Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Advanced Manufacturing Processes (AMPs)

Electron Beam machining (EBM)

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Chapter Description

- Aims
  - To provide and insight on advanced manufacturing processes
  - To provide details on why we need AMP and its characteristics

- Expected Outcomes
  - Learner will be able to know about AMPs
  - Learner will be able to identify role of AMPs in todays sceneries

- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials

- References

Lecture notes (Prof. N K Jain, IIT Indore)

ELECTRON BEAM MACHINING (EBM)

[1] HISTORY

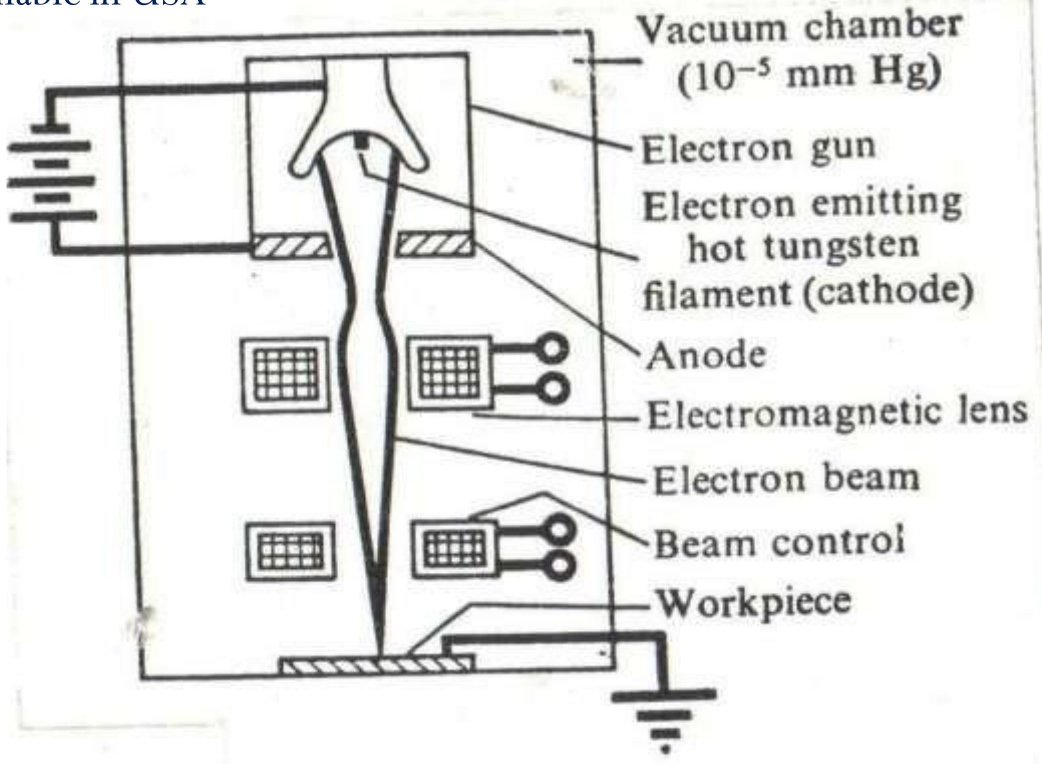
- Discovery that a **Beam of Electrons** has **Ability to Melt Materials Coincided** with the **Discovery of X-Ray Tube in Late 1800s**
- **In 1940s**, Individuals of Manufacturing Community Began to Consider the **Possibility of Using Electron Beam** for **Performing Various Fabrication Tasks**
- **In 1947**, **Dr. K. H. Steigerwald of Germany** Designed a **Prototype Machine for EBM**
- By **1952, First Electron Beam Machine** for Use as a **Welding Tool** was Built at **Carl Zeiss GmBH by Dr. K. H. Steigerwald**
- By **1959**, First **True Electron Beam Welding Machines** Became Available in USA

[2] PROCESS PRINCIPLE

- A Thermal Process which Uses a **Focused Beam of High-Velocity Electrons** to **Perform High-Speed Drilling** and **Cutting Operations**
- When **High-Velocity Electrons** Strike the Workpiece their **Kinetic Energy** is **Converted into the Heat** Necessary for **Rapid Melting** and **Vaporization** of **Any Material**

Kinetic Energy of the Electron Beam Depends on the **Mass** and **Velocity** of **Electrons**

Though **Mass of an Electron** is Only **10^{-27} g** but it **can Attain Velocity up to 30 – 75% of Speed of Light (= 3 x 108 m/s) by Using Enough Voltage**



