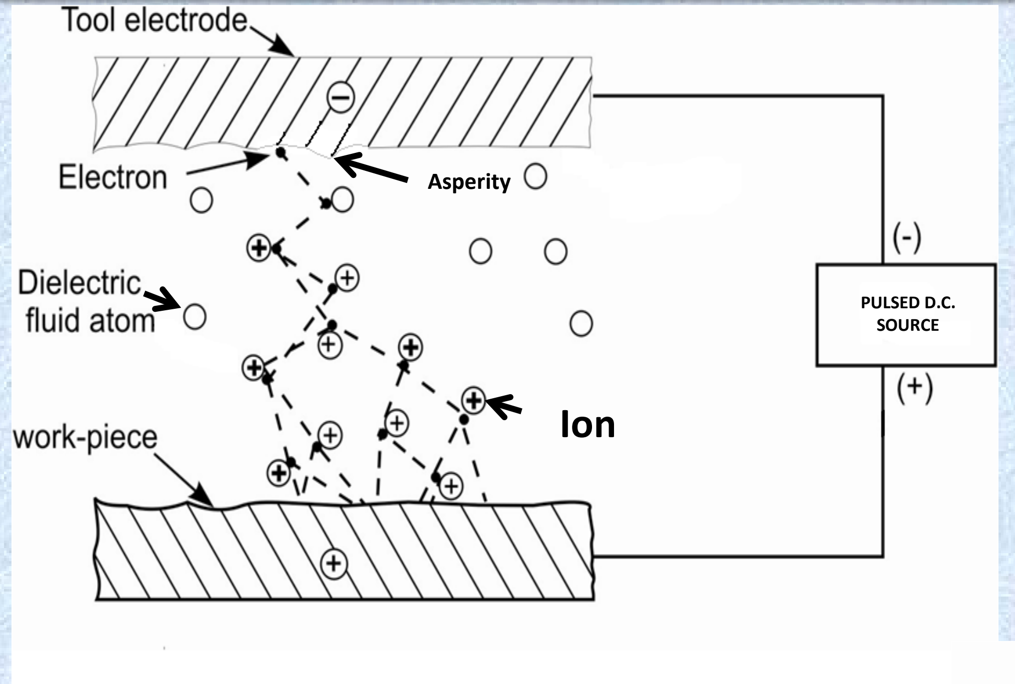
CRATER

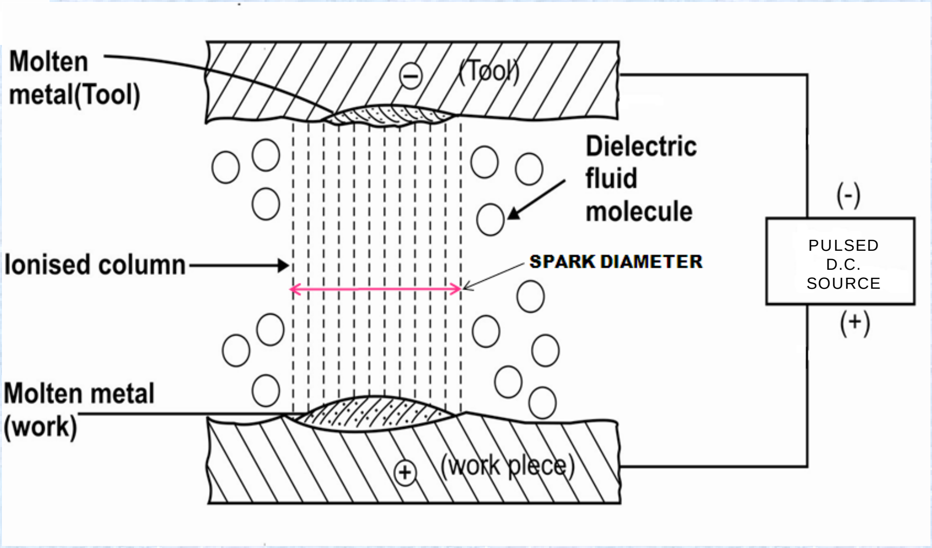
MELTING AND / OR VAPORIZATION

100 M ICRONS

CRATER

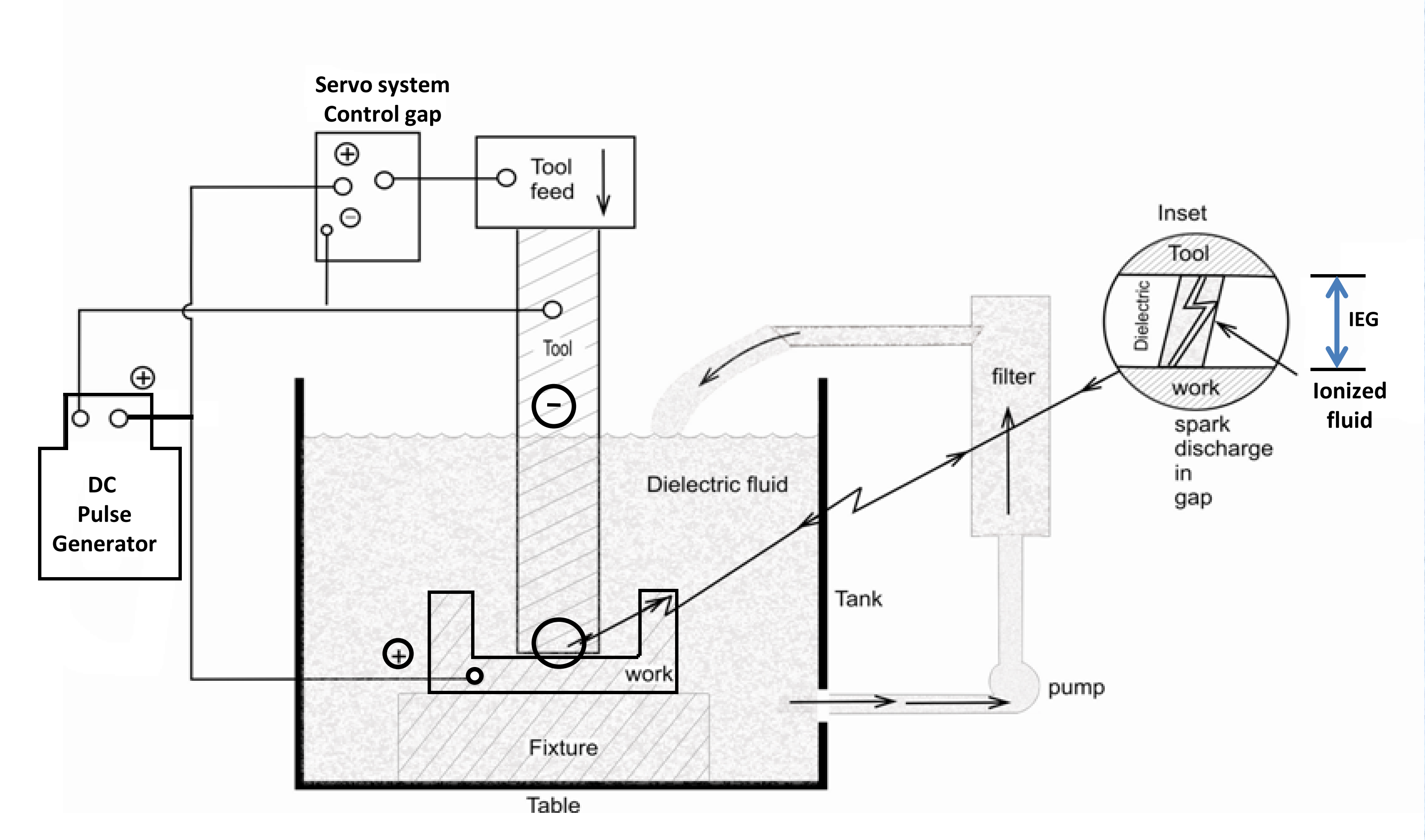
ELECTRIC DISCHARGE MACHINING : HOW SPARKING TAKES PLACE?





EDM: WORKING PRINCIPLE

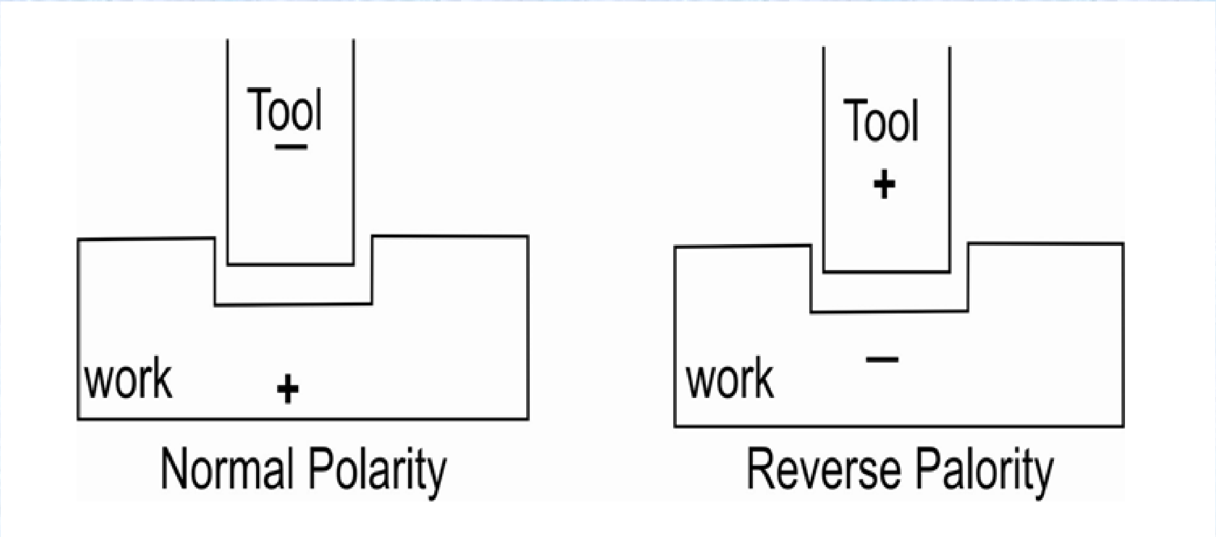
- ❖ BREAK DOWN OF DIELECTRIC (AT PRE DETERMINED ELECTRIC FIELD) OF DIELECTRIC (USUALLY KEROSENE OR WATER) TAKES PLACE BETWEEN TWO ELECTRODES (TOOL & WORKPIECE).
- ❖ DIELECTRIC IONIZATION ➔ MOLECULES (ELECTRONS FROM CATHODE COLLIDE THE MOLECULES) SPLIT INTO IONS, AND ELECTRONS.
- ❖ IONS ➔ MOVE TOWARDS CATHODE AND ELECTRONS MOVE TOWARDS ➔ ANODE
- ELECTRONS HIT THE CATHODE AND IONS HIT ANODE
- DUE TO THEIR K.E., THEY PRODUCE HEAT ON CATHODE (LESS) AND ANODE (MORE)
- THIS HEAT MELTS AND EVEN VAPORIZES A SMALL PART OF CATHODE AND ANODE.



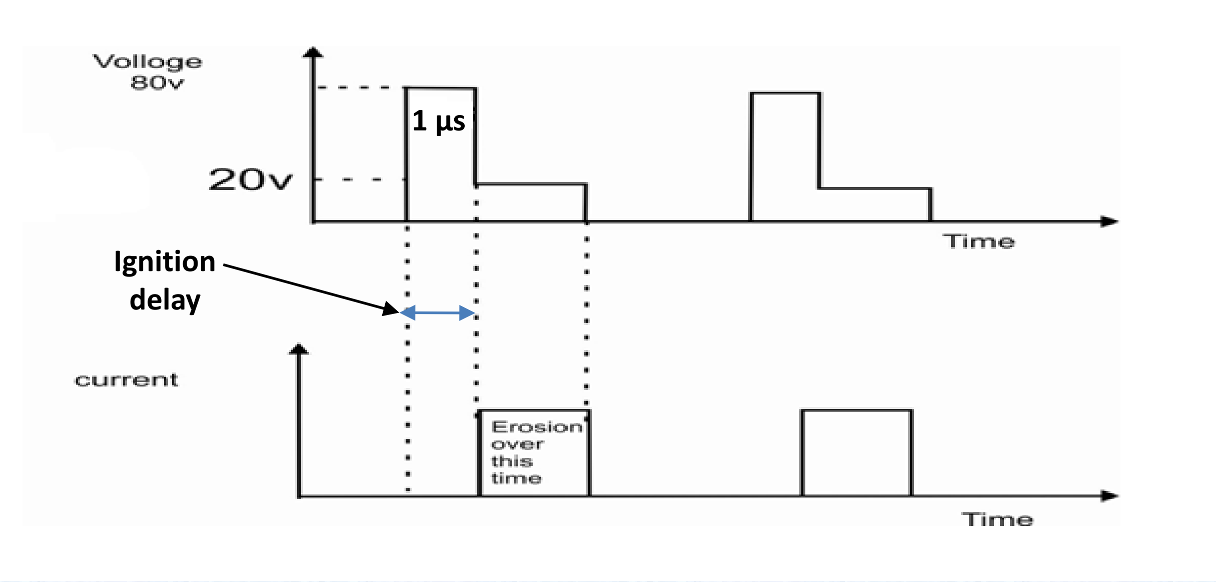
REPLICA OF THE TOOL → WORKPIECE

ELECTRIC DISCHARGE MACHINING (EDM)

POLARITY IN EDM

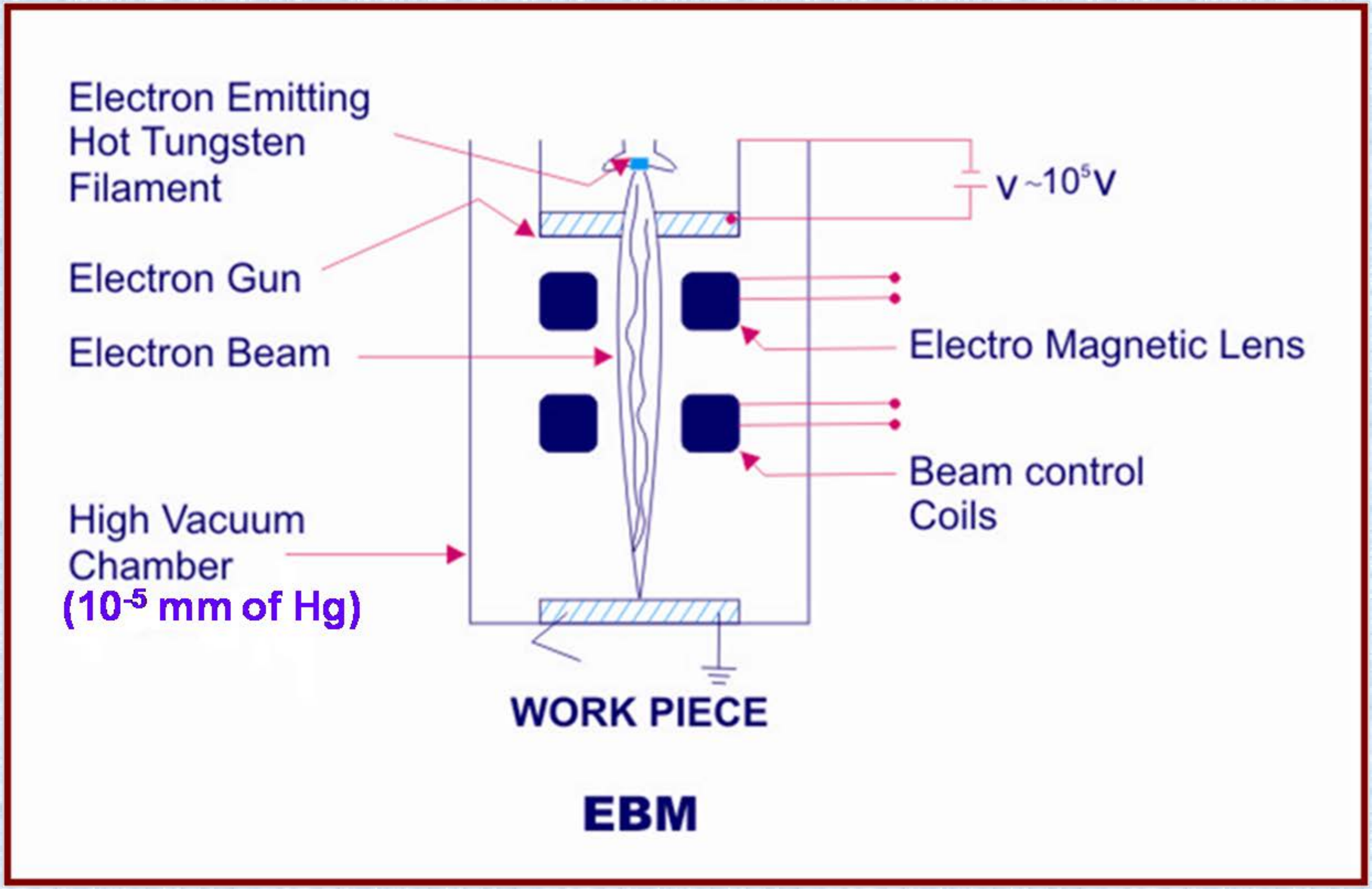


VOLTAGE / CURRENT PULSES IN EDM



(SOURCE: Advanced Machining Processes by V.K.Jain, Allied Publishers, New Delhi)

ELECTRON BEAM MACHINING (EBM)



FOCUSSED ION BEAM MACHNING (IBM)

- **SPUTTERING OFF: KNOCKING OUT ATOMS FROM THE WORK-PIECE SURFACE BY THE KINETIC MOMENTUM TRANSFER FROM INCIDENT ION TO THE TARGET ATOMS**
- **REMOVAL OF ATOMS WILL OCCUR WHEN THE ACTUAL ENERGY TRANSFERRED EXCEEDS THE USUAL BINDING ENERGY.**

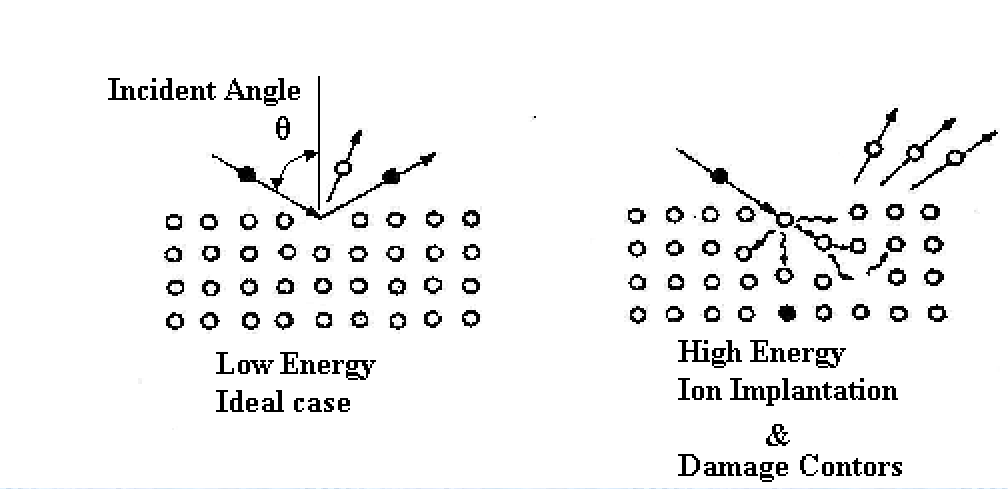


FIG. SCHEMATIC ILLUSTRATION

- **AT SUFFICIENTLY HIGH ENERGY, THE CASCADING EVENTS WILL PENETRATE MORE DEEPLY INTO THE SOLID, SEVERAL ATOMS OR MOLECULES WILL BE EJECTED OUT AND THE BOMBARDING ION WILL BECOME IMPLANTED DEEP WITHIN THE MATERIAL.**

