ELECTRON BEAM & LASER BEAM MACHING-(EBM/LBM)

Dr. G. Takyi

Instructional Objective

- Describe the basic mechanism of material removal in EBM & LBM
- Identify major components of EBM & LBM equipments
- State the working principle of EBM & LBM equipments
- Draw schematically EBM & LBM equipments
- Identify the process parameters of EBM & LBM
- Identify the machining characteristics of EBM & LBM
- List three applications of EBM & LBM
- List three limitations of EBM & LBM

Classification of NTM Processes

- **Mechanical Processes**
  - Abrasive Jet Machining (AJM)
  - Ultrasonic Machining (USM)
  - Water Jet Machining (WJM)
  - Abrasive Water Jet Machining (AWJM)
- **Electrochemical Processes**
  - Electrochemical Machining (ECM)
  - Electro Chemical Grinding (ECG)
  - Electro Jet Drilling (EJD)

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  - Electrochemical Machining (ECM)
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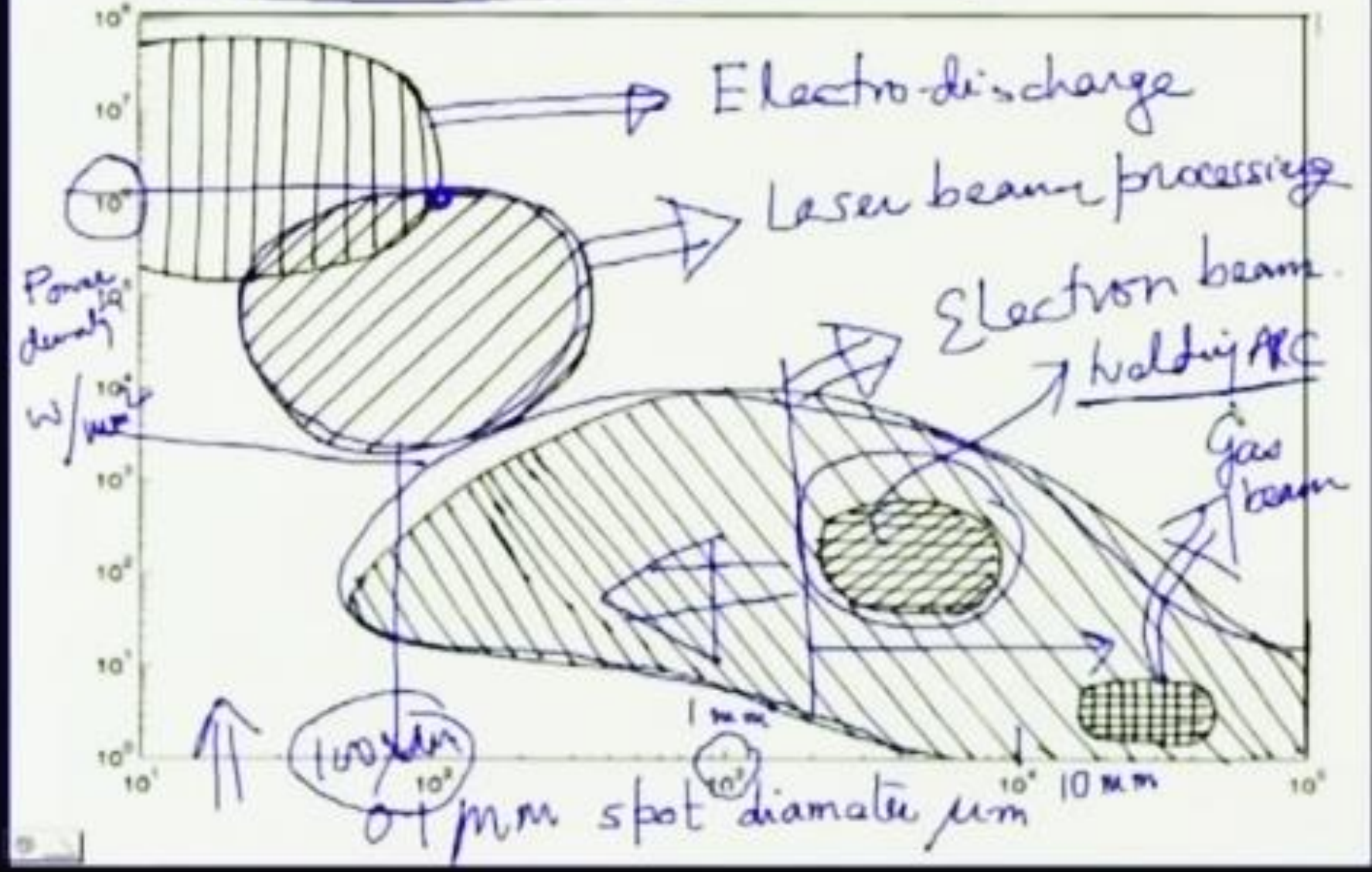
Classification of NTM Processes