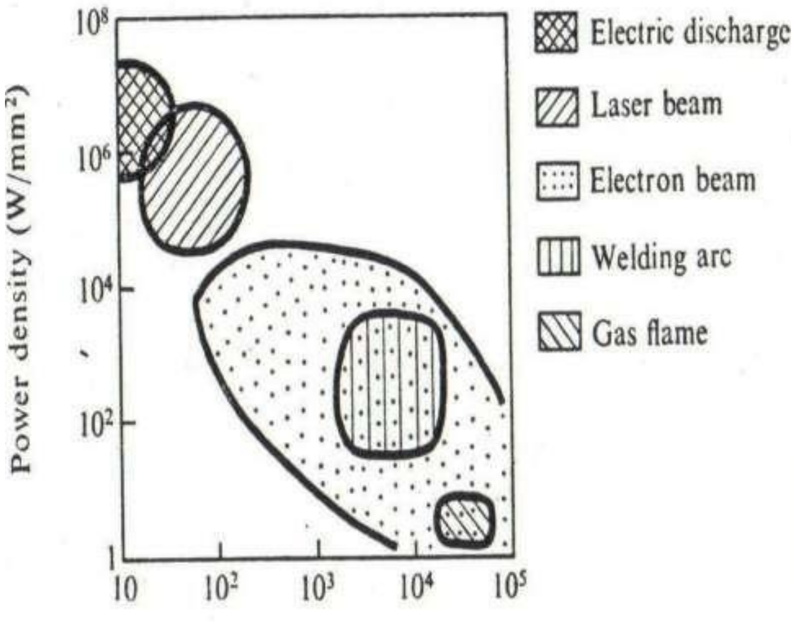
Schematic view of electron beam machine.

- The Process of **Heating by an Electron Beam** can be Used for **Annealing, Welding, or Machining**
- Electron Beams are **Focused** to a **Point** within **10 –200 µm** by **Means of Magnetic Fields** and **Power Density** can be as **High as 6.5 x 10^{12} W/mm2**
- EBM is a ***Precisely Controlled Vaporization Process***
- Most of EBM Processes are Performed in a ***High Vacuum Chamber* (up to 10^{-5} mm of Hg)** to **Ensure Optimum Beam Propagation** and **Focusing**

Why Vacuum is Needed for EBM ?

→ Since **Electrons** have **Mass** they **Interact with Air Molecules** which **Results** in **Beam Dispersion** and **Large Loss of Energy**, to Avoid the Collision of the Accelerating Electrons with the Air Molecules Vacuum is Necessary

→ Use of Vacuum also **Prevents** the **Molten Material** in the **Machining Zone** from **Spreading** into the **Surrounding Environment**



Hot spot diameter (µm)
Power density-hot spot diameter combination for various types of heat sources.

Discovery Magazine in 1982 *Reported about the* ***World's Smallest Man-Made Creation*** *Using* ***Electron Beam*** *at* ***National Research and Resource Facility for Submicron Structures*** *at* ***Cornell University*** *in which the Worlds "MOLECULAR DEVICES" were Engraved into a* ***Single Crystal of Salt.*** *The Lines Forming the Letters of the Word were Only 20 Hydrogen Atom Wide (i.e. ~ 2 nm)*

SUMMARY of EBM

Use of electron beam:

- **Welding**
- **Machining (cutting, drilling); first prototype: 1947, Steigerwald.**
- **'Etching'**
- **Heat treatment, etc**

Materials that can be cut:

diamond, carbide, ceramic oxide (and other very hard materials), metals, plastics.

Basis for using electron:

- ✓ Electrons can be formed into small beam using electric field
- ✓ Electrons can be accelerated
- ✓ Electrons can be focused and bent using electrostatic and electromagnetic fields

Parameter	Details
Accelerating Voltage	**50 – 200 kV**
Beam Current	**100 – 1000 μ A**
Power	**0.5 to 50 kW**
Pulse Duration	**4 – 65 ms**
Pulse Frequency	**0.1 Hz – 16,000 Hz**
Vacuum	**10^{-2} to 10^{-5} mm Hg**
Beam Spot Size (minimum)	**12 to 25 μm**
Beam Power Density	**1.55 x 10^5 to 1.55 x 10^9 W/cm^2**
Beam Deflection Angle	**6.5 mm square**
Tool	**Beam of High Velocity Electrons**
Work Materials	**All Materials**
Maximum MRR	**10 mm^3/min**
Specific Power Consumption	**450 W/mm^3/min**
Critical Parameters	☐ **Accelerating Voltage,** ☐ **Beam Current,** ☐ **Pulse Duration,** ☐ **Spot Diameter (or Beam Diameter),** ☐ **Beam Deflection Signal** ☐ **Work Speed i.e. Speed of the Rotation and Translation axes** ☐ **Melting Temperature**