MECHANICAL MICROMACHINING PROCESSES

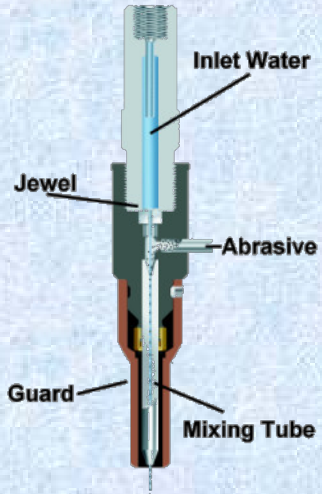
ULTRASONIC MICROMACHINIG

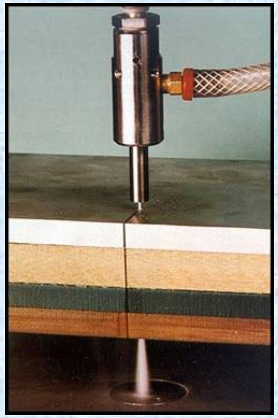
ABRASIVE JET MICROMACHINING

1. WATERJET MICROMACHINING
2. ABRASIVE WATER JET MICROMACHINING

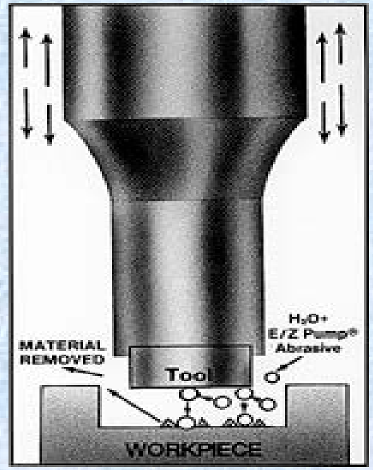
PRINCIPLE OF MECHANICAL MICROMACHINING MECHANISM

ABRASIVE WATR JET MACHINING

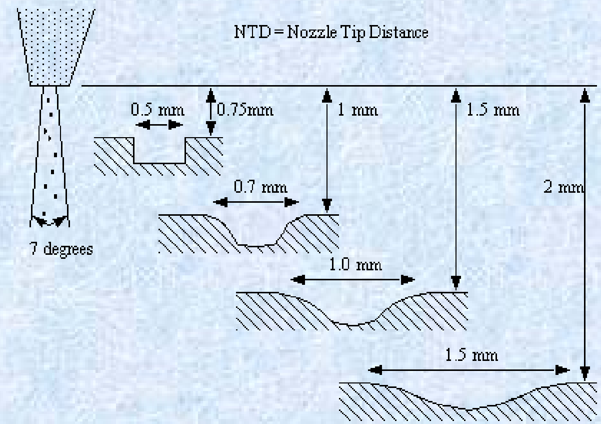




ULTRASONIC MACHINING

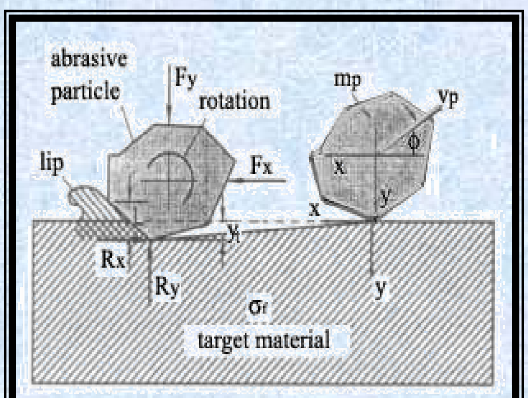


ABRASIVE JET MACHINING

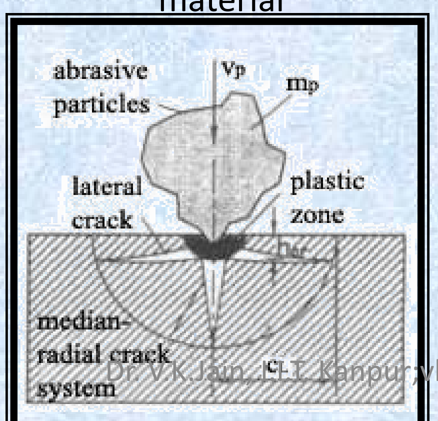


AWJM, AJM, USM

Mechanism of material removal in ductile material

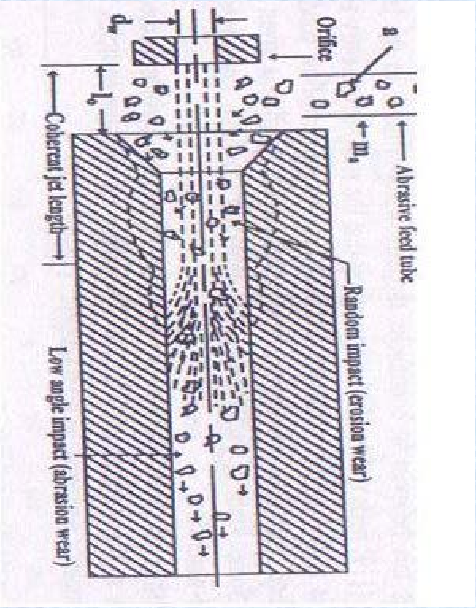


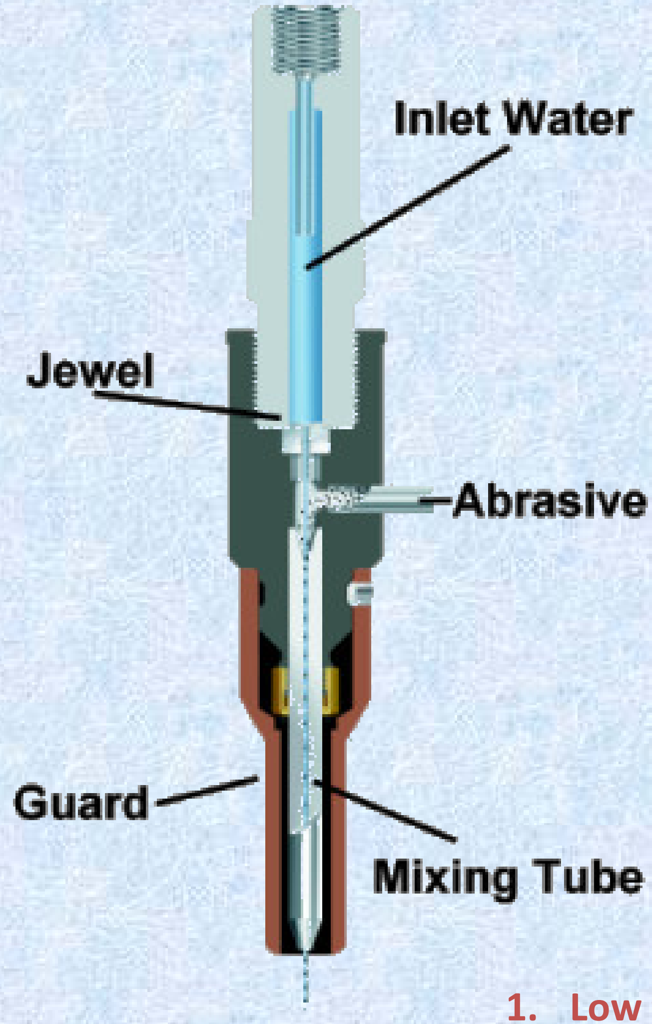
Mechanism of material removal in brittle material

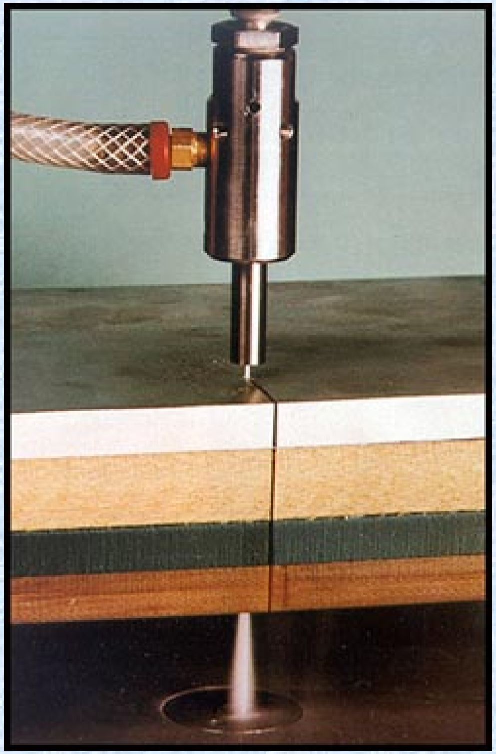


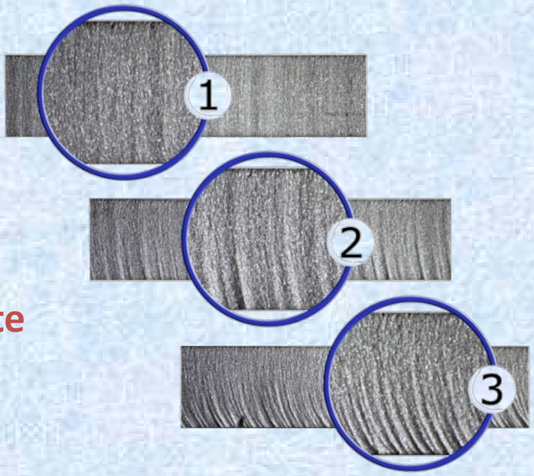
FORCES ACTING ON EACH PARTICLE AND PARTICLE SIZE
WILL DEC IDE THE SCALE OF MATERIAL REMOVED : MACRO, MICRO, NANO

ABRASIVE WATER JET MICRO-MACHINING (AWJM)



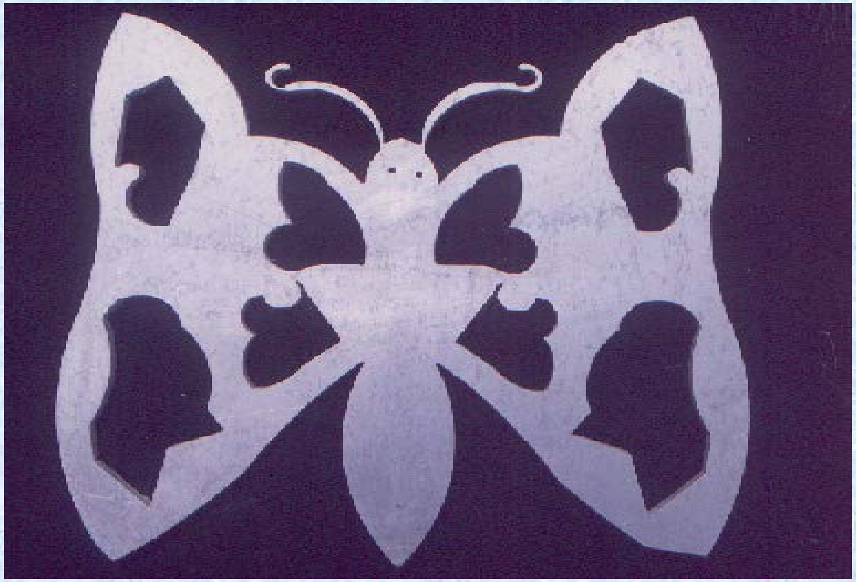






1. Low feed rate
2. Medium feed rate
3. High feed rate

APPLICATIONS OF ABRASIVE WATER JET CUTTING (AWJC)



Granite cutting

(COURTESY : IITM CHENNAI)

Material Removal Processes

Micro/nano machining

- Traditional machining processes
- Advanced machining processes

Micro/nano finishing

- Traditional finishing processes
- Advanced finishing processes

Micro-manufacturing

A set of processes used to fabricate features, components, or systems with dimensions most conveniently described in micrometers

MICROMACHINING : AN OVERVIEW

Why miniaturization?

- Minimizing energy and materials use in manufacturing
- Reduction of power budget
- Faster devices
- Increased selectivity and sensitivity
- Improved accuracy and reliability
- Cost / performance advantages
- Integration with electronics, simplifying systems

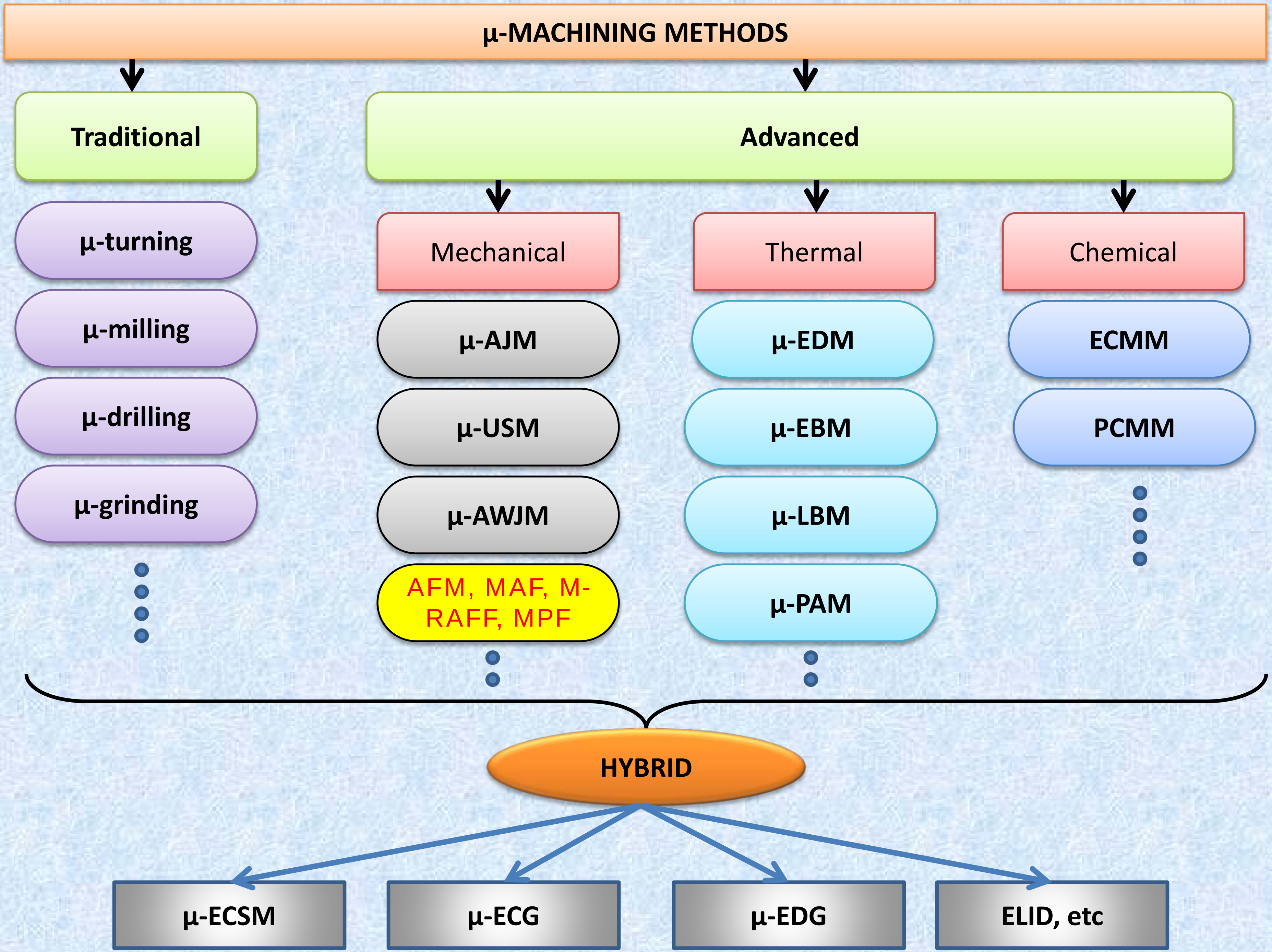
Size Comparisons in Micromanufacturing

- 100 micrometers ~ paper thickness, human hair
- 8 micrometers ~ red blood cell, capillaries
- 0.5 micrometers ~ visible light, machining tolerance
- 0.07 micrometers ~ year 2010 IC production design rules
- 0.0003 micrometers ~ atomic spacing in solids

Methods of Micro-manufacturing

- **Material deposition**
  - Electro chemical spark deposition
  - Electro discharge deposition
  - Chemical vapor deposition
  - Physical vapor deposition
  - Rapid prototype / rapid tooling
  - LIGA
- **Material Removal**
  - Traditional material removal processes
  - Advanced material removal processes
- **Forming / shaping**
  - Rolling
  - Forging
  - Extrusion & drawing
  - Sheet metal
- **Joining**
  - Welding
  - Brazing
  - Soldering
- **Casting**

MICROFABRICATION IS GOING TO WITNESS AN EXCELLENCE IN R & D AT A REMARKABLE RATE



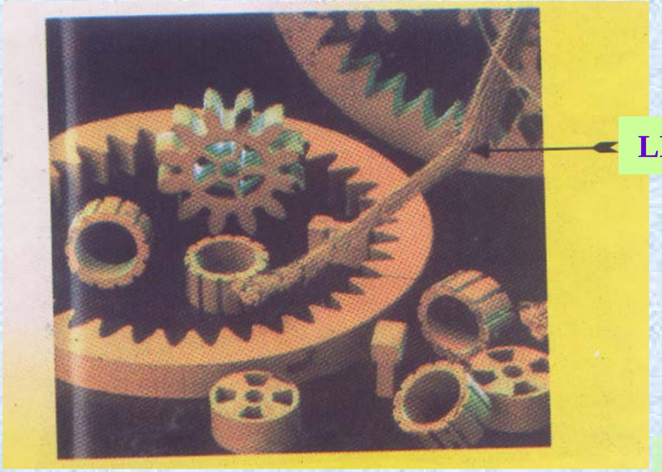
µ-MACHINING METHODS
Traditional
Advanced
µ-turning
µ-milling
µ-drilling
µ-grinding
Mechanical
Thermal
Chemical
µ-AJM
µ-USM
µ-AWJM
AFM, MAF, M-RAFF, MPF
µ-EDM
µ-EBM
µ-LBM
µ-PAM
ECMM
PCMM
HYBRID
µ-ECSM
µ-ECG
µ-EDG
ELID, etc

MICRO MACHINING

Micro + **Machining**

Removal of material at micro level

1. Macro components but material removal is at micro/nano level
2. Micro/nano components and material removal is at micro/nano level (Ex. MEMS, NEMS)



LEG OF A HOUSE FLY

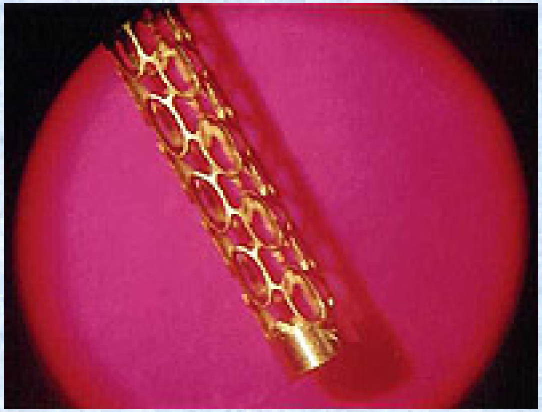
SIZE : 2mm x 2mm

Unfortunately , the present day notion is

Machining of highly miniature components with miniature features.
Literally it should NOT be so

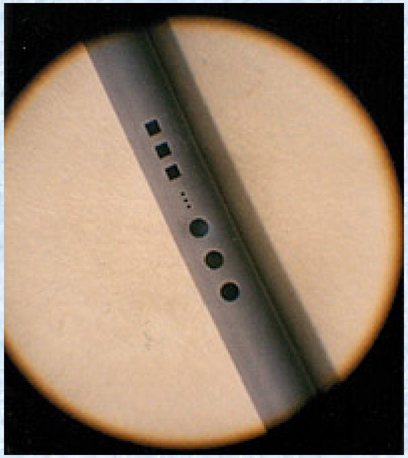
MORE CORRECT DEFINITION IS material removal is at micro/nano level WITH NO CONSTRAINT ON THE SIZE OF THE COMPONENT

SOME MICROMACHINED PARTS



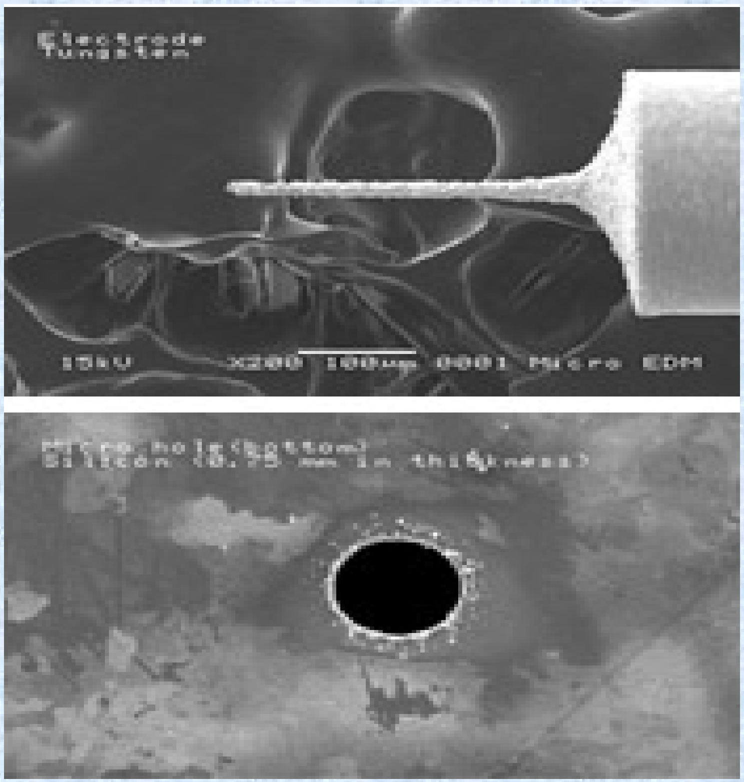
LASER-CUT STENTLIKE PATTERN IN MINIATURE STAINLESS- STEEL TUBE WITH 1.25-mm OD.