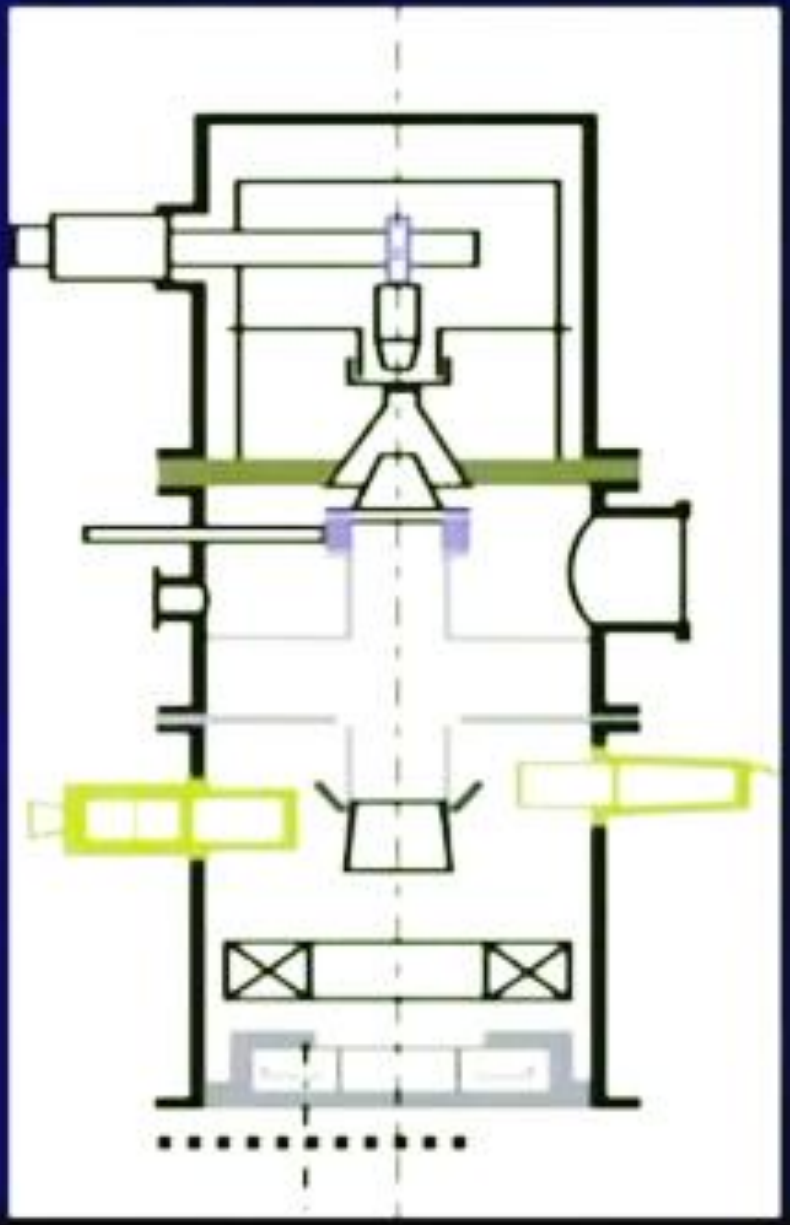
- **Electro-Thermal Processes**
  - Electro-discharge machining (EDM)
  - **Electron Beam Machining (EBM)**
  - **Laser Jet Machining (LJM)**
  - **Electro-Optical-Thermal Process**
- **Chemical Processes**
  - Chemical Milling (CHM)
  - Photochemical Milling (PCM) etc