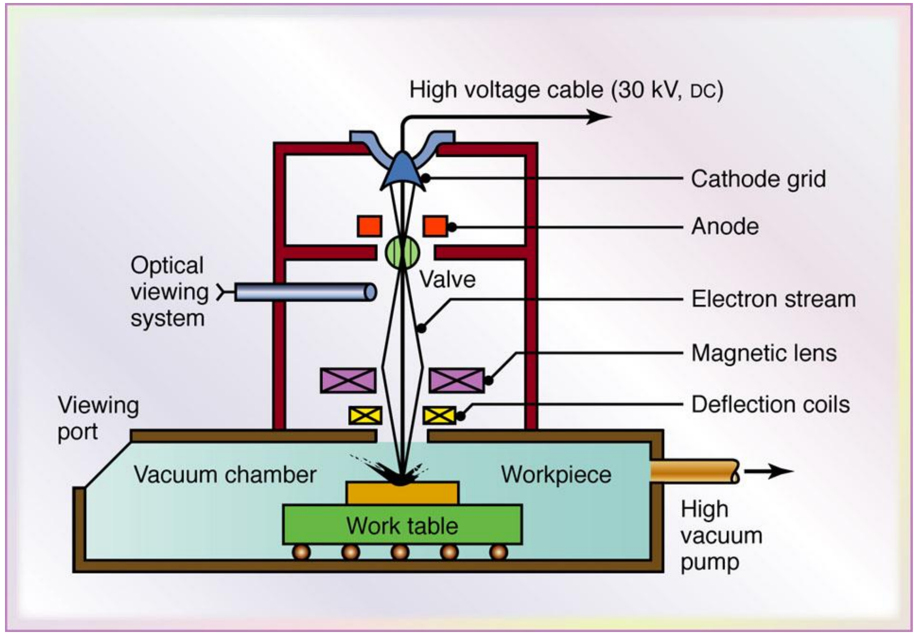
EBM EQUIPMENT

Equipment is contained in vacuum (10^{-4} mm Hg or more) in order to ensure cutting energy.

Electron source is an 'electron gun' (several times the intensity of a TV gun).

An electron gun is basically a **triode** consisting of:

- **Cathode**, to emit high negative potential electrons
- **Grid cup** (negatively biased with respect to cathode)
- **Anode** (at ground potential).



- Cathode is made from tungsten filament,
- Heated to 2500 – 3000 °C to emit electrons
- Emission current 25 – 100 mA depending on cathode material;
- Current density 5 – 14 A/cm^2 temperature of accelerating voltage.
- Electrons are **accelerated** using **high potential** between cathode and anode.

- The accelerated electrons are **focused** by the **grid cup**.
- The electrons will flow through the anode.

After exiting the anode, the electrons are **refocused** using **magnetic** and **electrostatic lenses** (controlled beam direction).

- Electrons maintain speed (in excess of half the speed of light) because they move in **vacuum** (no collision environment) until they hit the workpiece in a small circle of ≈ ϕ 0.025 mm.
- **Cutting path** can be controlled by **diverting the electron** beam or by moving the **worktable**.

EBM EQUIPMENT

1. **Power Supply:** ☐ To **Generate** a **Very High Voltage** up to **150 kV** to **Accelerate** the **Electrons**

2. **Electron Beam Gun:** ☐ To **Generate, Shape** and **Deflect** the **Electron Beam** to **Machine** the **Workpiece**