LASER-DRILLED HOLE (DIA. 15 µm) PATTERN IN POLYURETHANE TUBE

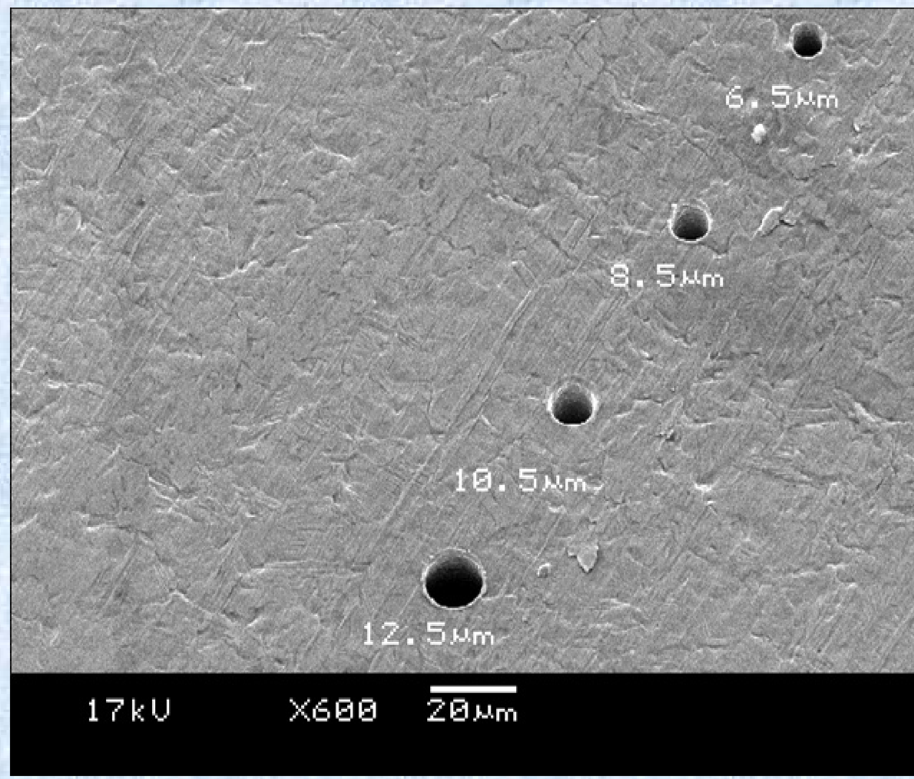


ELECTRO DISCHARGE MICROMACHINING (EDMM)

EXAMPLES OF EDMM

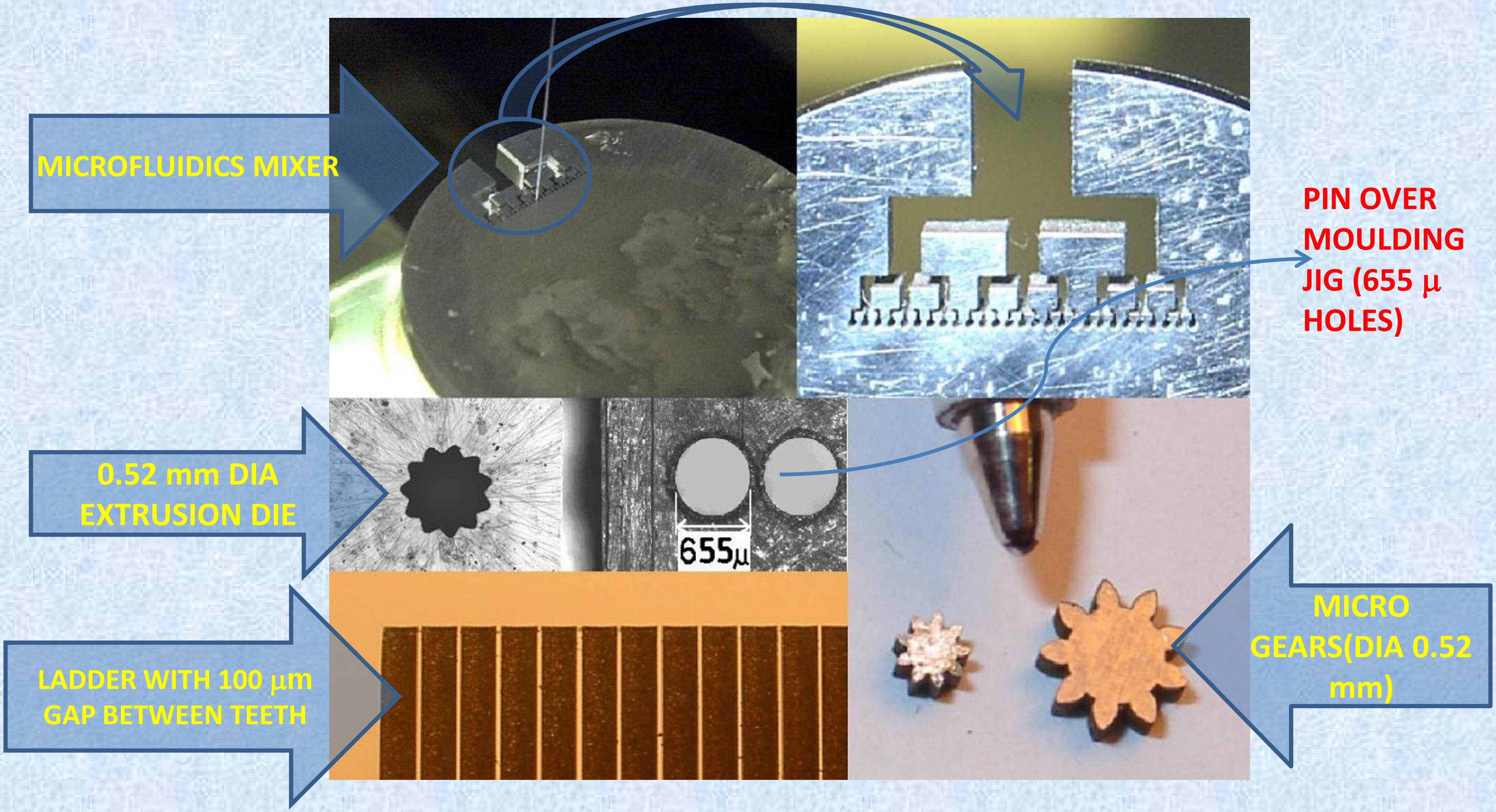


30-micron shafts and 50-micron holes produced by micro-EDM.



Holes as small as 6.5 microns in diameter and an aspect ratio of 7.5

EXAMPLES OF EDMM



LASER BEAM MICROMACHINING (LBMM)

BASIC PRINCIPLES OF LASER

- LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION.
- LIGHT ENERGY OF A PARTICULAR FREQUENCY CAN BE USED TO STIMULATE THE ELECTRONS IN AN ATOM TO EMIT ADDITIONAL LIGHT WITH EXACTLY THE SAME CHARACTERISTICS AS THE ORIGINAL STIMULATING LIGHT SOURCE.
- PHOTON ENERGY IS PROPORTIONAL TO FREQUENCY BUT INVERSELY PROPORTIONAL TO WAVELENGTH.
- THE PHOTON STIMULATES THE ATOM, CAUSING IT TO EMIT AN ADDITIONAL PHOTON WITH IDENTICAL CHARACTERISTICS TO THE STIMULATING PHOTON.

PROPERTIES OF LASER BEAM

- MONOCHROMATIC – **SINGLE WAVELENGTH**.
- COHERENT – **SAME PHASE RELATIONSHIP**.
- DIRECTIONAL – **LOW DIVERGENCE, BEAM SPREADS VERY LITTLE**.
- INTENSE – **HIGH DENSITY OF USABLE PHOTONS**.

TWO TYPES OF LASERS: CONTINUOUS WAVE AND PULSED LASERS

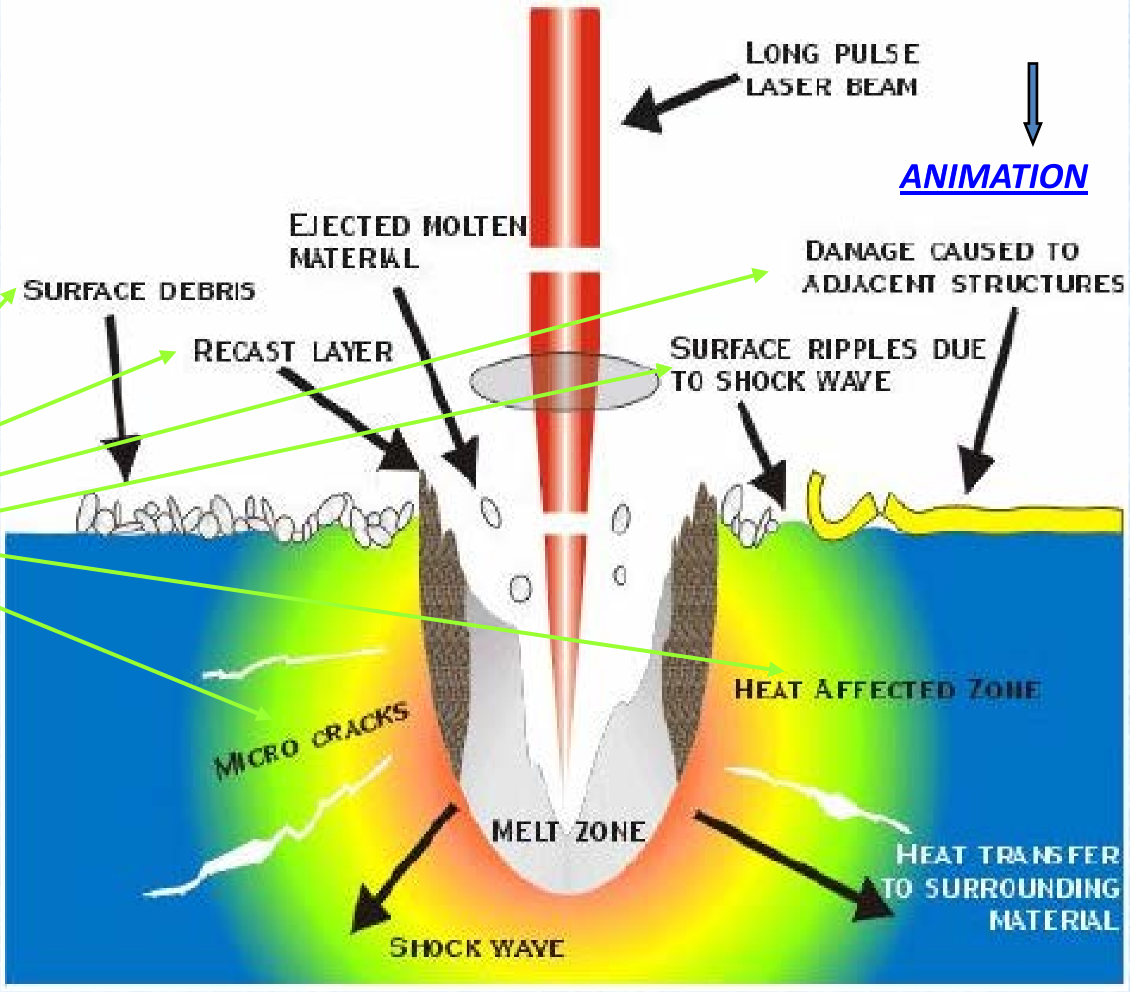
LONG PULSED LASES AND SHORT PULSED LASERS

TYPES OF LASERS

TIME SCALES:

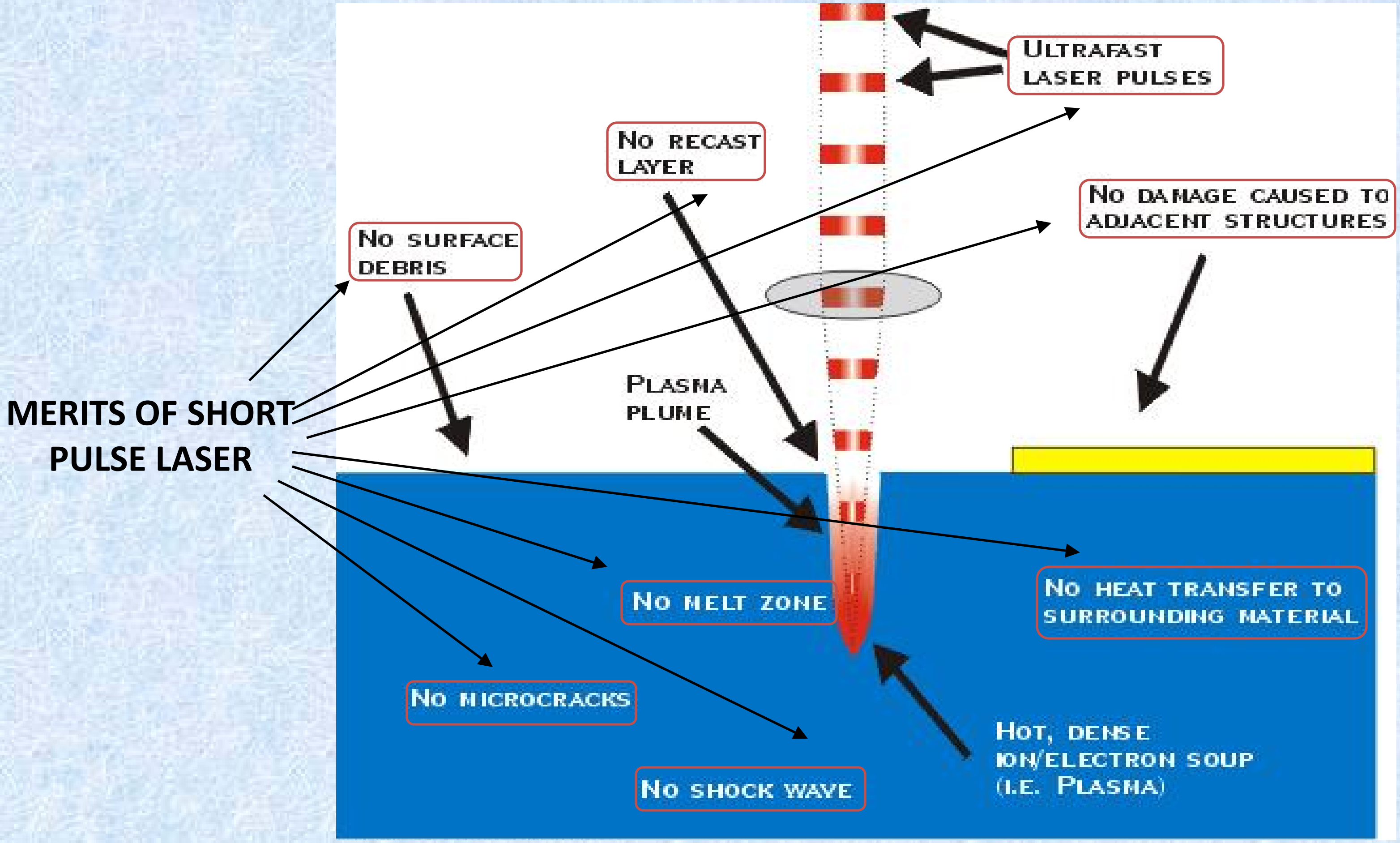
Millisecond	$1*10^{-3}$ second
Micro second	$1*10^{-6}$ second
Nano second	$1*10^{-9}$ second
Pico second	$1*10^{-12}$ second
Femto second	$1*10^{-15}$ second

LONG PULSE LASER MACHINING

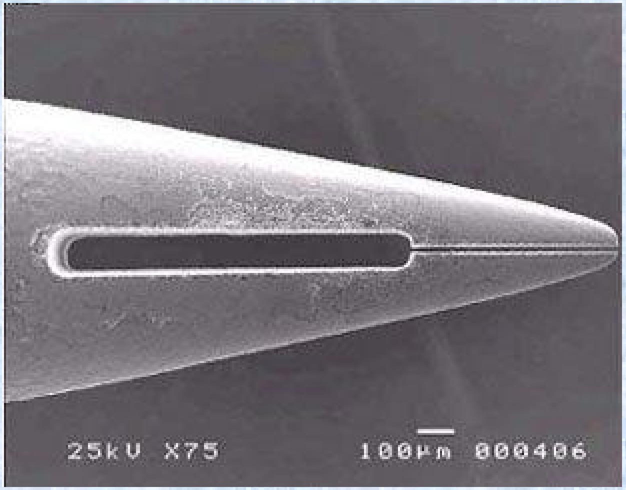


DEMERITS OF LONG PULSE LASER

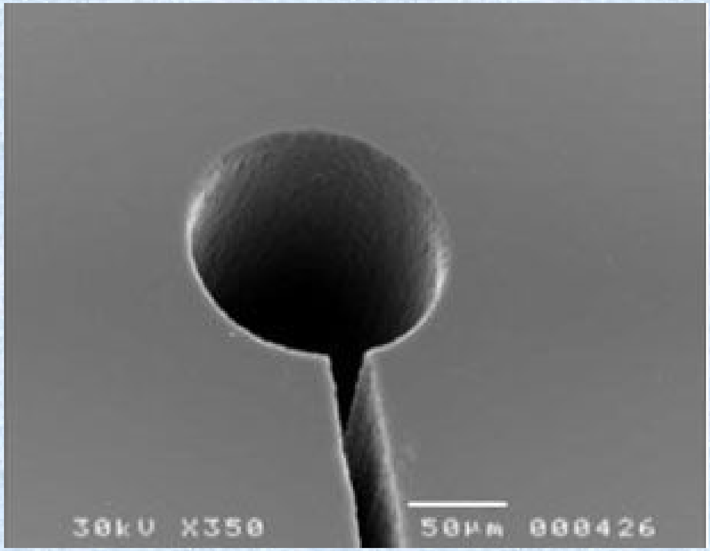
SHORT PULSE LASER MACHINING



APPLICATIONS OF LBM

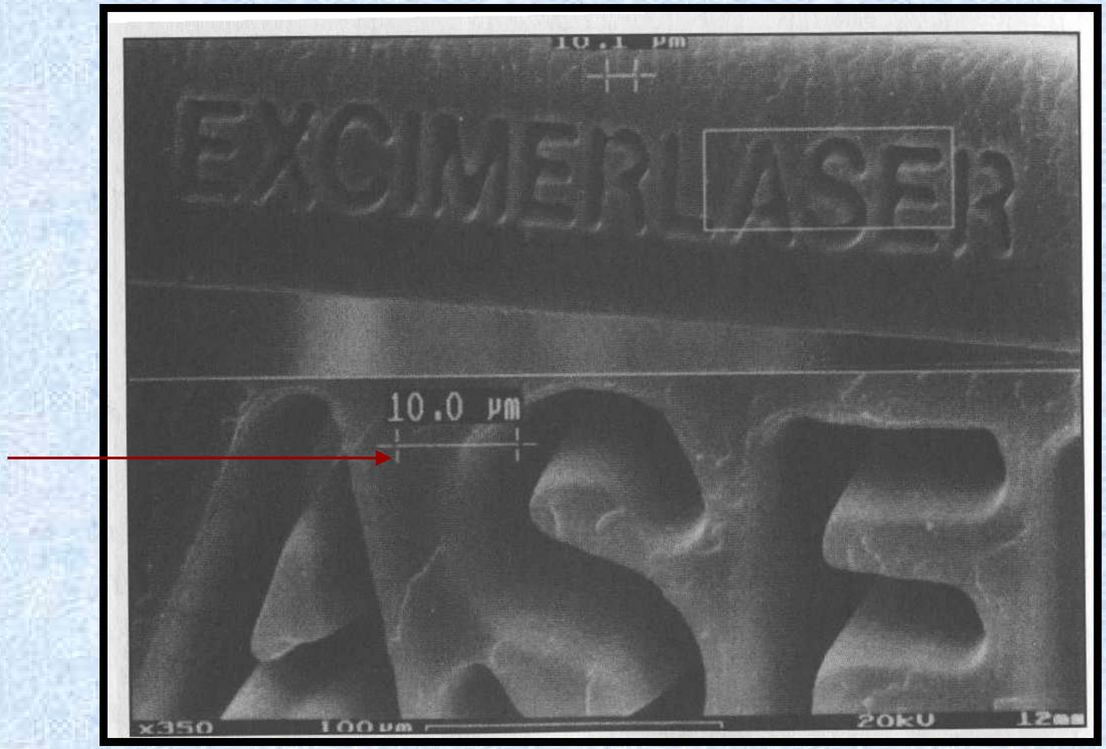


MICRO CUTTING IN A TUNGSTEN PIN USING 511nm ND LASER



MICRO FLUIDIC DEVICE IN SILICON SHOWING LASER DRILLED VIA HOLE AND CONNECTING CHANNEL

LASERS AND THEIR CONFIGURATION



MICRO MACHINED LETTERS ON A SINGLE HUMAN HAIR
NOTE THE CLARITY OF THE LETTERS IN THE CLOSE-UP VIEW

ELECTRON BEAM MICROMACHINING (EBMM)

BASICS OF EBM

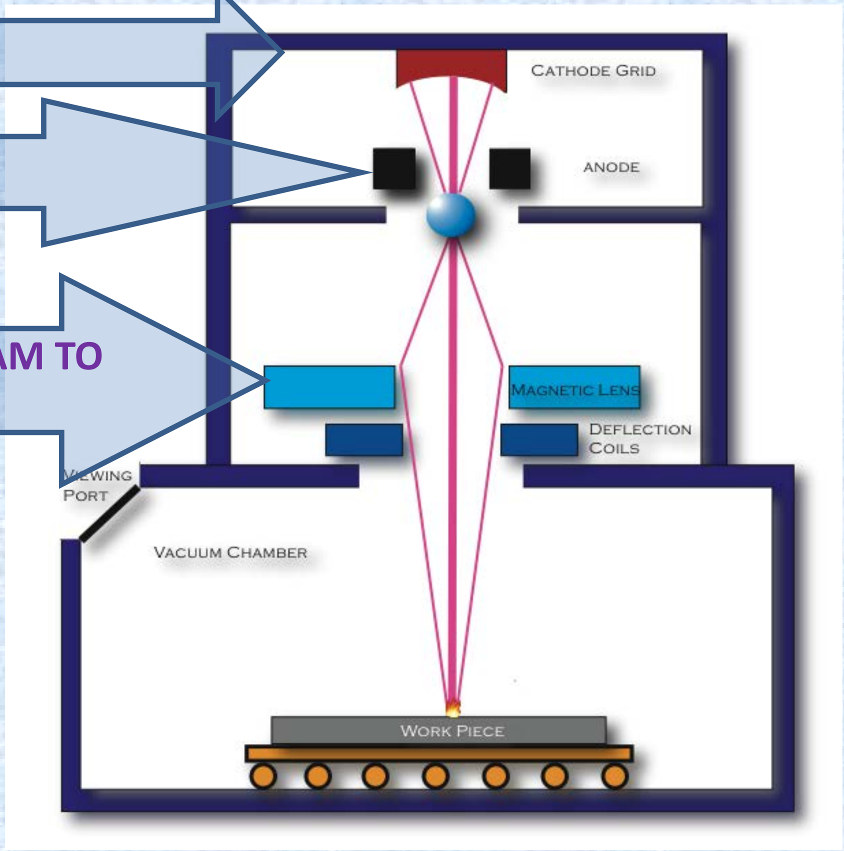
- IT WORKS IN MUCH THE SAME WAY AS A CATHODE RAY TUBE IN A TELEVISION.