High Energy Density Processes

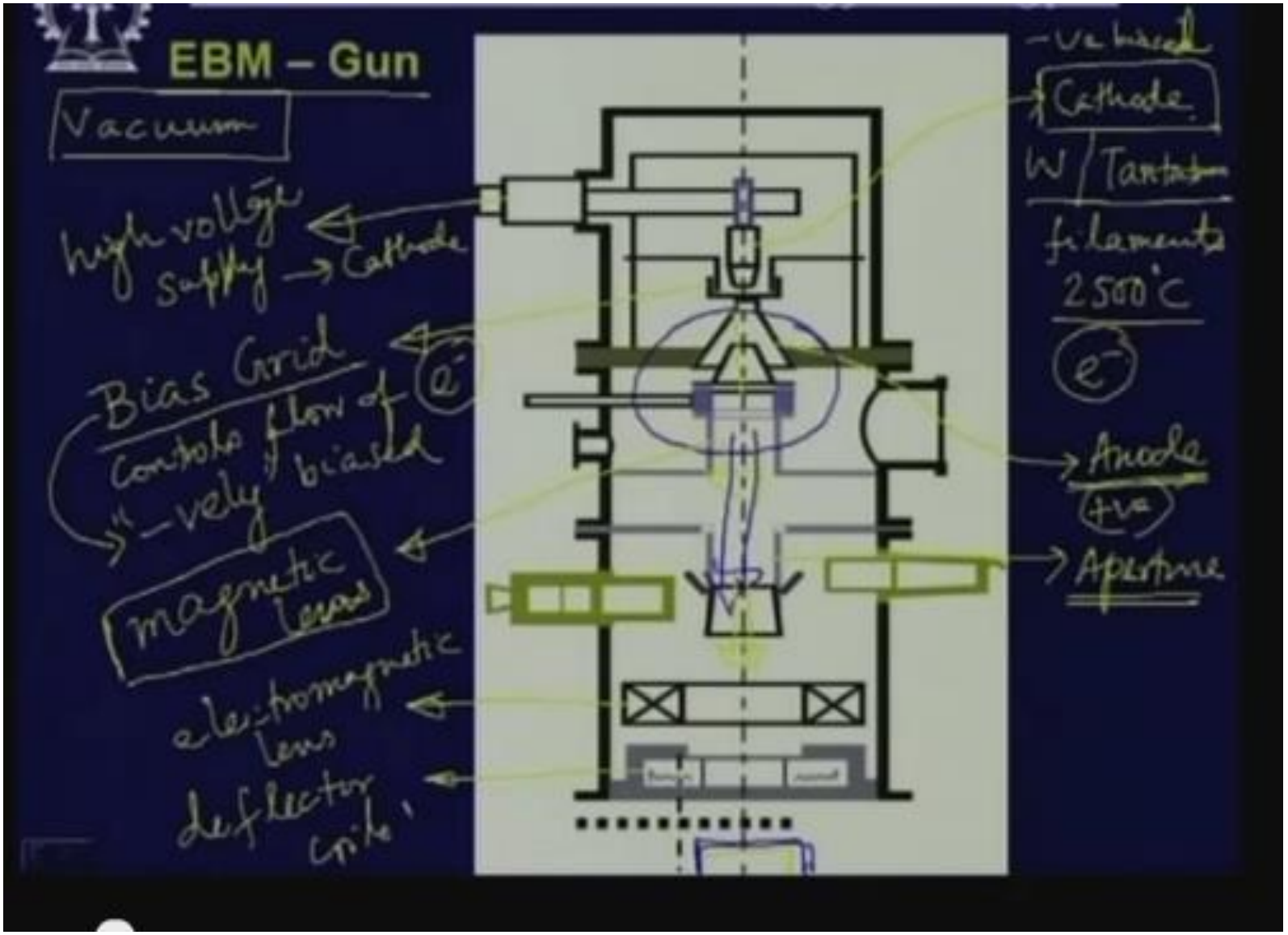


EBM – Gun

Vacuum



EQUIPMENT INTENSIVE PROCESSES



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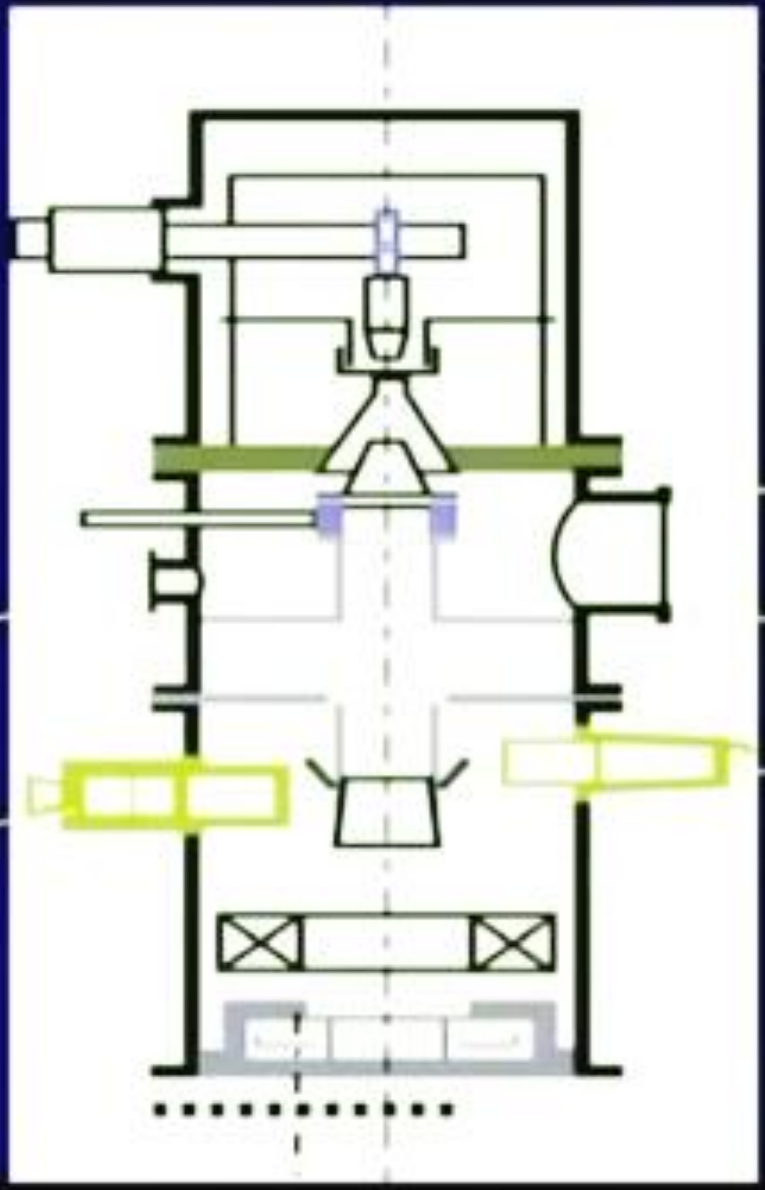