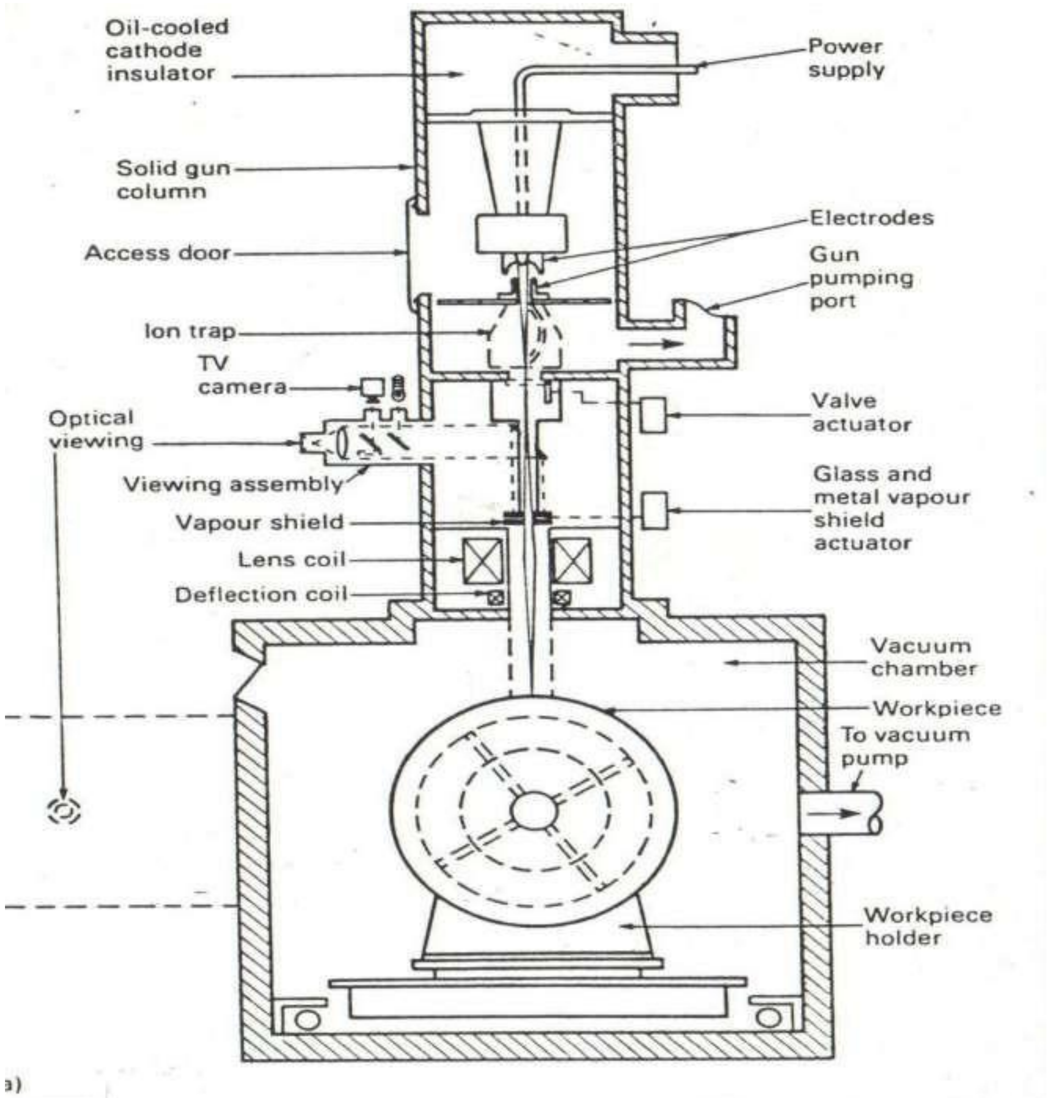
3. **Vacuum System:** To **Facilitate** the **Generation** and **Travel** of the **Electron Beam** AND **Cause Machining** to **Take Place in a Vacuum Chamber**

4. **Workpiece Positioning system**

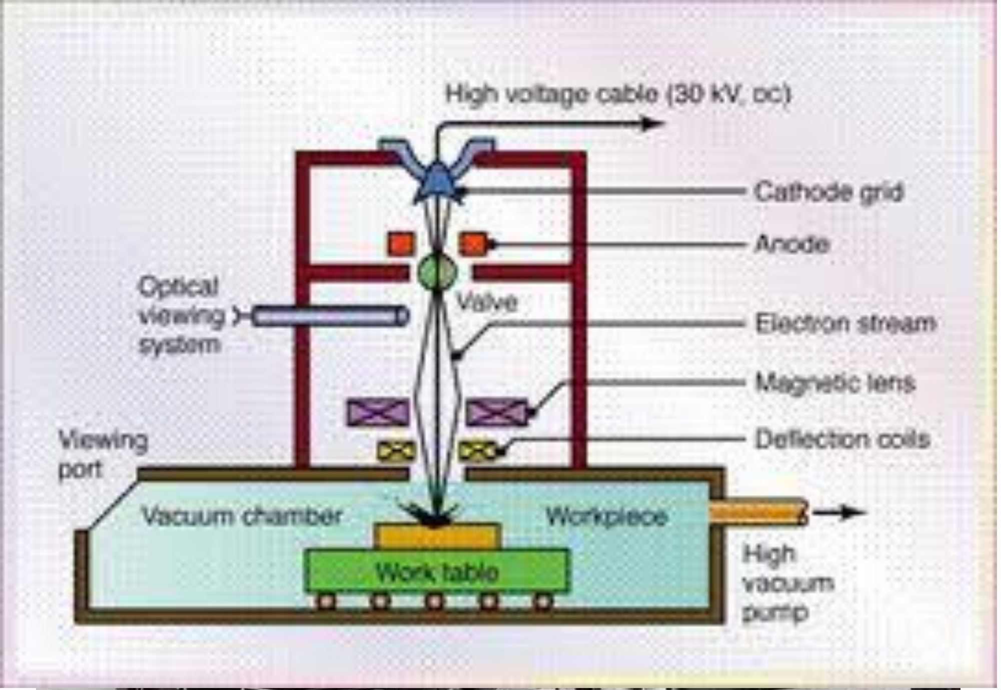
☐For **Controlled Manipulation of the Workpiece Position**