CATHODE SECTION(GENERATES BEAM)

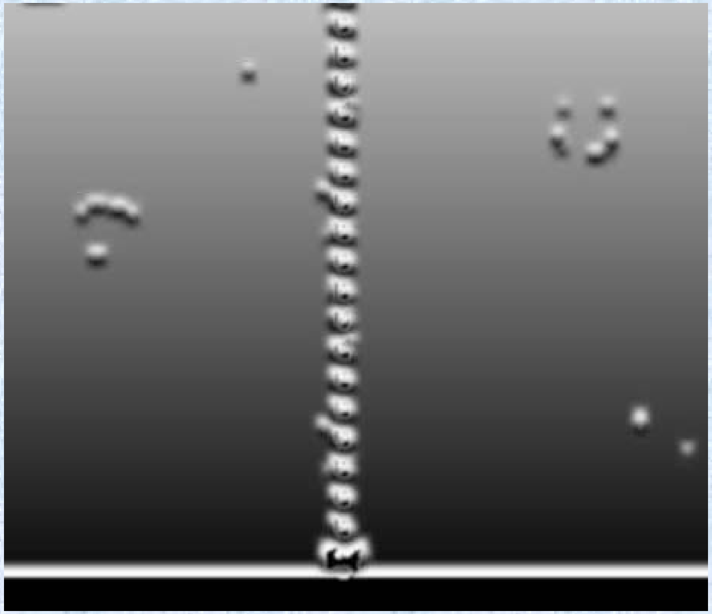
ANODE SECTION(ACCELERATES THE BEAM)

LENS SYSTEM CONVERGES AND DEFLECTS THE BEAM TO THE DESIRED POSITION

ELECTRON-BEAM MACHINING PROCESS

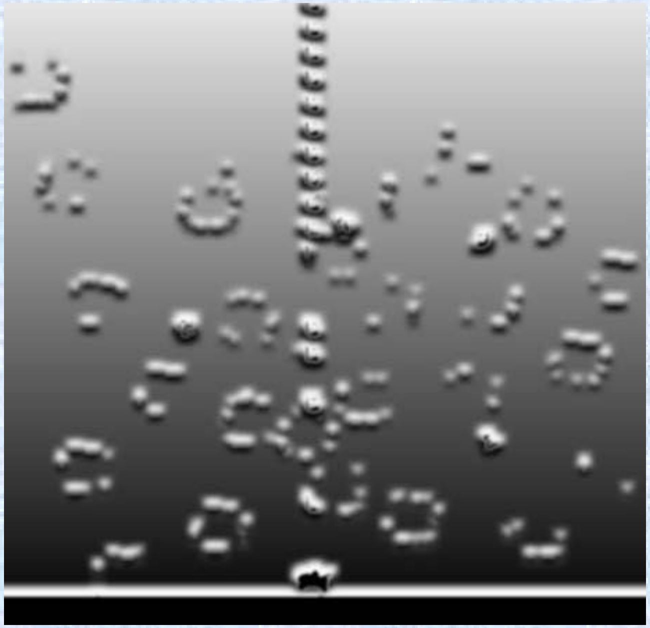


WHY VACCUM IS REQUIRED?

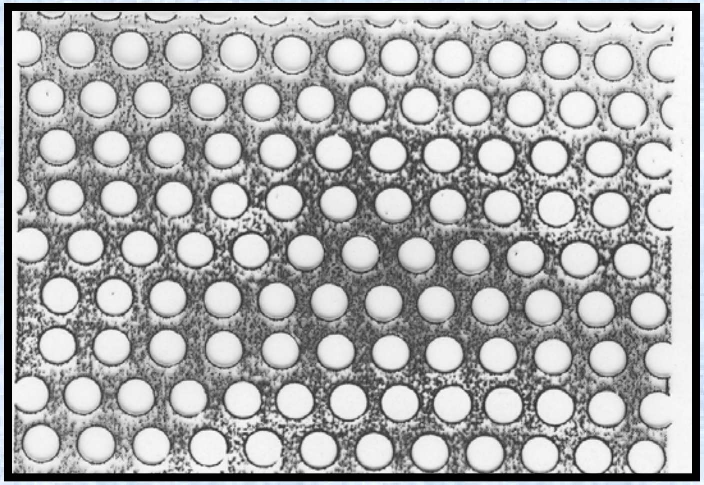


ELECTRON-BEAM IN A VACUUM

ELECTRON BEAM IN AMBIENT AIR



PATTERN OF HOLES DRILLED BY EBM



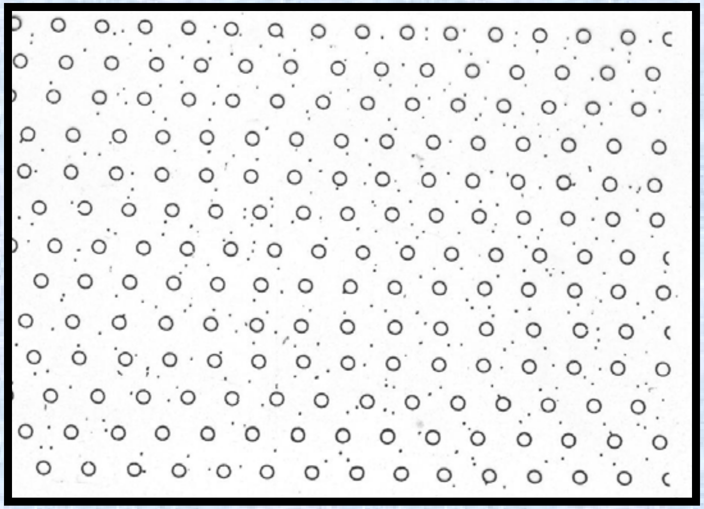
HOLE=0.09 mmϕ

HOLES DENSITY = 4000/cm^2

WORKPIECE- S.S.

THICK = 0.2 mm

TIME = 10 μS/HOLE



HOLE ϕ =0.006 mm (6 μm)

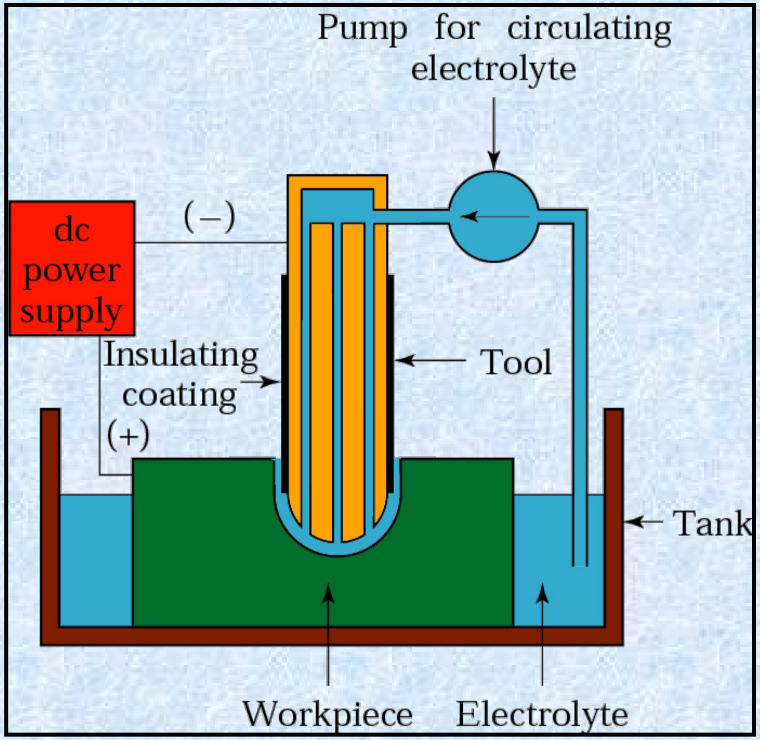
HOLES DENSITY = 200,000 / cm^2

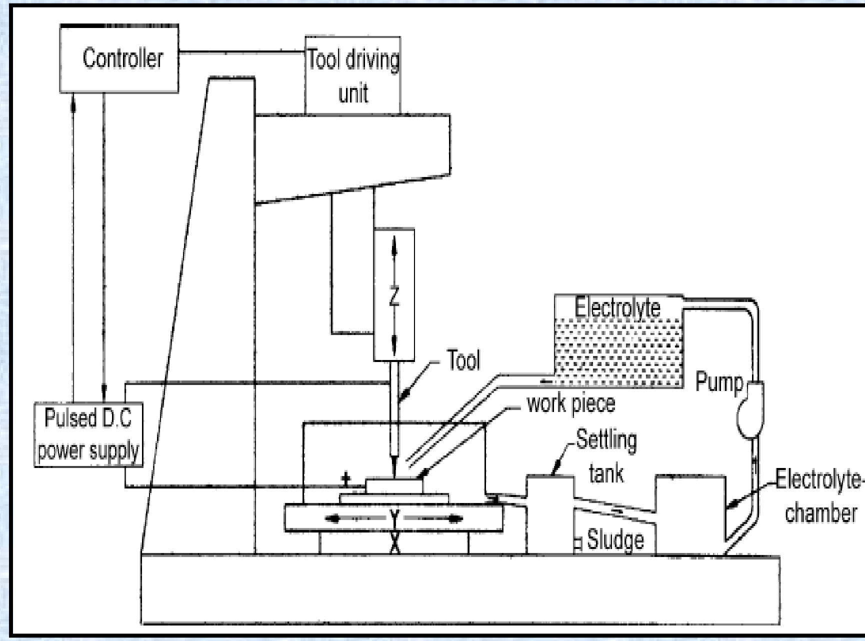
THICKNESS = 0.12 mm

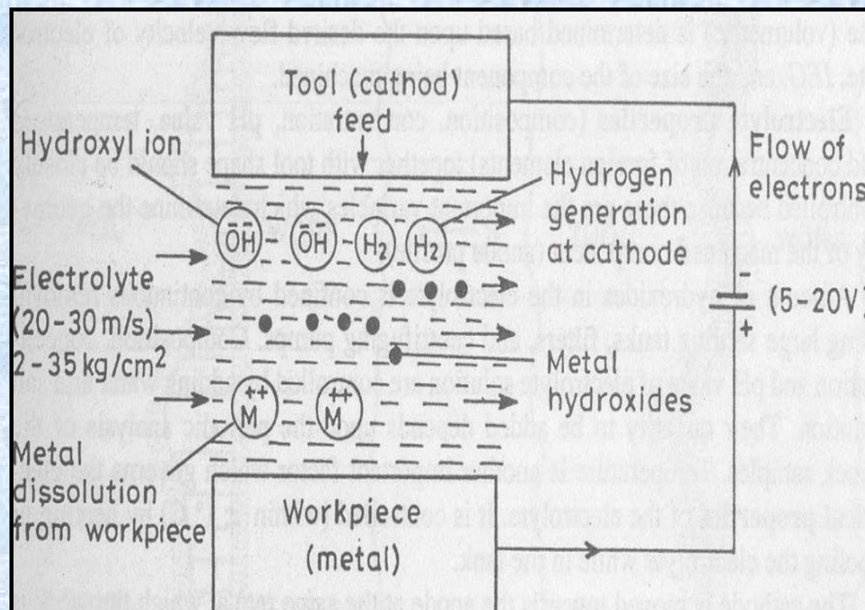
TIME= 2μs / HOLE

ELECTRO CHEMICAL MICROMACHINING (ECMM)

ELECTRO CHEMICAL MACHINING (ECM)



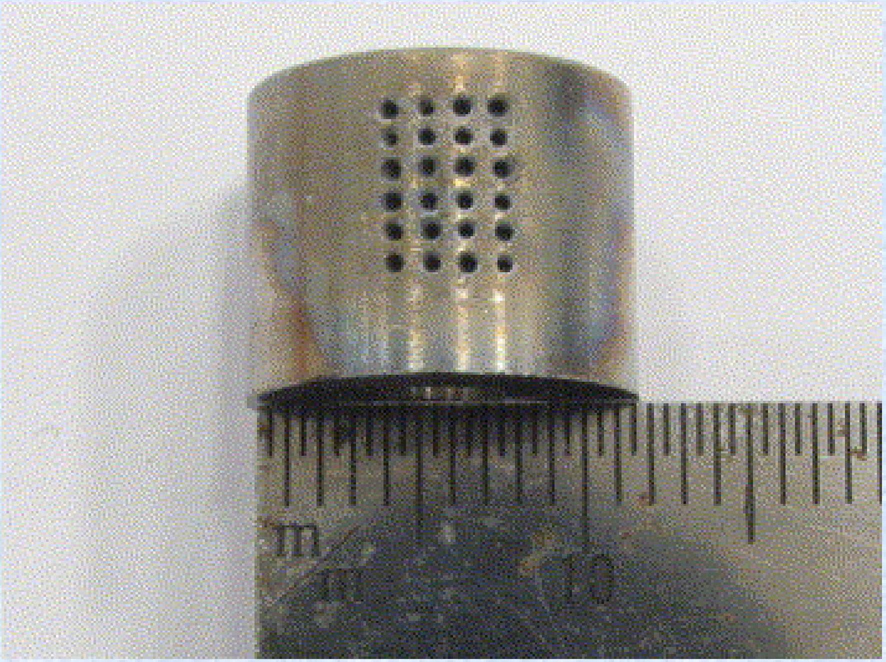




$Fe + 2H_2O \qquad Fe(OH)_2 + H_2$

$4Fe(OH)_2 + 2H_2O + O_2 \qquad 4Fe(OH)_3$

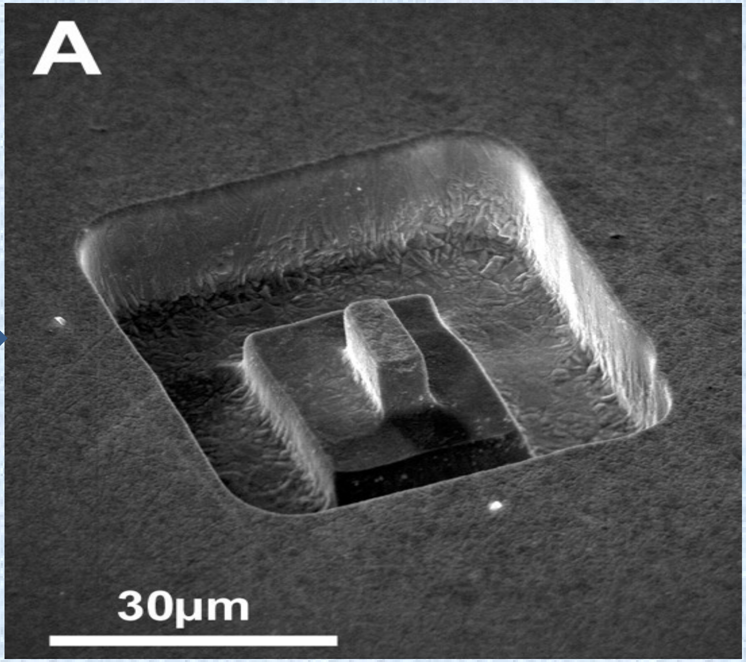
APPLICATIONS OF ECMM



MICRO-HOLES PRODUCED ON A Ti_6Al_4V CYLINDER USING JET-EMM

PRODUCTION OF HIGH ACCURACY HOLES

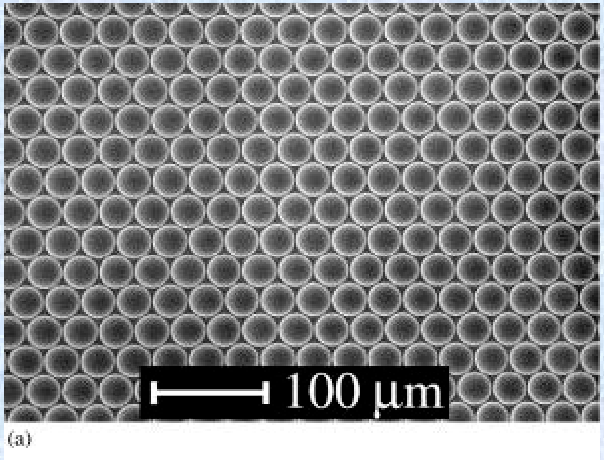
CU STRUCTURE (SMALL PRISM, 5 µm BY 10 µm BY 12 µm) MACHINED INTO THE CU SHEET OF AN ELECTRONIC CIRCUIT BOARD



3D MICRO-MACHINING

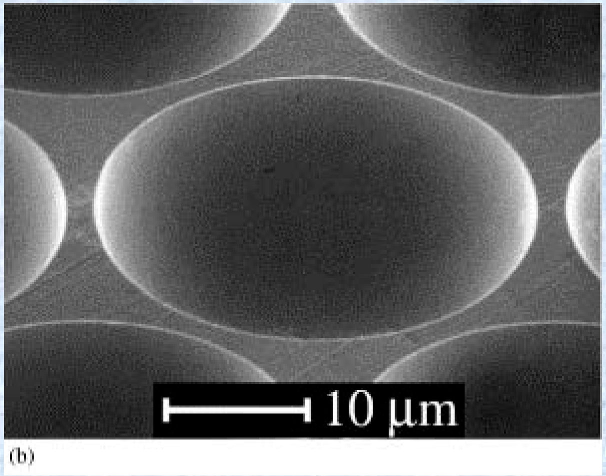
APPLICATIONS OF ECMM

Titanium surface microstructure by through-mask EMM



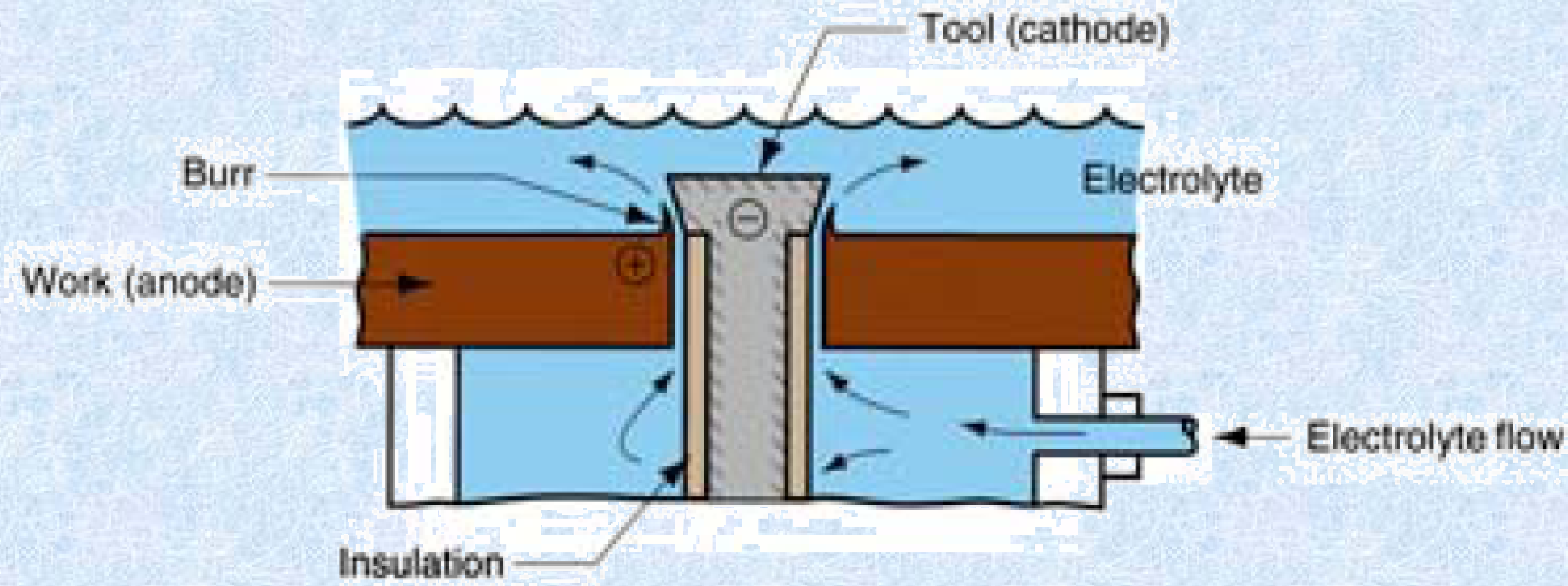
LONG-RANGE ACCURACY AND REPRODUCIBILITY OF 30 μm CAVITIES

SMOOTH SURFACE AND SHARP BORDERS THAT ARE ACHIEVED UNDER OPTIMIZED DISSOLUTION CONDITIONS



ELECTRO CHEMICAL DEBURRING (ECD)

- **Adaptation of ECM to remove burrs or round sharp corners on holes in metal parts produced by conventional through-hole drilling.**



ION BEAM MICROMACHINING (IBMM)

MECHANISM OF ION BEAM MACHINING

- **SPUTTERING OFF: KNOCKING OUT ATOMS FROM THE WORK-PIECE SURFACE BY THE KINETIC MOMENTUM TRANSFER FROM INCIDENT ION TO THE TARGET ATOMS**
- **REMOVAL OF ATOMS WILL OCCUR WHEN THE ACTUAL ENERGY TRANSFERRED EXCEEDS THE USUAL BINDING ENERGY.**

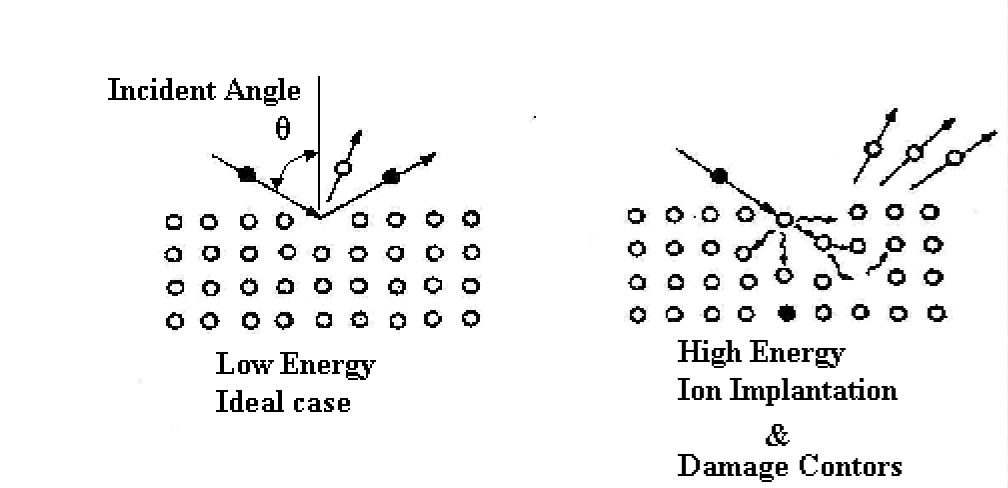
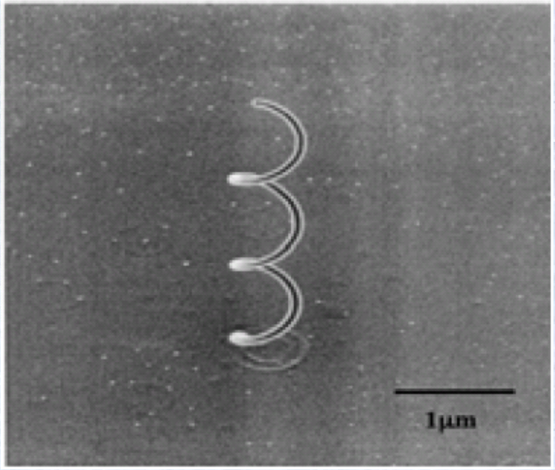


FIG.SCHEMATIC ILLUSTRATION OF THE MECHANISM OF MATERIAL REMOVAL IN IBM

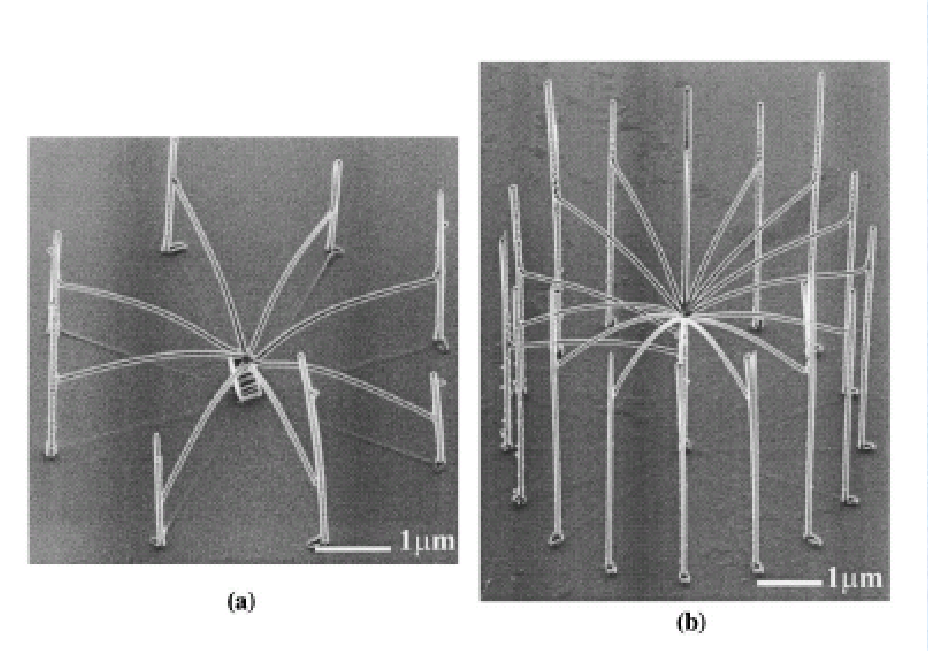
- **AT SUFFICIENTLY HIGH ENERGY, THE CASCADING EVENTS WILL PENETRATE MORE DEEPLY INTO THE SOLID, SEVERAL ATOMS OR MOLECULES WILL BE EJECTED OUT AND THE BOMBARDING ION WILL BECOME IMPLANTED DEEP WITHIN THE MATERIAL.**



Coil 700 nm pitch, 80 nm line width, diamond like amorphous carbon, Fabricated by FIB induced deposition

Micro wine glass with 2.75 μm external diameter and 12 μm height.

Shinji Matsui et al, J. Vac. Sci. Technol. B 18(2000) 3181



(a) Radial DLC free-space-wiring grown into eight directions from the center. (b) Radial DLC free-space-wiring grown into 16 directions from the center.

*T. Morita et al, J. Vac. Sci. Technol. B **21** (2003)*

TYPICAL MATERIAL REMOVAL RATE IN ION BEAM MACHINING

TABLE1: REMOVAL RATES BY IBM (SPENCER AND SCHMIDIT,1972 [1])

DATA : ARGON ION BEAM 60 TO 70^0 FROM NORMAL

PRESSURE = $3X10^{-4}$ TORR

VOLTAGE = 6 KV

CURRENT = 100 μA

CURRENT DENSITY = 1 $MACM^{-2}$ OVER 1 CM DIAMETER AREA

MATERIAL	REMOVAL (MILLING) RATE, (μM HR^{-1})
QUARTZ	2
GARNET	1
CERAMIC	1
GLASS	1
GOLD	2
SILVER	3
PHOTO RESIST MATERIAL (KTFR)	1
PERMALLOY	1
DIAMOND	1

NANOFINISHING PROCESSES: AN OVERVIEW

Micro / nano finishing

Traditional

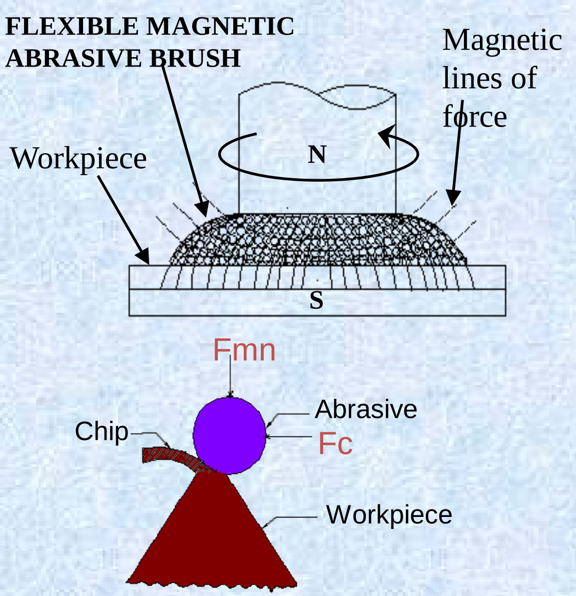
- Grinding
- Lapping
- Honing

SHAPE AND SIZE CONSTRAINTS
WITH EACH OF THESE
TRADITIONAL FINISHING PROCESSES

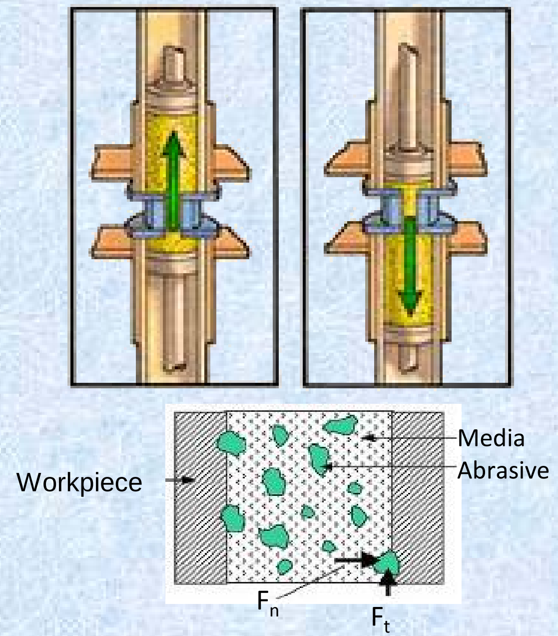
Advanced

- AFM
- MAF
- MRF
- CMP
- MRAFF
- ELID
- MFP
- CMMRF

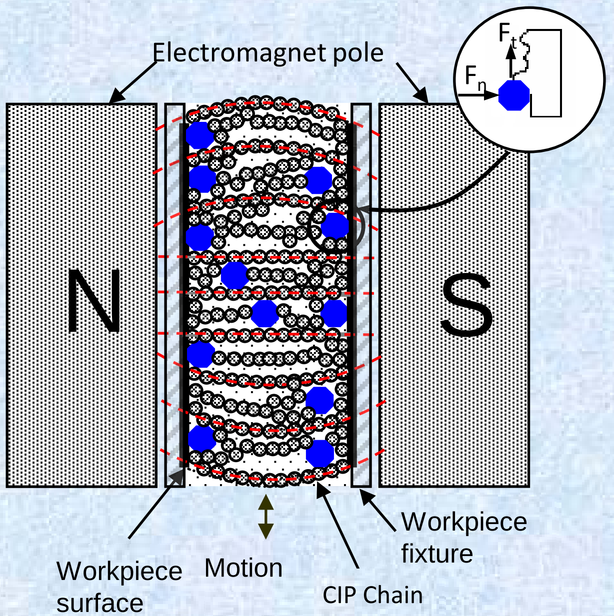
MAF



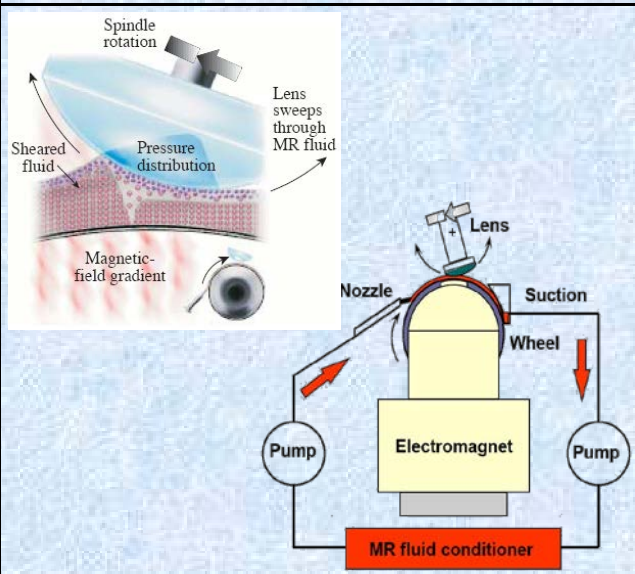
AFM



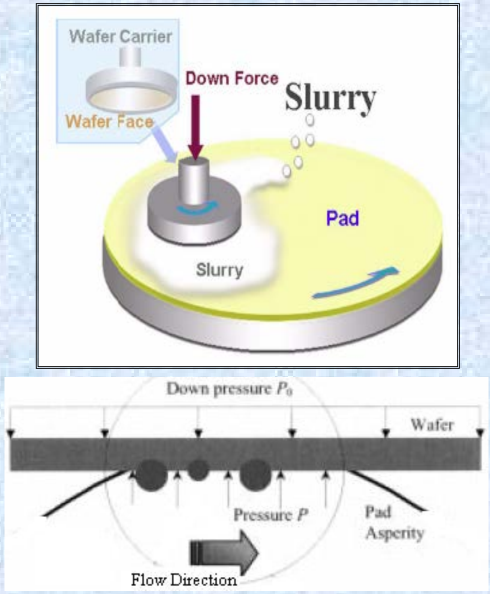
MRAFF



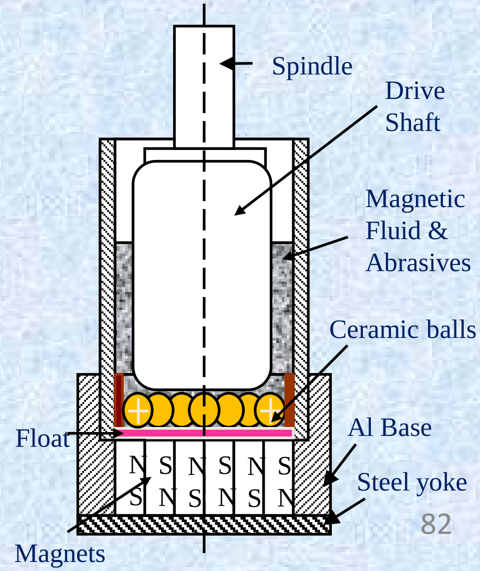
MRF



CMP



MFP



OVERVIEW OF ADVANCED ABRASIVE FINISHING PROCESSES

WHY ADVANCED ABRASIVE FINISHING PROCESSES?

- Complex Geometrical Shapes.
- Labor Intensive Nature of Traditional Finishing Operations.
- Difficulties in Controlling Abrading Forces.
- Nano-meter (10^{-9} m) Surface Finish Requirements.

ADVANCED ABRASIVE FINISHING PROCESSES

MAF	Magnetic Abrasive Finishing
AFF	Abrasive Flow Finishing
MRAFF	Magnetorheological Abrasive Flow Finishing
MRF	Magneto Rheological Finishing
CMP	Chemo Mechanical Polishing
MFP	Magnetic Float Polishing

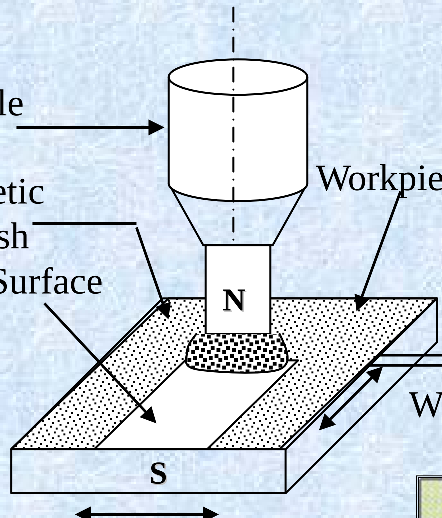
IN ALL THESE PROCESSES NORMAL FORCE IS RESPONSIBLE FOR PENETRATION OF ABRASIVE INTO WORKPIECE AND SHEAR FORCE TO REMOVE THE MATERIAL IN THE FORM OF MICROCHIP

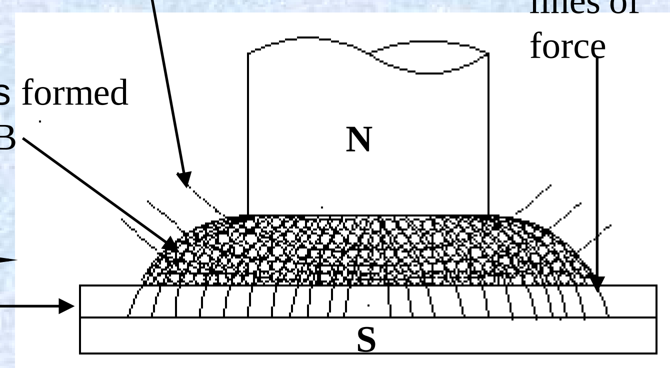
MAGNETIC ABRASIVE FINISHING (MAF)

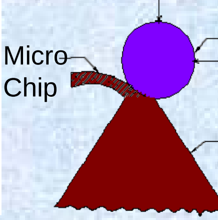
SCHEMATIC VIEW OF MAF WORKING PRINCIPLE

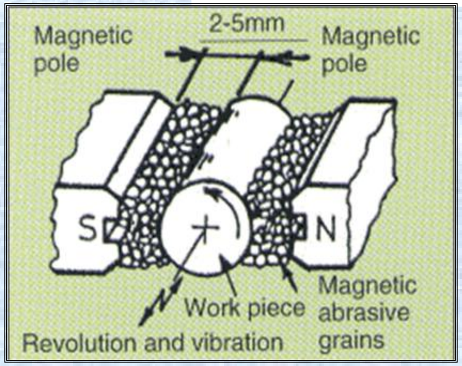
WORKING GAP ➔ FILLED WITH MAPs ➔ FORMS FMAB

MULTIPOINT CUTTING TOOL









SALIENT FEATURES

Ra = AS GOOD AS 8 nm

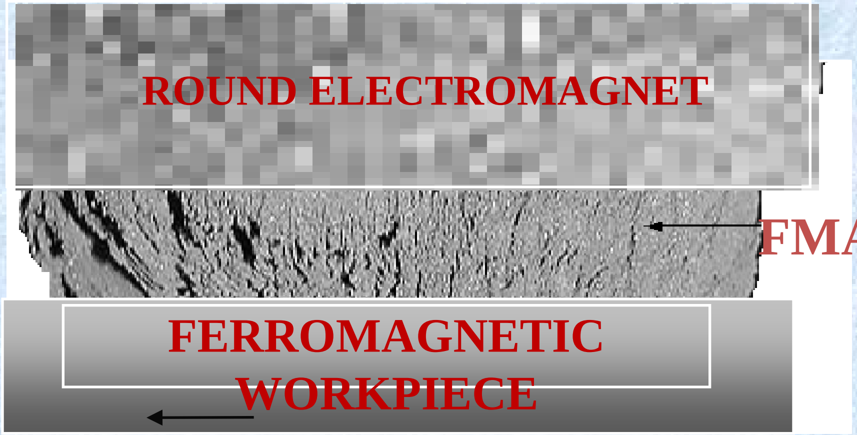
MAGNETIC ABRASIVE FINISHING (MAF)