☐May be **Simple** as a **Single, Motor Driven-Driven Rotary Axis** or

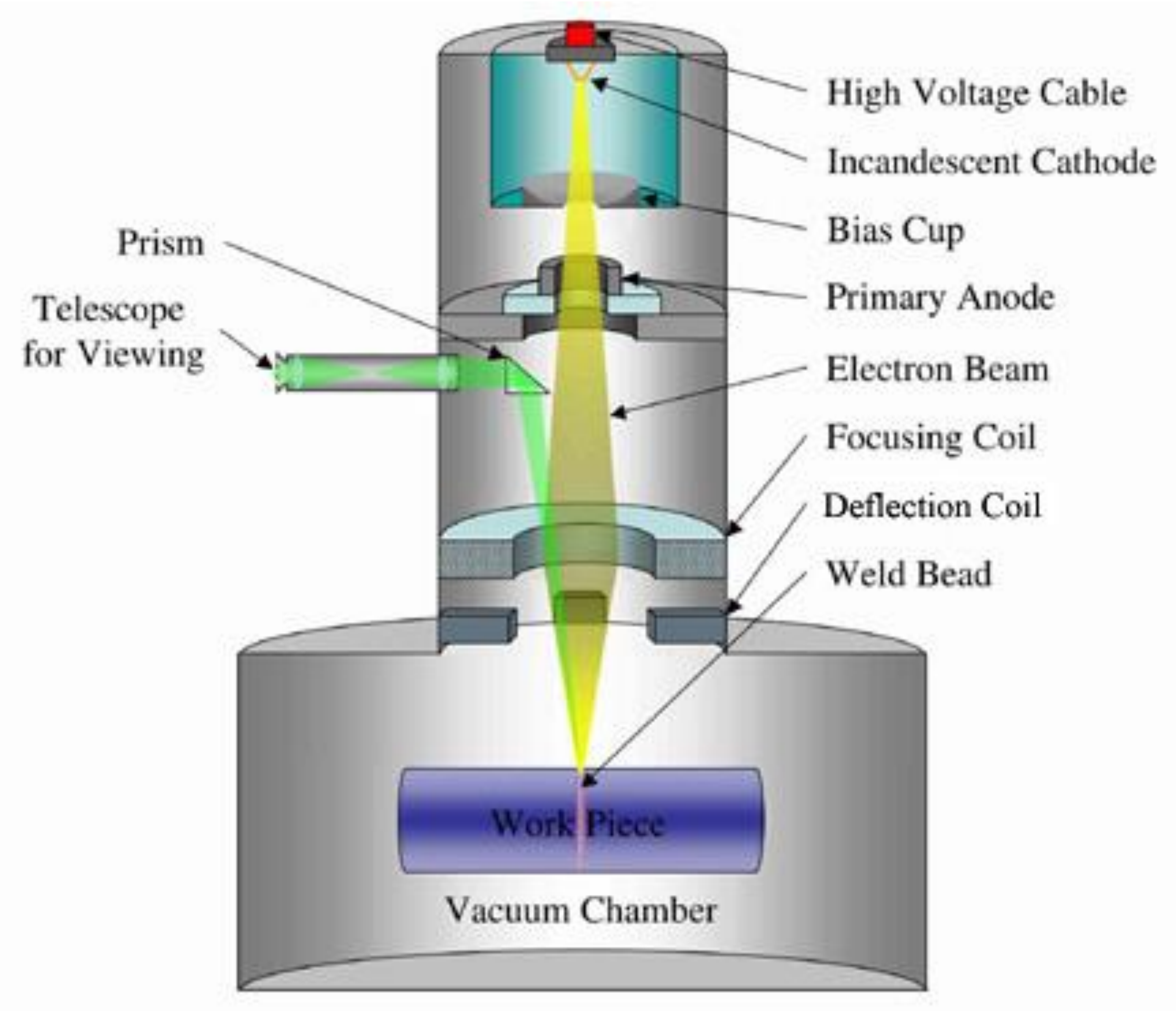
☐ As **Complex** as a **Fully CNC, Closed Loop, Five-Axis System**



Industrial electron beam machine. (Courtesy of Wentgate Dynaweld Ltd.)


High voltage cable (30 kV, DC)
Cathode grid
Anode
Optical viewing system
Valve
Electron stream
Magnetic lens
Viewing port
Deflection coils
Vacuum chamber
Workpiece
Work table
High vacuum pump


MESSER GRIESHEIM


High Voltage Cable
Incandescent Cathode
Bias Cup
Prism
Primary Anode
Telescope for Viewing
Electron Beam
Focusing Coil
Deflection Coil
Weld Bead
Work Piece
Vacuum Chamber