(DST SPONSORED PROJECT)

EXPERIMENTAL SET-UP

DESIGNED AND FABRICATED AT IITK

DIGITAL PHOTOGRAPH OF FLEXIBLE MAGNETIC ABRASIVE BRUSH (FMAB)

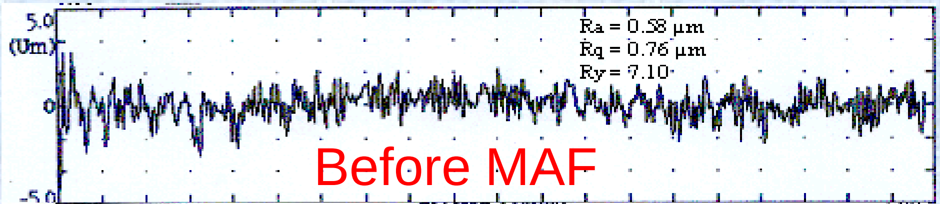


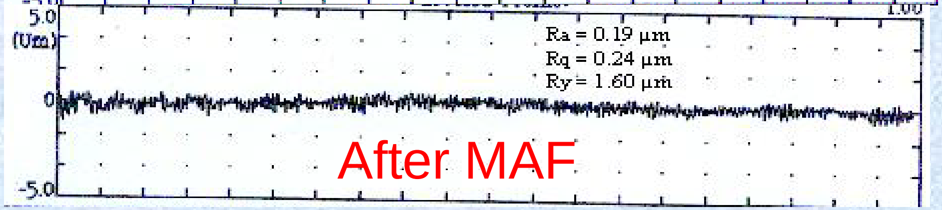
EXPERIMENTAL RESULTS OF MAF

Surface Profilometer Results

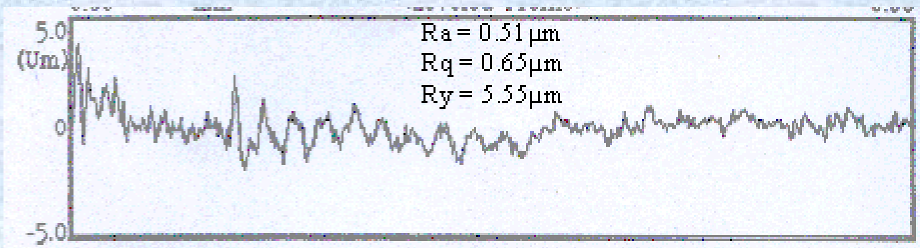
DC-MAF

I=0.88 A,
G= 500
N=11
(No. of cycles)

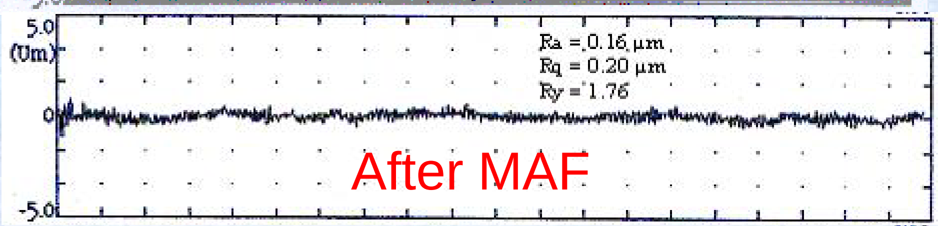




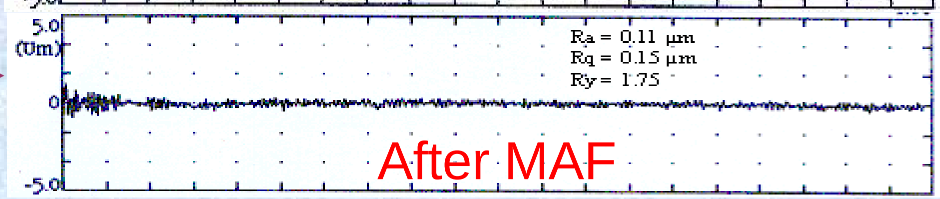
Before MAF



I=0.75 A,
G=600
N=9

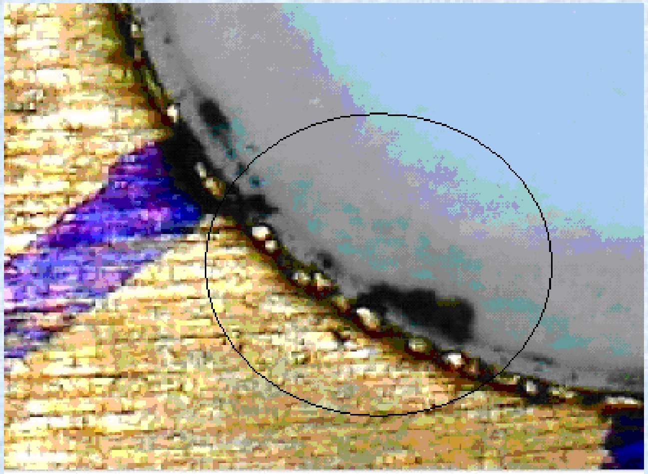


I=0.75 A,
G =800
N= 9

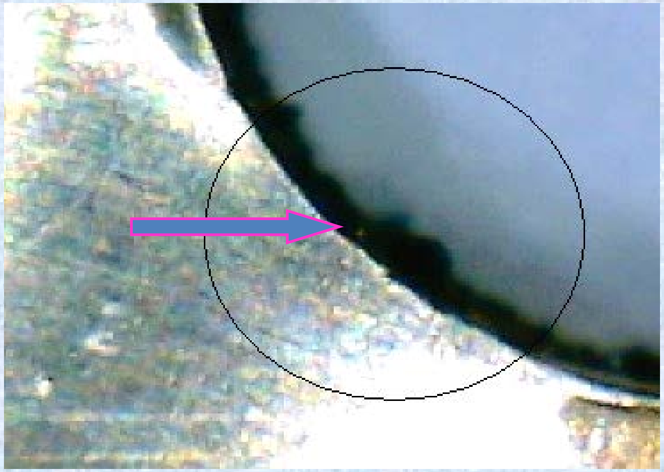


BEST SURFACE ROUGHNESS ACHIEVED WAS 40nm

MICRO DEBURRING APPLICATION OF MAF



(a)



(b)

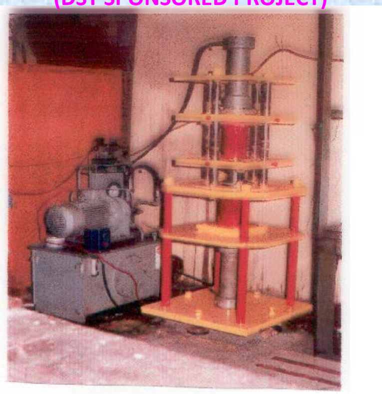
Drilled hole edge (a) before, (b) after deburring

ABRASIVE FLOW FINISHING (AFF)

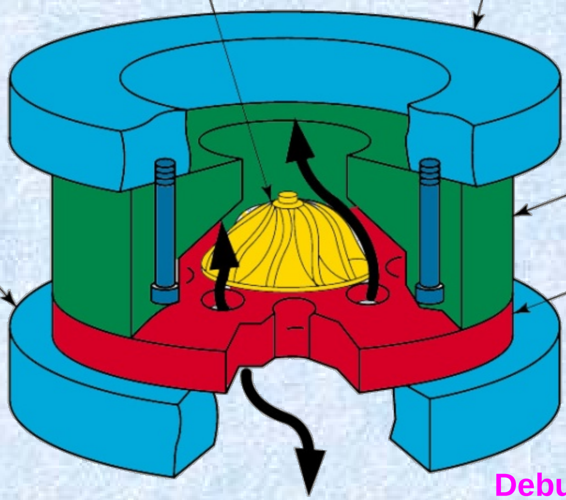
ABRASIVE FLOW MACHINING (AFM)

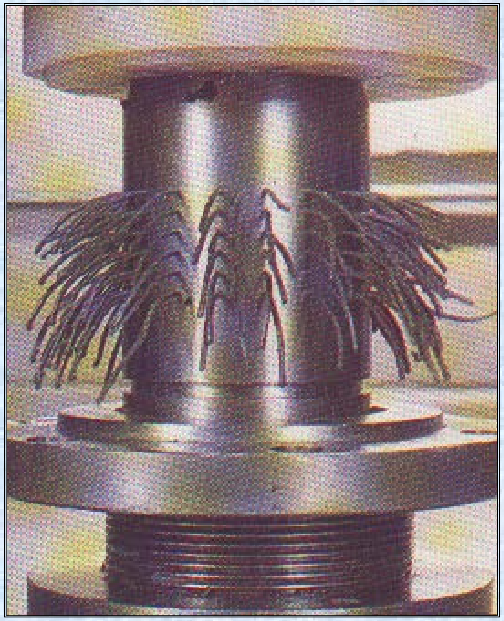
- Two vertically opposed cylinders extrude abrasive laden medium back & forth through passage formed by the workpiece & tooling
- **Medium :** Visco-elastic Polymer with special rheological properties + Fine Abrasive Particles

Abrasive Flow Machining (AFM) at IIT – K
(DST SPONSORED PROJECT)



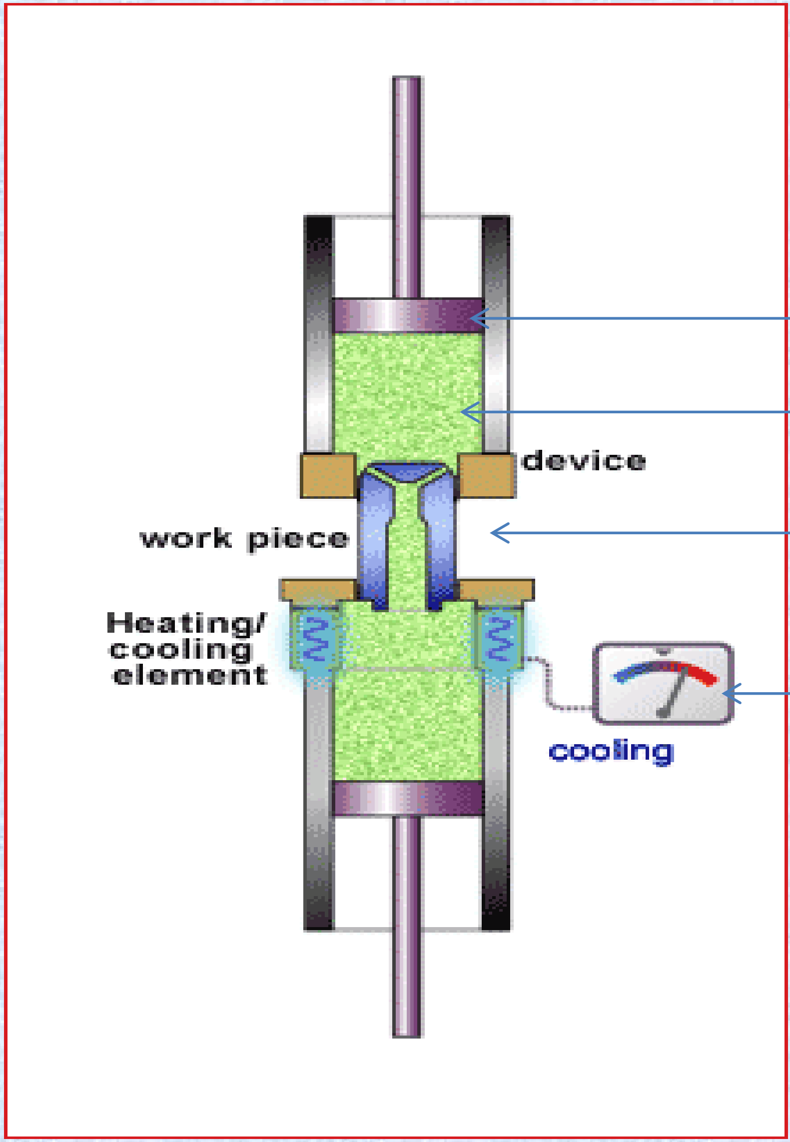
Photograph Showing AFM set-up





Deburring of turbine impeller

Fig: Abrasive flow finishing setup for knee joint finishing



Piston

Silly Putty (viscoelastic) + SiC (abrasive)

Workpiece held in fixture

Thermostat for temp control

KEY FEATURES OF AFM

VERSATILITY – FINISH COMPLEX SURFACES OF VARIOUS SIZES.

- **SURFACE FINISH - 0.1 μm to 0.05 μm R_a.**

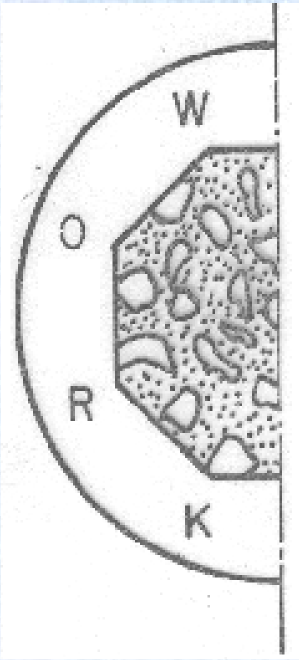
  FORCE : 0.0009N -- 0.002N Per Particle

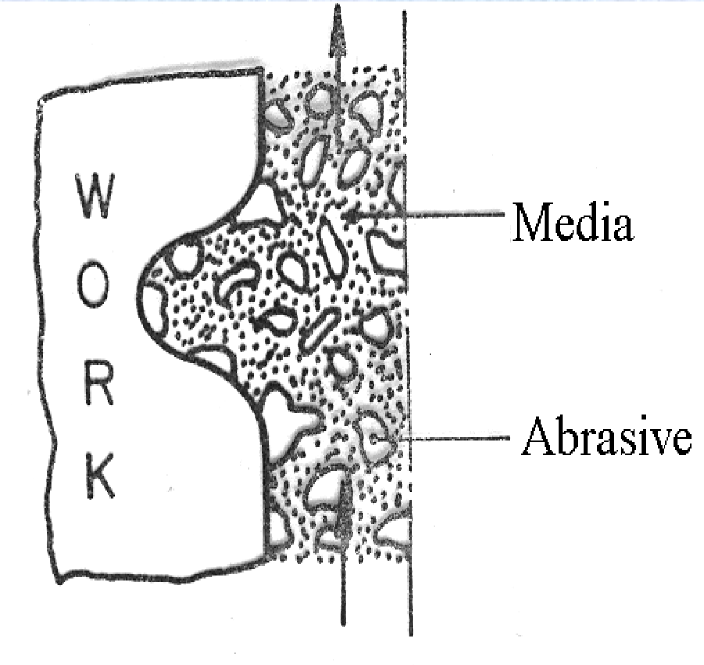
  DEPTH OF PENETRATION : 5nm -- 30nm

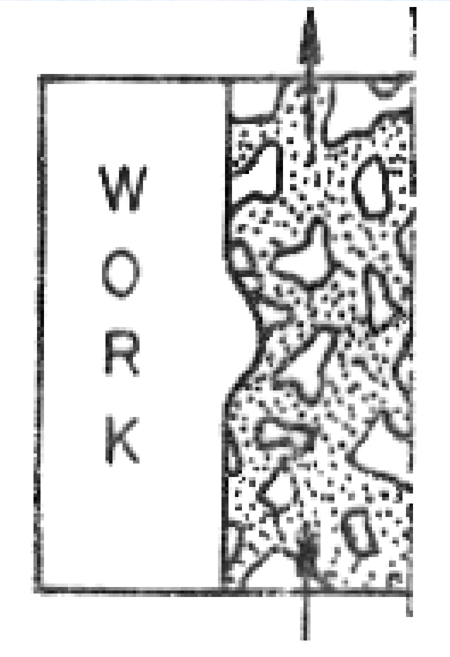
LIMITATIONS:

- **VISCOELASTIC POLYMERIC MEDIUM – COSTLY AND LACK OF AVAILABILITY.**
- **MEDIUM RHEOLOGICAL PROPERTIES – VARY IN UNCONTROLLED MANNER DURING PROCESS.**
- **LACK OF DETERMINISM.**

AFM MEDIA ACTS AS A *SELF-DEFORMABLE STONE*



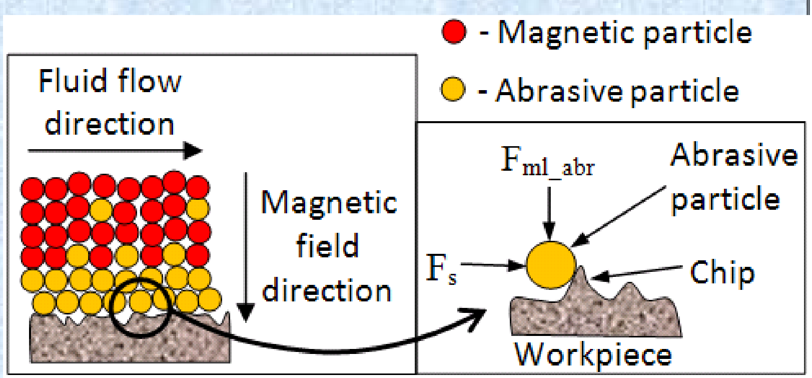


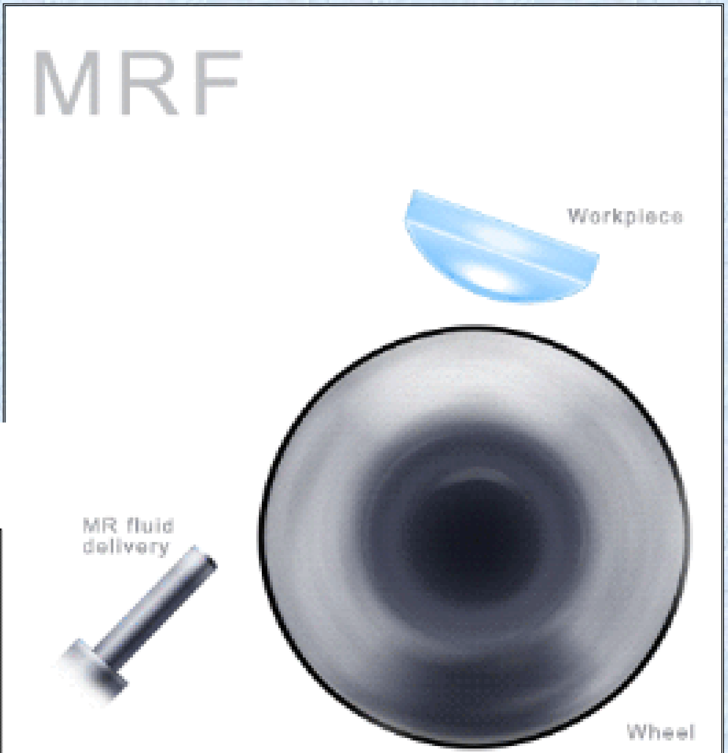


MAGNETORHEOLOGICAL FINISHING (MRF)

MRF- Mechanism of material removal

- CI particles form a chain-like columnar structure, with the application of magnetic field and they are aligned along the lines of magnetic force.
- The magnetic force between iron particles provides bonding strength to it.
- When these chains have relative motion with respect to the workpiece surface the asperities on the surface are abraded due to shearing / plastic deformation at the tips.