APPLICATIONS of EBM

MATERIAL APPLICATIONS

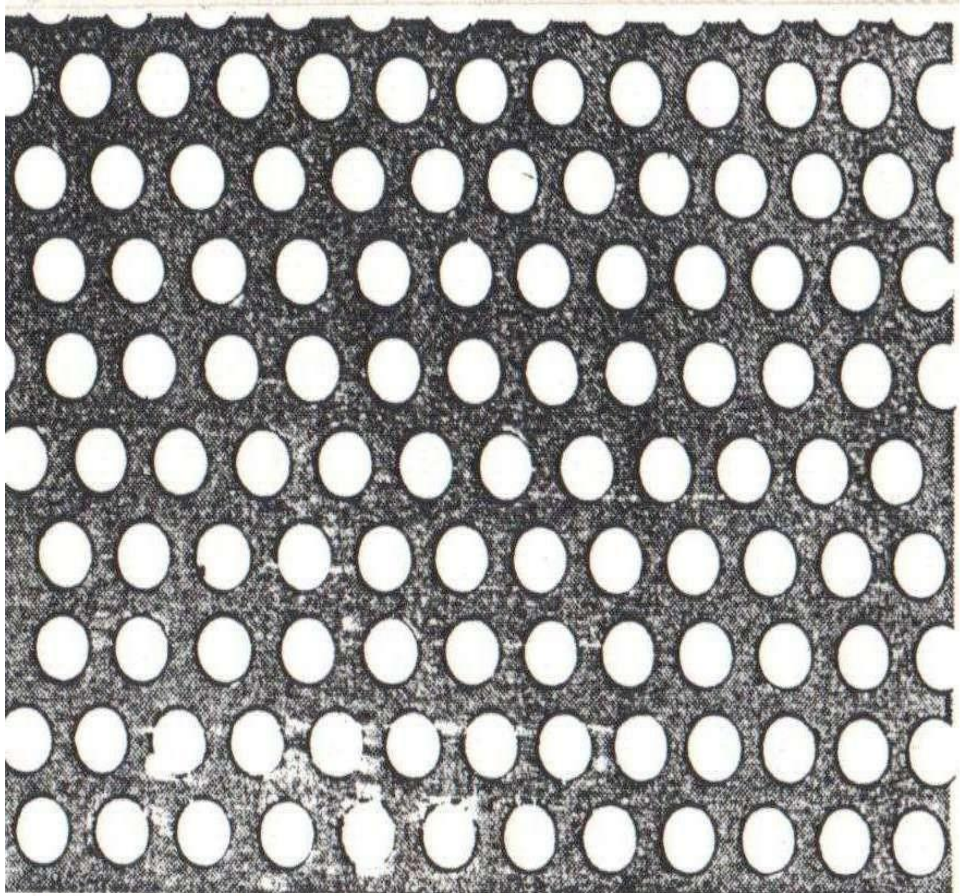
- All Materials those can Exist in Vacuum
- **Metals:** Al, Be, Cu, Ni, Mo, Ti, Ta, W, Zr, Mo, Ferrite
- Carbon, Silicon
- **Alloys: Cu-Alloys, Ni-Alloys, Stainless Steel, Alloy Steel**
- **Ceramics: Glass, Refractories, Abrasives, Ruby, Sapphire, Quartz**
- **Composites:** Cemented or Sintered Carbides,
- **Plastics, Leather**

[SHAPE APPLICATIONS

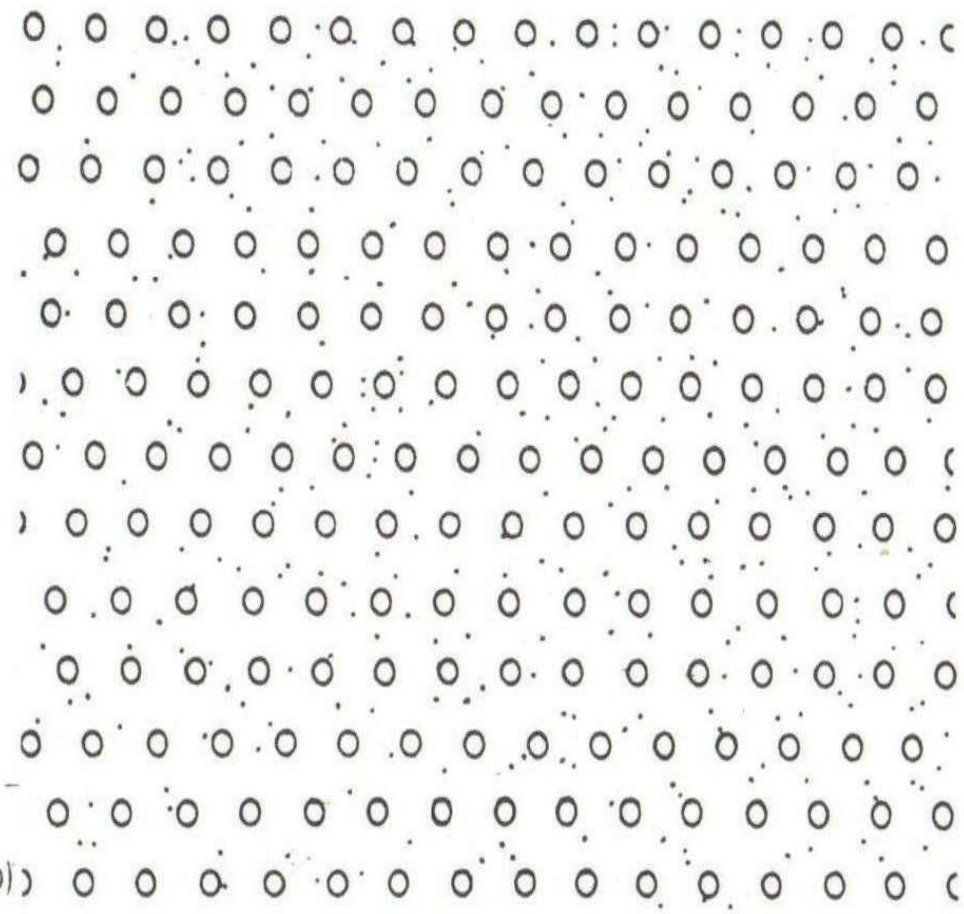
- **Drilling of Various Types of Holes**: **Inclined Holes (Shallow up to 20^0), Micro-Holes (Dia. < 1 mm)**
- **Drilling of Non-circular Holes, Tapered Holes**
- **High Speed Perforation of Small Diameter Holes**
- **2D-Contouring Profiling or Blanking**
- **Engraving of Metals, Ceramics** and **Vaporized Layers**
- **Machining of Thin Films to Produce Resistor Network in IC Chips**
- **Pattern Generation**
- **Through Cutting**
- **Thin Film Machining**
- **Surface Treatment** Including **Surface Alloying**

Drilling Performance of EBM						
Material	Workpiece Thickness (mm)	Hole Dia. (mm)	Aspect Ratio	Drilling Time (Sec)	Accelerating Voltage (kV)	Beam Current (μA)
Tungsten	0.25	0.025	10	< 1	140	50
Stainless Steel	2.50	0.125	20	10	140	100
Stainless Steel	1.00	0.125	8	< 1	140	100
Aluminium	2.50	0.125	20	10	140	100
Alumina	0.75	0.300	2.5	30	125	60
Quartz	3.00	0.025	120	< 1	140	10

Cutting Performance of EBM					
Material	Workpiece Thickness (mm)	Slot Width (mm)	Cutting Speed (mm/min)	Accelerating Voltage (kV)	Beam Current (μA)
Stainless Steel	0.175	0.1	50	130	50
Tungsten	0.05	0.025	125	150	30
Brass	0.25	0.1	50	130	50
Alumina	0.75	0.1	600	150	200

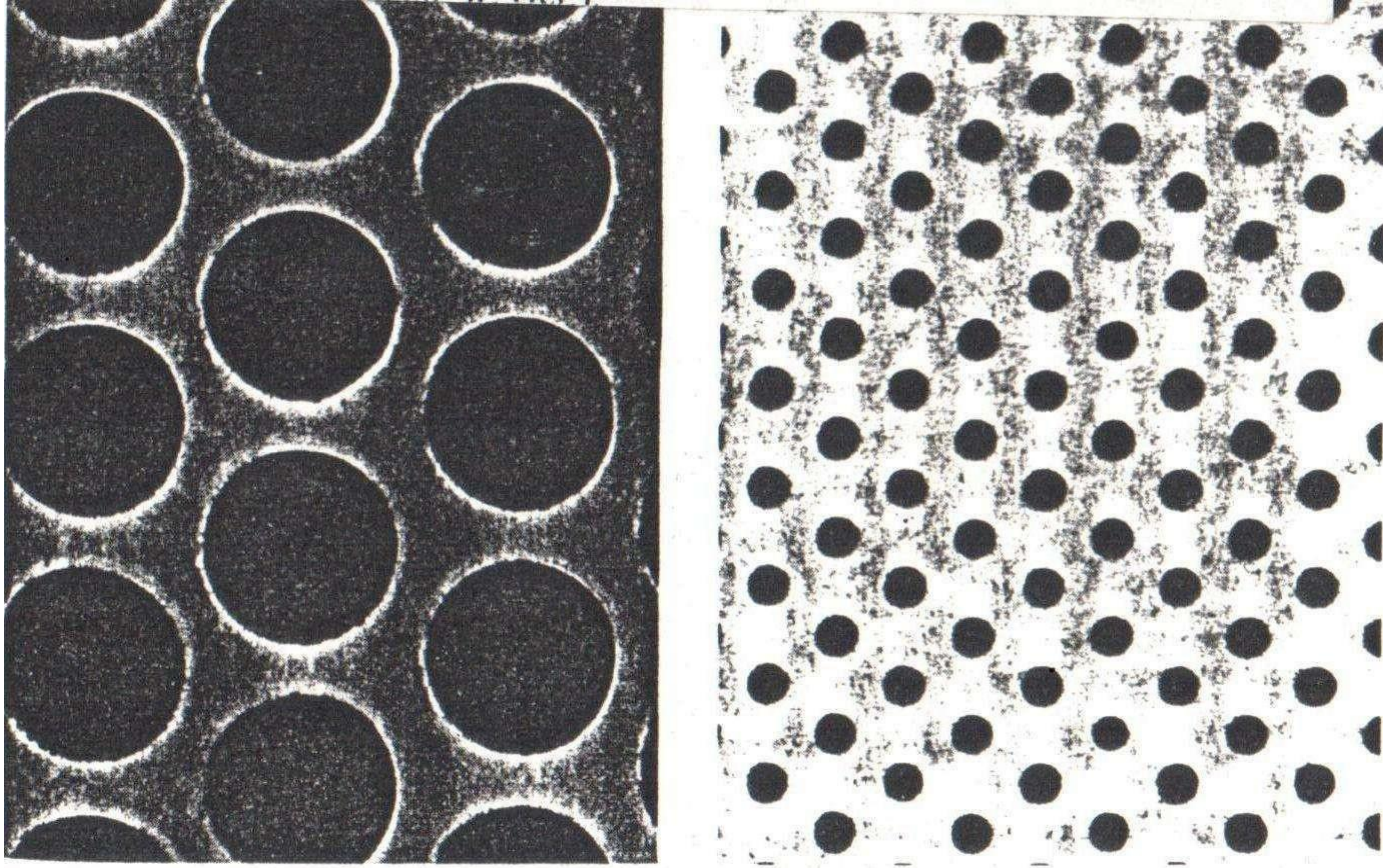


Pattern of holes drilled by EBM. (After Steigerwald and Meyer, 1967.)
(a) Workpiece material: stainless steel; thickness: 0.2 mm; diameter of holes: 0.09 mm; density of holes: 4000 per cm^2; distance between holes: 0.16 mm; distance between rows: 0.16 mm; time required to drill one hole: 10 μs.



(b)

(b) Workpiece material: synthetic fabric; thickness: 0.012 mm; diameter of holes: 0.006 mm; density of holes: 20 000 per cm^2; distance between holes: 0.07 mm; distance between rows: 0.07 mm; time required to drill one hole: 2 μs.



BM) Examples of EBM-drilled holes in 1-mm thick sheet metal (10 X magnification). (*Source*: courtesy, Messer Griesheim GmbH, Puchheim, W. Ger.).

SUMMARY of PROCESS CAPABILITIES and OPERATIONAL CHARACTERISTICS of EBM PROCESS

Type	Capability/Characteristics		Common Value/Range (Attainable)
Finishing Capabilities	Surface Roughness [CLA in µm]		0.8 – 6.3 (0.2)
	Dimensional Tolerance or Accuracy [± µm]		25 – 125 or 5 – 10 % of Diameter (5.0)
	Minimum Corner Radii (mm)		Data Unavailable
	Minimum Overcut (mm)		Data Unavailable