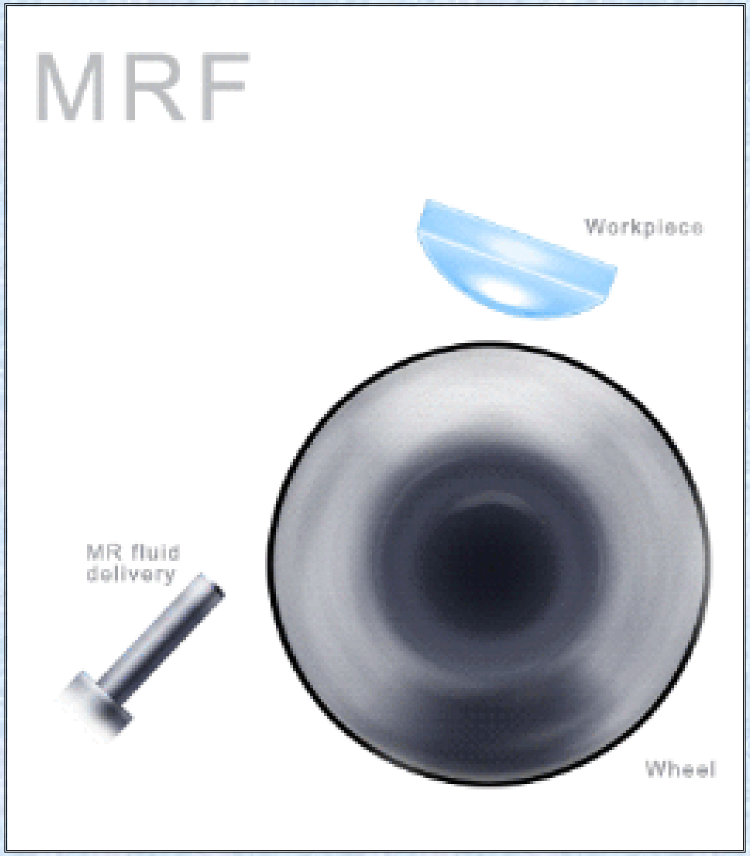
Source: www. qedmrf.com

MAGNETORHEOLOGICAL FINISHING (MRF)

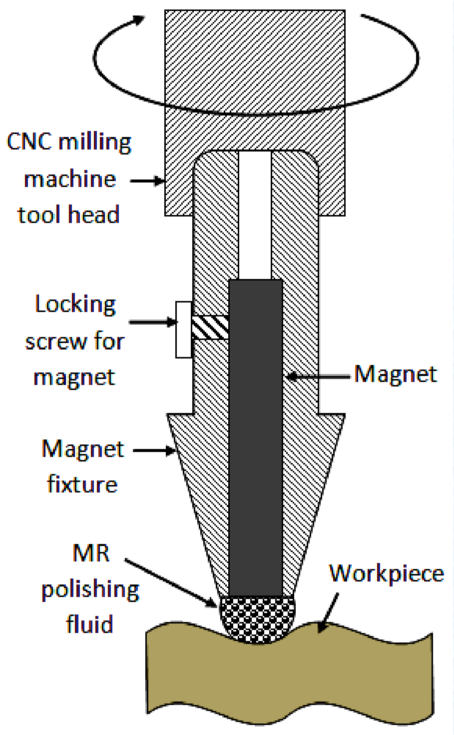
- Fluid is extruded onto a rotating wheel in a **thin ribbon** that contacts the optical / WORKPIECE surface.
- **Electromagnet** below the polishing wheel exerts a strong local **Magnetic field gradient**.
- Precisely controlled zone of **magnetized fluid** becomes the **Polishing tool**.

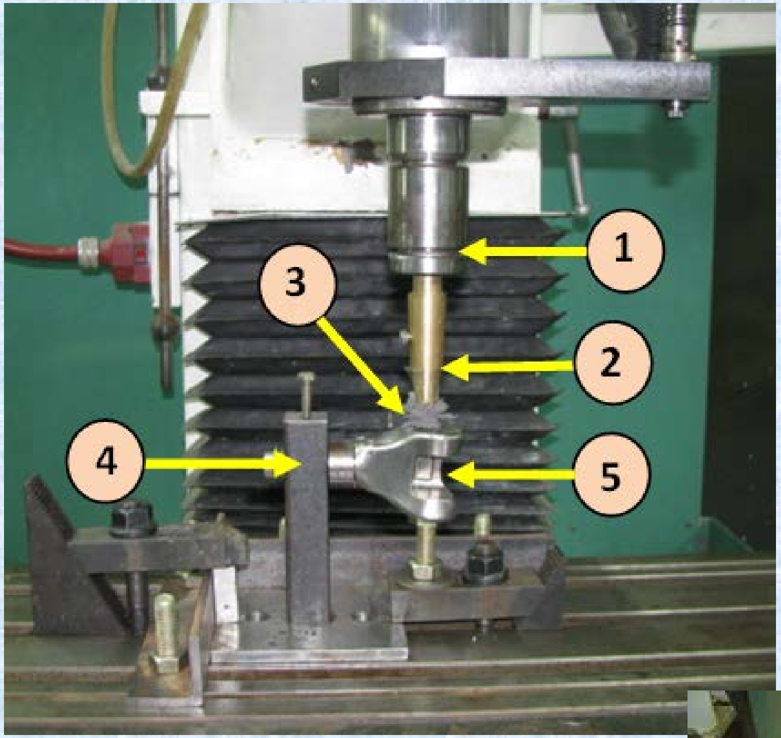
MR-fluids are suspension of ferromagnetic particles in water/oil that reversibly stiffens under the influence of magnetic field.

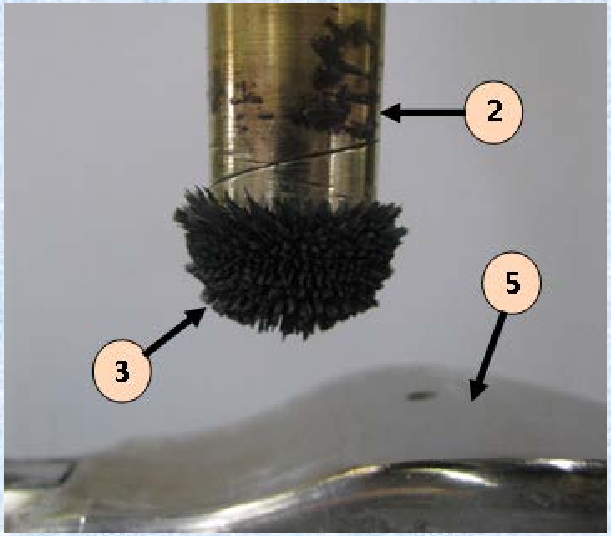
Stiffness of the fluid α Magnetic Field Strength.



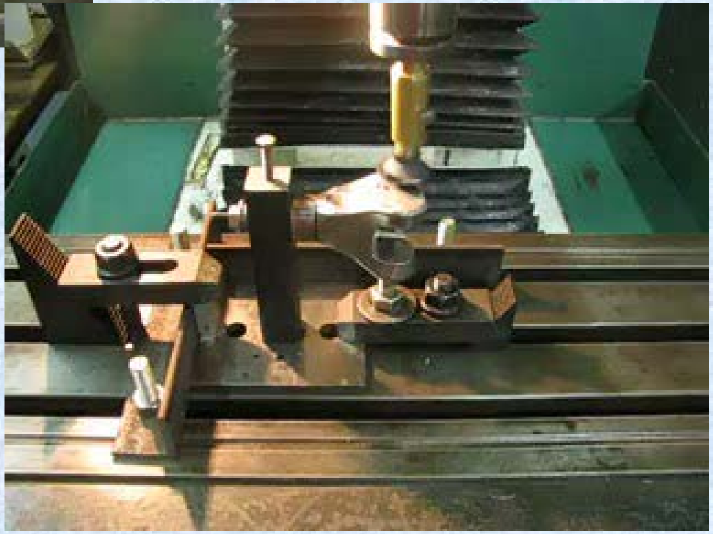
Apparatus and tooling for freeform surface





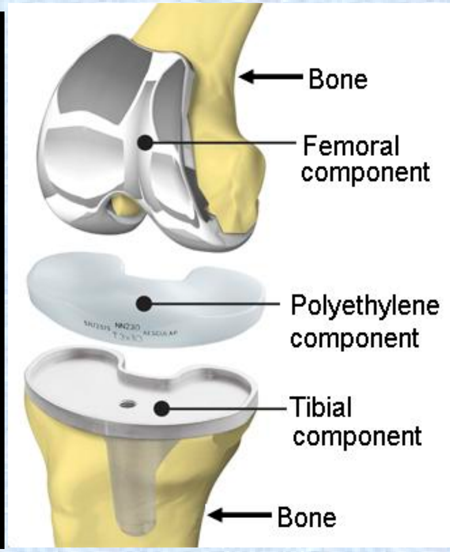


(**1**- CNC milling M/c head, **2**- MR finishing tool, **3**- MR polishing fluid, **4**- fixture for knee joint implant (Ti6Al4V), **5**- knee joint implant)



Finishing of freeform surface

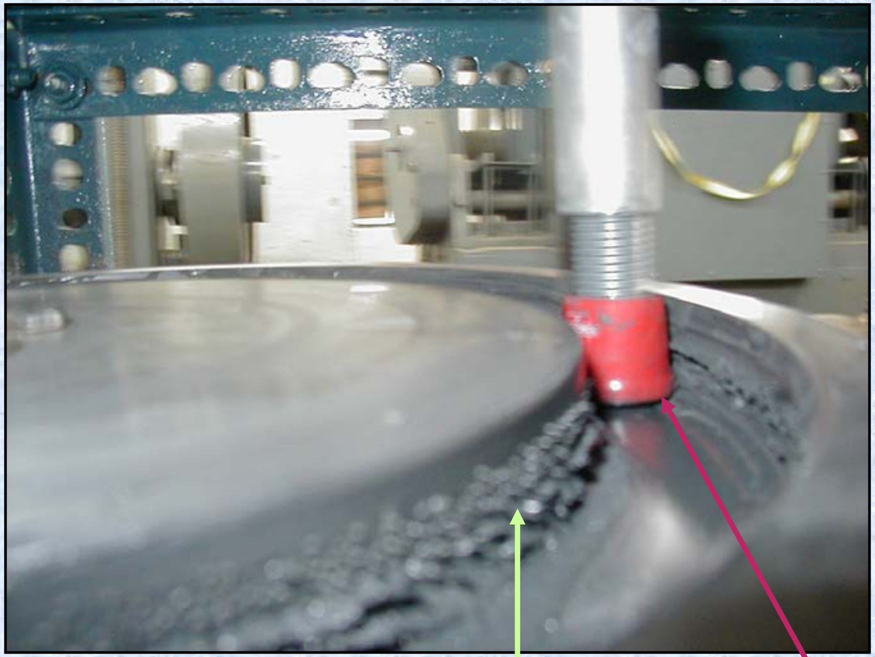
- Knee joint implants consist of metal femoral and tibial components with a plastic polyethylene insert sandwiched between to restore joint function.
- Surface roughness of knee joint implant has a significant effect on the force at the connection and reaction of tissues in the joint area and behaviour of germs in bone tissue (Mathia et al., 2011).
- **Wear by abrasion** is one of the main causes for **failures of knee joints** because over time, the continuous movement between the metal and plastic can cause the polyethylene to crack, pit and delaminate.
- It may also cause microscopic particles to break off which in turn attack the body's immune system.



Components of knee joint implants (Courtesy: Aesculap Implant Systems, LLC, www.soactivesofast.com).

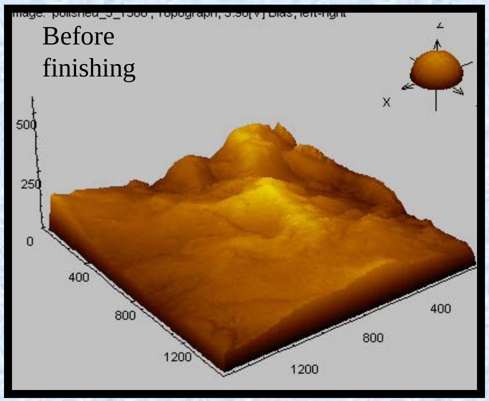
MRF EXPERIEMTNAL SETUP AT IIT - K

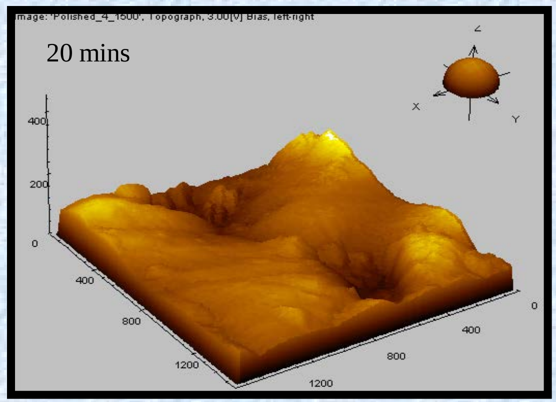
(BY B. TECH. STUDENTS PROJECT)

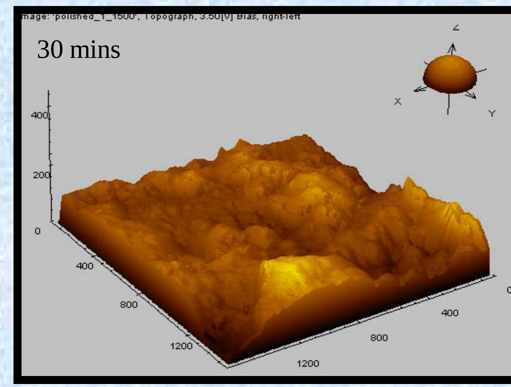


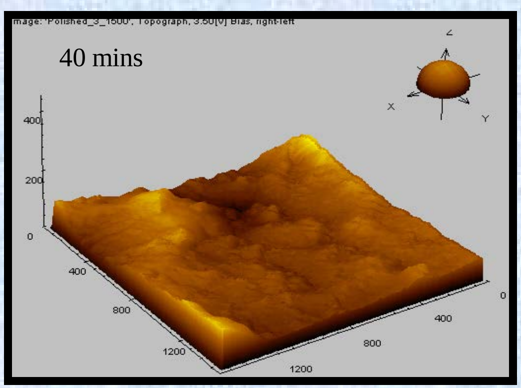
EXPERIMENTAL RESULTS OF MRF

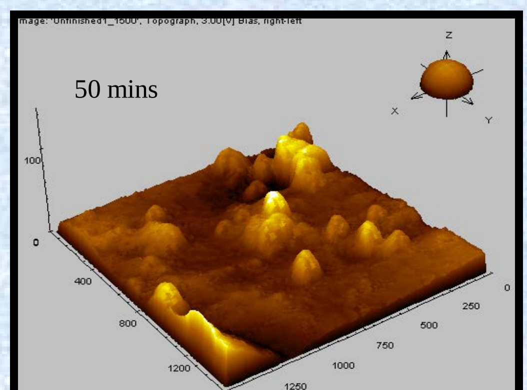
53 nm (RMS)







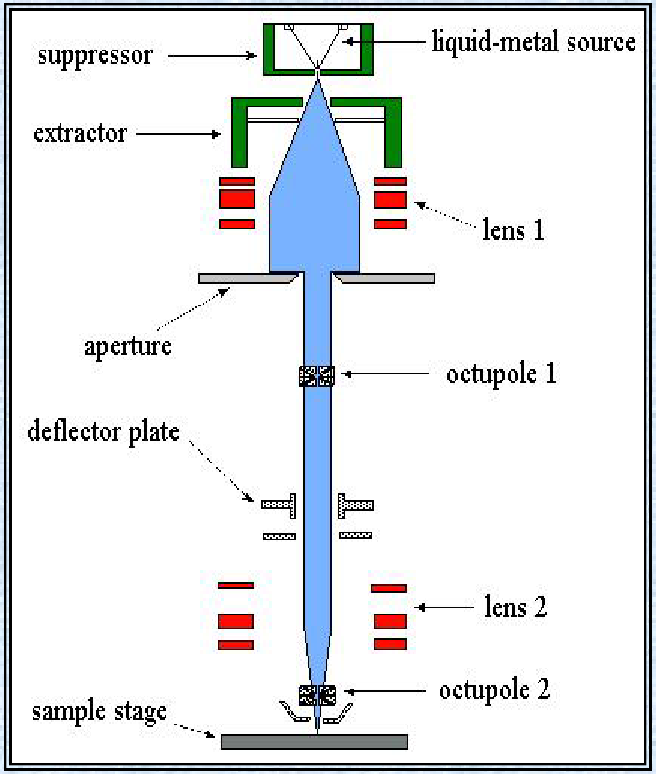


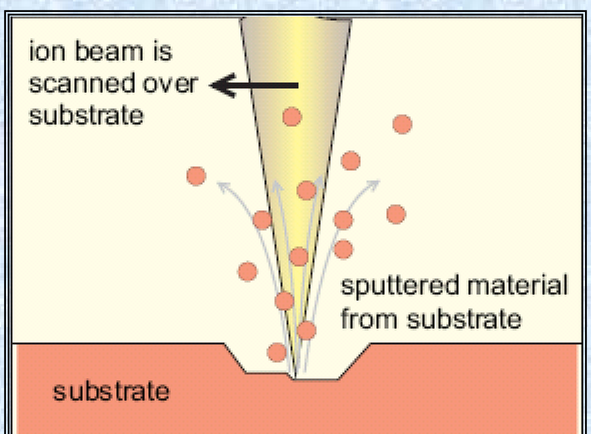


11 nm (RMS)