	Minimum Surface Damage (µm)	Chemical Damage	No
		Mechanical Damage	10.0
		Thermal Damage	25 – 250
Drilling Capabilities	Hole Diameter (mm)		0.025 – 1.27 (0.02)
	Aspect Ratio		6 – 15 (100)
	Hole Depth (mm)		0.15 – 2.5 (10)
	Minimum Taper (µm /mm)		10 – 70 (1 - 4^0)
	Maximum No. of Holes that can be Drilled Simultaneously		No
	Minimum Angle of Inclination Hole Axis with Surface		20^0
Cutting Capabilities	Minimum Width of Cut (mm)		0.025 (0.02) mm
	Thickness of Cut (mm)		0.15 – 2.5 (10.0)
	Range of Cutting Rate (mm/min)		150.0
Economic Aspects	Initial Investment or Capital Cost		High
	Tooling and Fixtures Cost		Low
	Power Consumption Cost		Medium
	Tool Consumption Cost		No Tool Wear
Environmental Aspects	Safety		Normal Problem
	Toxicity		Normal Problem
	Contamination of Machining Medium		Normal Problem

[12] ADVANTAGES of EBM

- No Mechanical Distortion Because No Cutting Force during the Machining
- Limited Thermal Effects because only one Pulse is Used to Make and Pulse duration is Short
- Very High Drilling Rates [Up To 4000 Holes/S]
- Can Drill in Many Different Configurations
- Can Drill Any Material

  i.e. No Limitations Imposed by the Hardness, Thermal Capacity, Ductility, Electrical Properties and Surface Properties (Reflectivity) of the Workpiece Material
- Can Drill Inclined Holes
- No Tool Wear
- High Accuracy and Repeatability
- Relatively Low Operating Costs as Compared to other Processes Used to Produce Very Small Holes

LIMITATIONS of EBM

- High Capital Investment due to Costly Equipment
- Non-productive Pump-Down Time
- Presence of a Thin Recast Layer
- High Level of Operator Skills Required
- Limited to 10 mm Thick Materials Only
- Necessity for auxiliary backing material

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