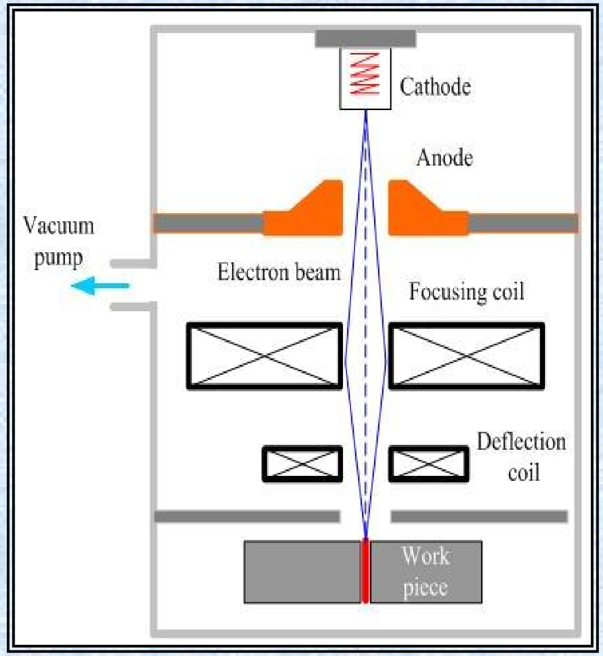
THANK YOU

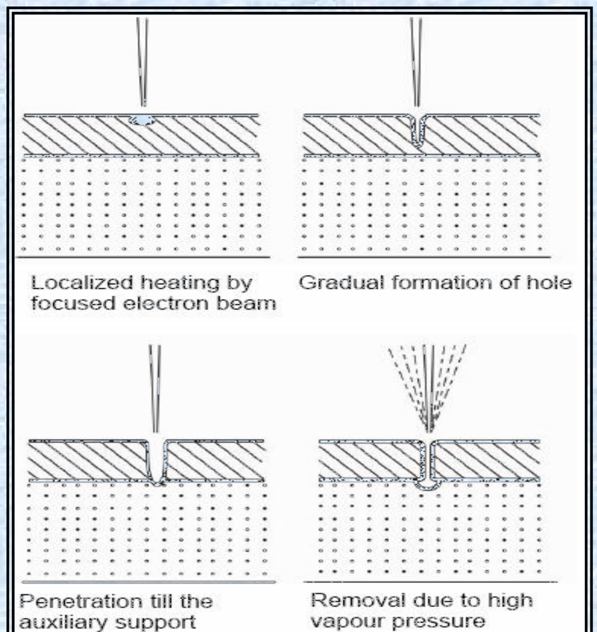
IBM



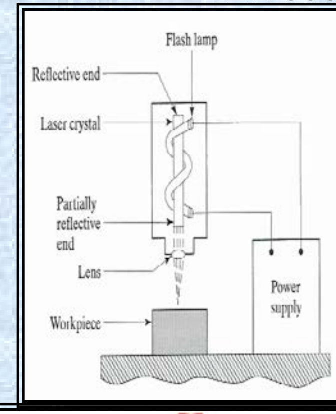


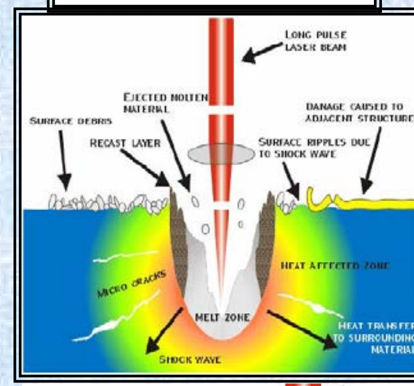
EBM

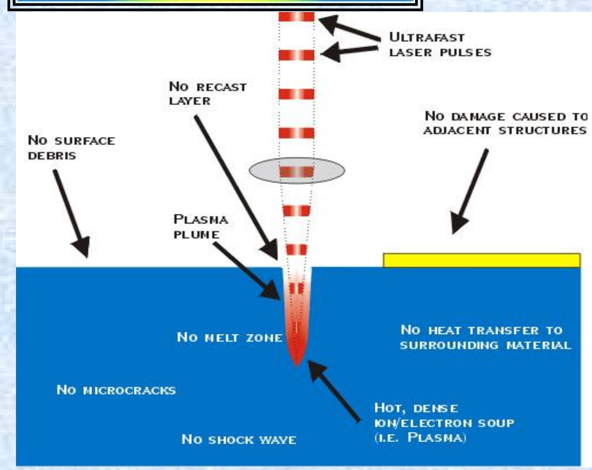




LBM





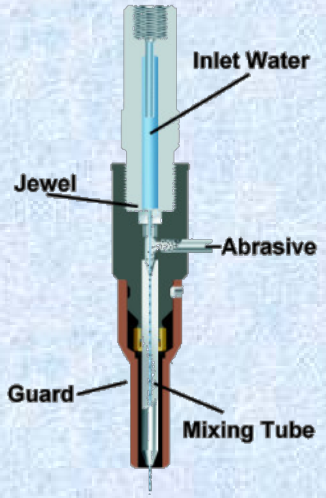


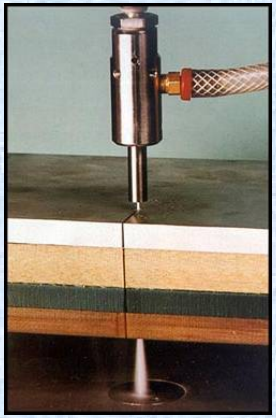
SHORT PULSE LASER MACHINING

Ref.: Cmxr lasers industry,
www.cmxr.com/industrial/handbook/

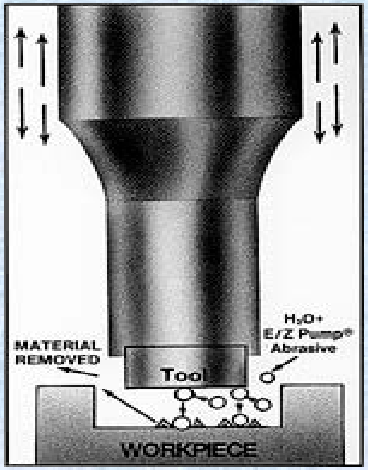
MECHANISM OF MATERIAL REMOVAL IN MECHANICAL MICROMACHINING

ABRASIVE WATR JET MACHINING

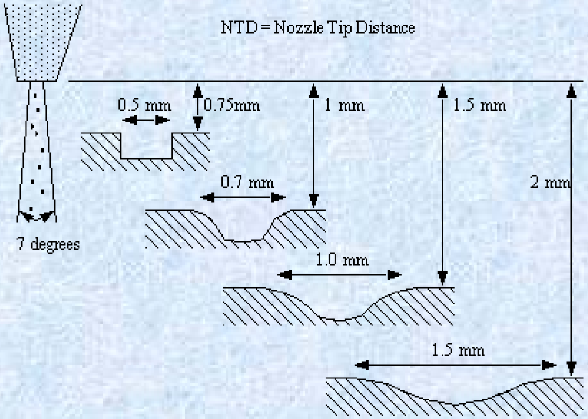




ULTRASONIC MACHINING

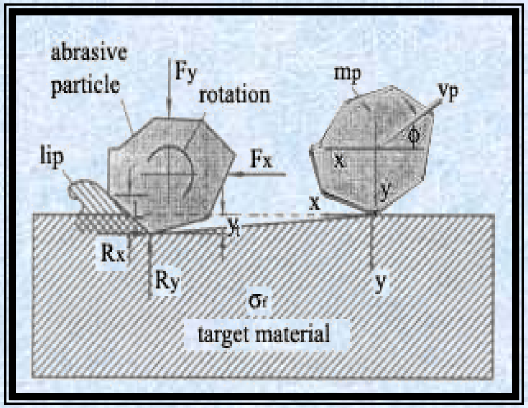


ABRASIVE JET MACHINING

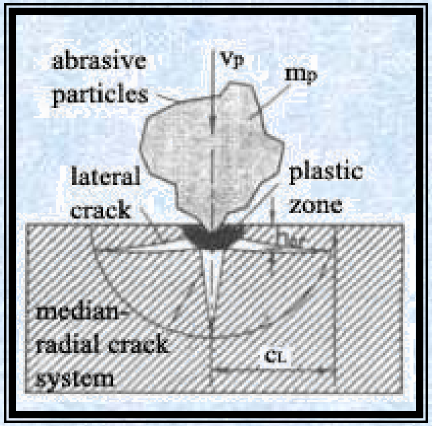


AWJM, AJM, USM

Mechanism of material removal in ductile material

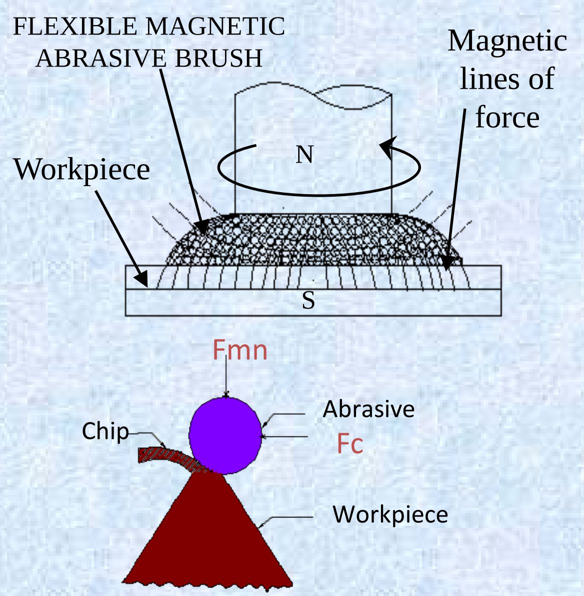


Mechanism of material removal in brittle material

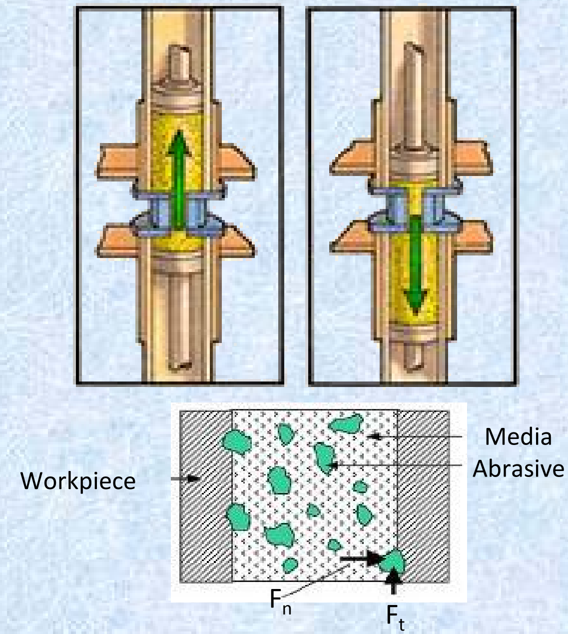


FORCES ACTING ON EACH PARTICLE AND PARTICLE SIZE WILL DEC IDE THE SCALE OF MATERIAL REMOVED : MACRO, MICRO, NANO

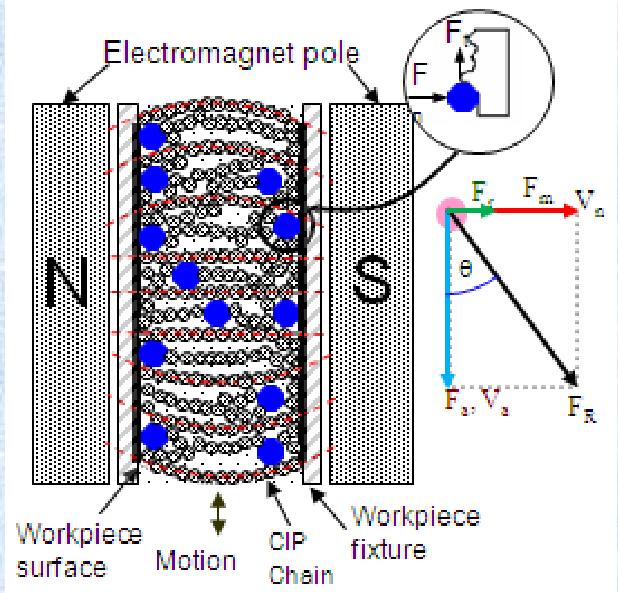
MAF



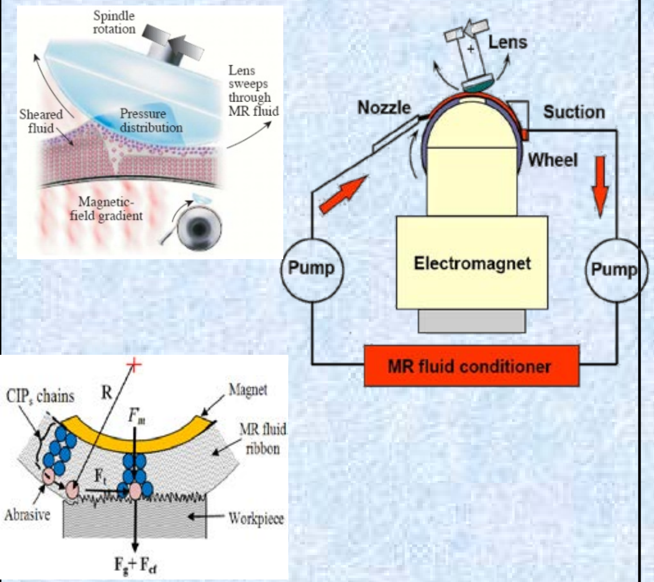
AFM



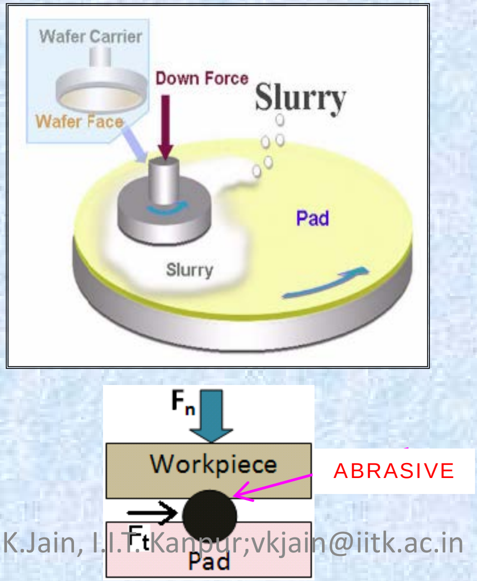
MRAFF



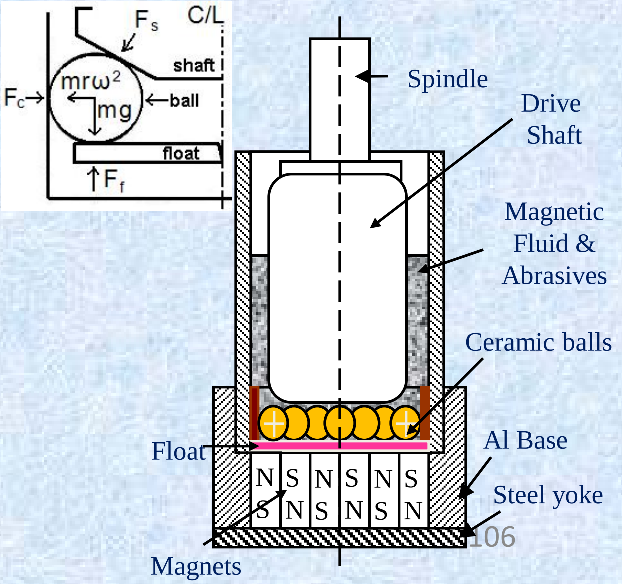
MRF



CMP



MFP



ADVANCED MACHINING PROCESSES

QUESTIONS BANK

Questions bank for "introduction to AMPs"

Q.1 Name the important factors that should be considered during the selection of an Advanced Machining Process for a given job.

Q.2 Classify the different types of Advanced Machining Processes based on different criteria.

Q.3 What do you understand by the term "Micromachining"? Classify the different types of micromachining methods. Also write down the ranges of macro, meso, micro, and Nano machining.

Q.4 What do you understand by "hybrid process"? List out the names of hybrid processes and the advantages of a hybrid process over its constituent processes.

Q.5 Classify the advanced machining processes based on electrical properties of materials.

Q.6 what is the mechanism of material removal in Laser beam machining?

Q.7 Differentiate between chemical and electrochemical machining processes.

Q.8 Write the element of EBM.

Q.9 what do you understand by a finishing process?

Q.10 what are the constraints that limit the performance of different kinds of AMPs

Q.11 what do you understand by the word "unconventional" in unconventional machining processes ? Is it justified to use this word in the context of the present day medium and large scale engineering industries?

Q.12 Classify the advanced machining processes on the basis of type of the energy employed.

Q.13 What are the advanced machining processes which can be used for magnetic material?

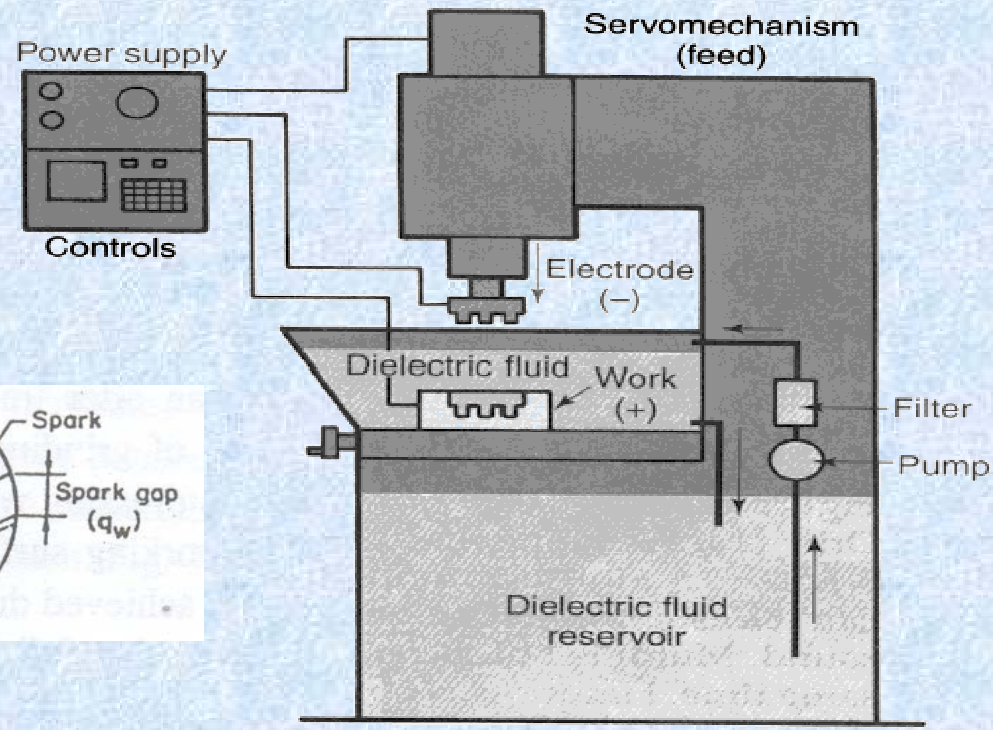
BASICS OF EDMM

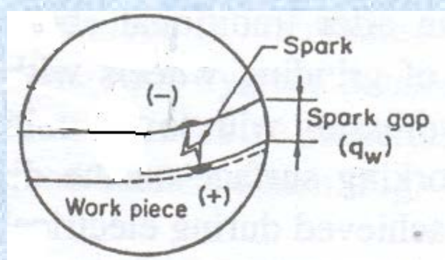
- IN EDM MATERIAL IS REMOVED BY THE THERMAL EROSIVE ACTION OF ELECTRICAL DISCHARGES (SPARKS) PROVIDED BY THE OF A PULSE GENERATOR.

- THE SAME PRINCIPLE OF EDM IS APPLIED TO REMOVE MTERIAL AT MICRON LEVEL FOR MICROMACHINING.

- IN MICRO-EDM, THE KEY IS TO LIMIT THE ENERGY IN THE DISCHARGE (SPARK)

Diagram of EDM process

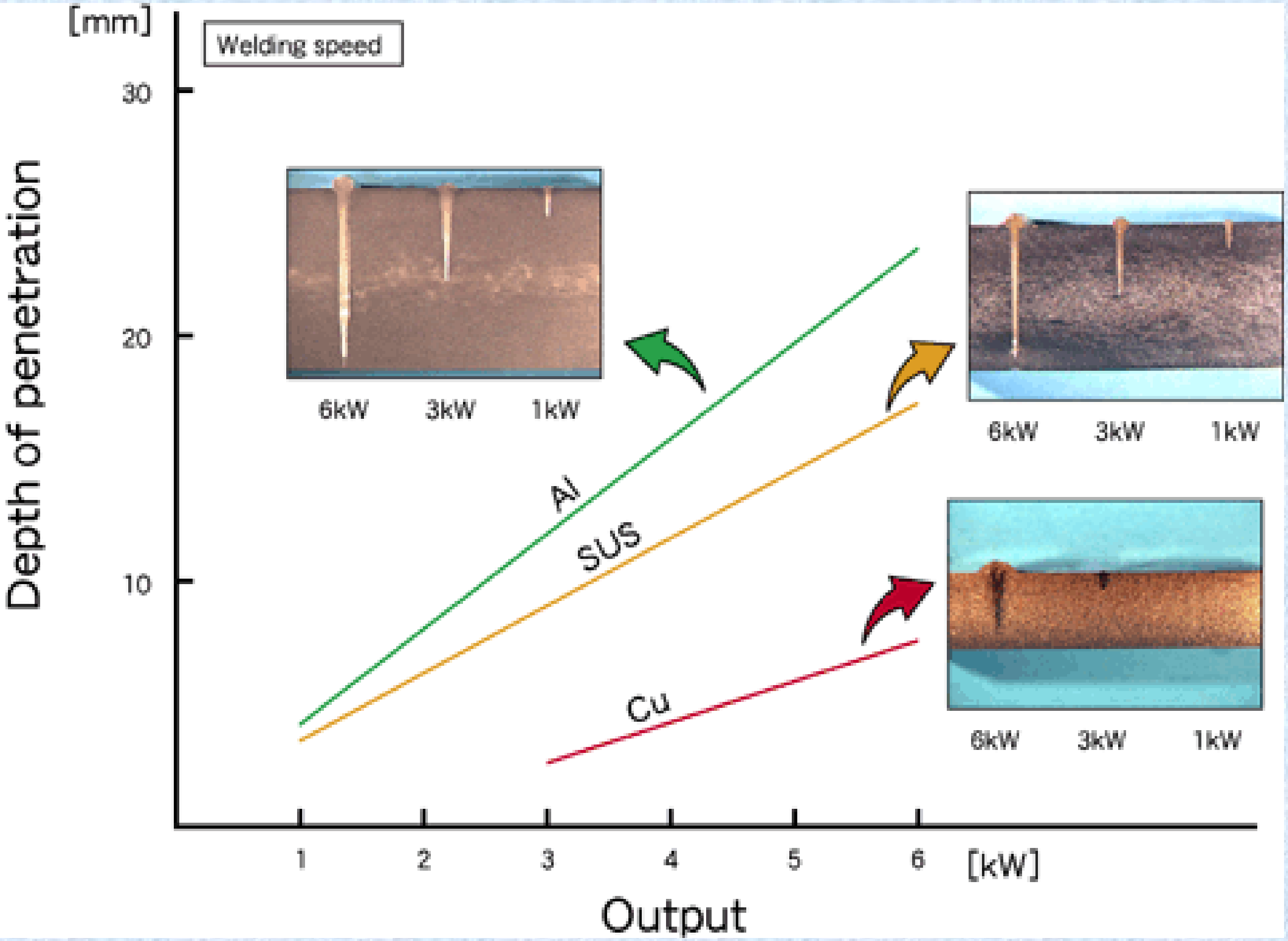




PROCESS CHARACTERSTICS

PROPERTY	VALUE
MECHANISM OF MATERIAL REMOVAL	MELTING, VAPORIZATION
MEDIUM	VACUUM
TOOL	BEAM OF ELECTRON MOVING AT VERY HIGH SPEED
MAX. MRR	10 mm^3/min (MAY BE IN SPECIAL CONDITIONS)
SPECIFIC POWER CONSUMPTION	450 W/mm^3-min
CRITICAL PARAMETERS	ACCELERATING VOLTAGE, BEAM CURRENT, BEAM DIA., WORK SPEED, MELTING TEMPERATURE
MATERIALS APPLICATION	ALL MATERIALS (CONDUCTIN & NON-CONDUCTING BOTH)
SHAPE APPLICATION	DRILLING FINE HOLES, CUTTING CONTOURS IN SHEETS, CUTTING NARROW SLOTS
LIMITATIONS	VERY HIGH SPECIFIC ENERGY CONSUMPTION, NECESSITY OF VACUUM, EXPENSIVE MACHINE

E-BEAM WELDING



SUS –>> SULPHUR STEEL

Micro / nano finishing

traditional

- Grinding
- Lapping
- Honing

Advanced

- AFM
- MAF
- MRF
- CMP
- MRAFF
- ELID
- MFP