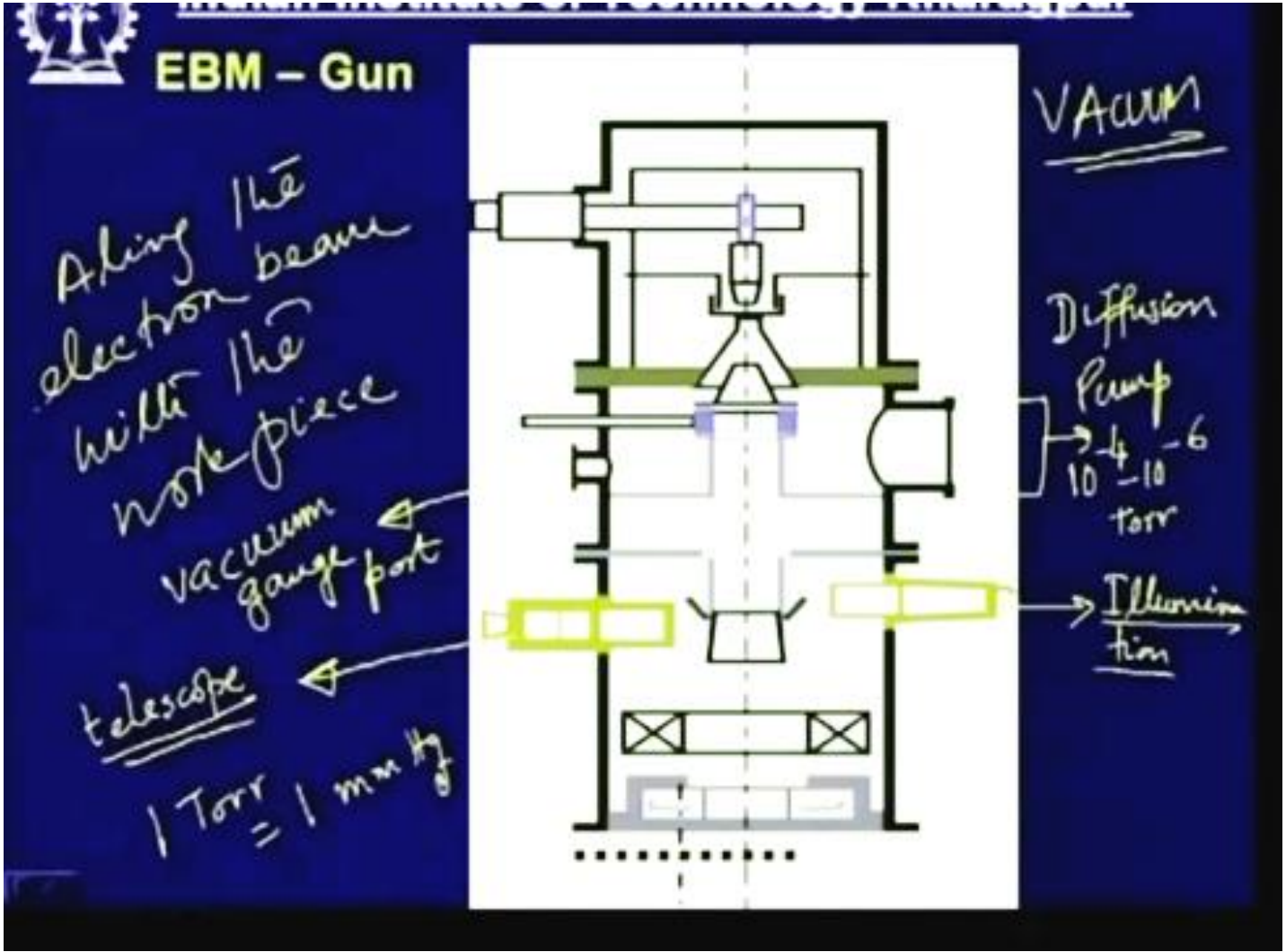
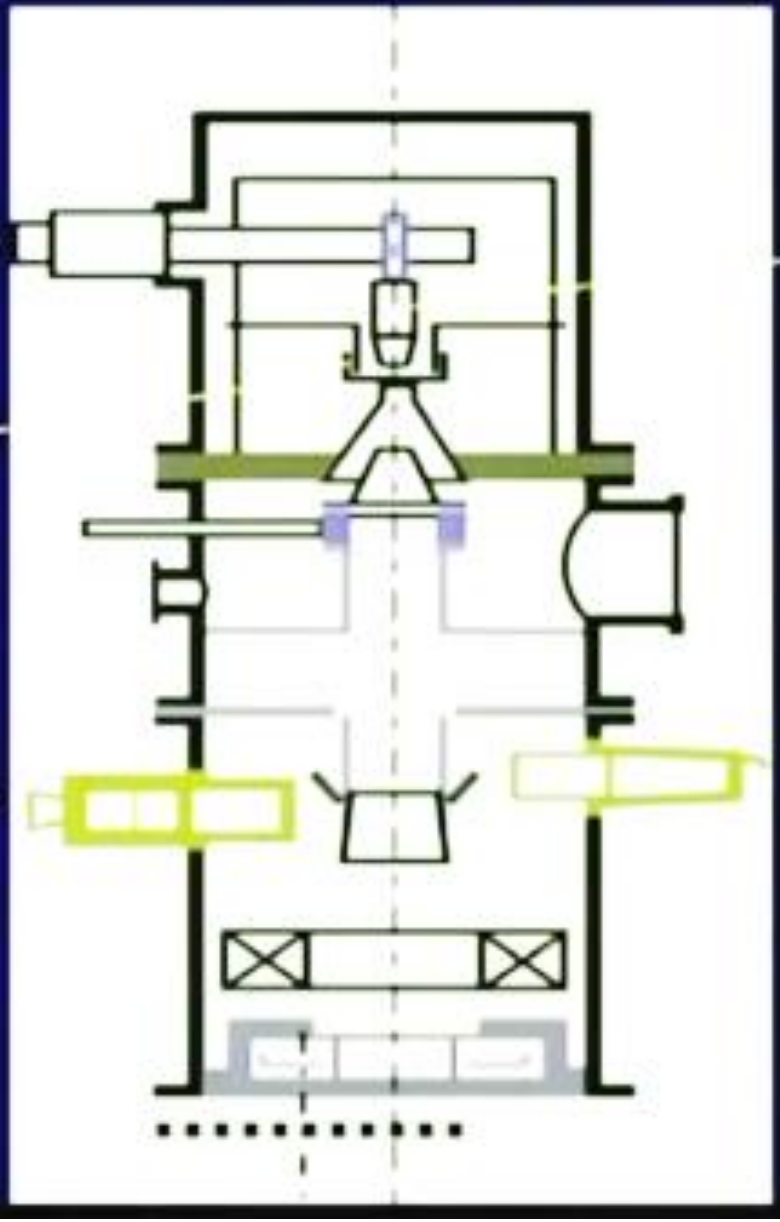

Aiming the electron beam with the work piece
vacuum gauge port
telescope
VACUUM
Diffusion Pump
Illumination

EBM takes place in a vacuum to avoid collision so that thermo-ionic can take place



EBM – Gun


Bias Grid
"-vely" biased
continuous
Contrl the flow electron
Cathode

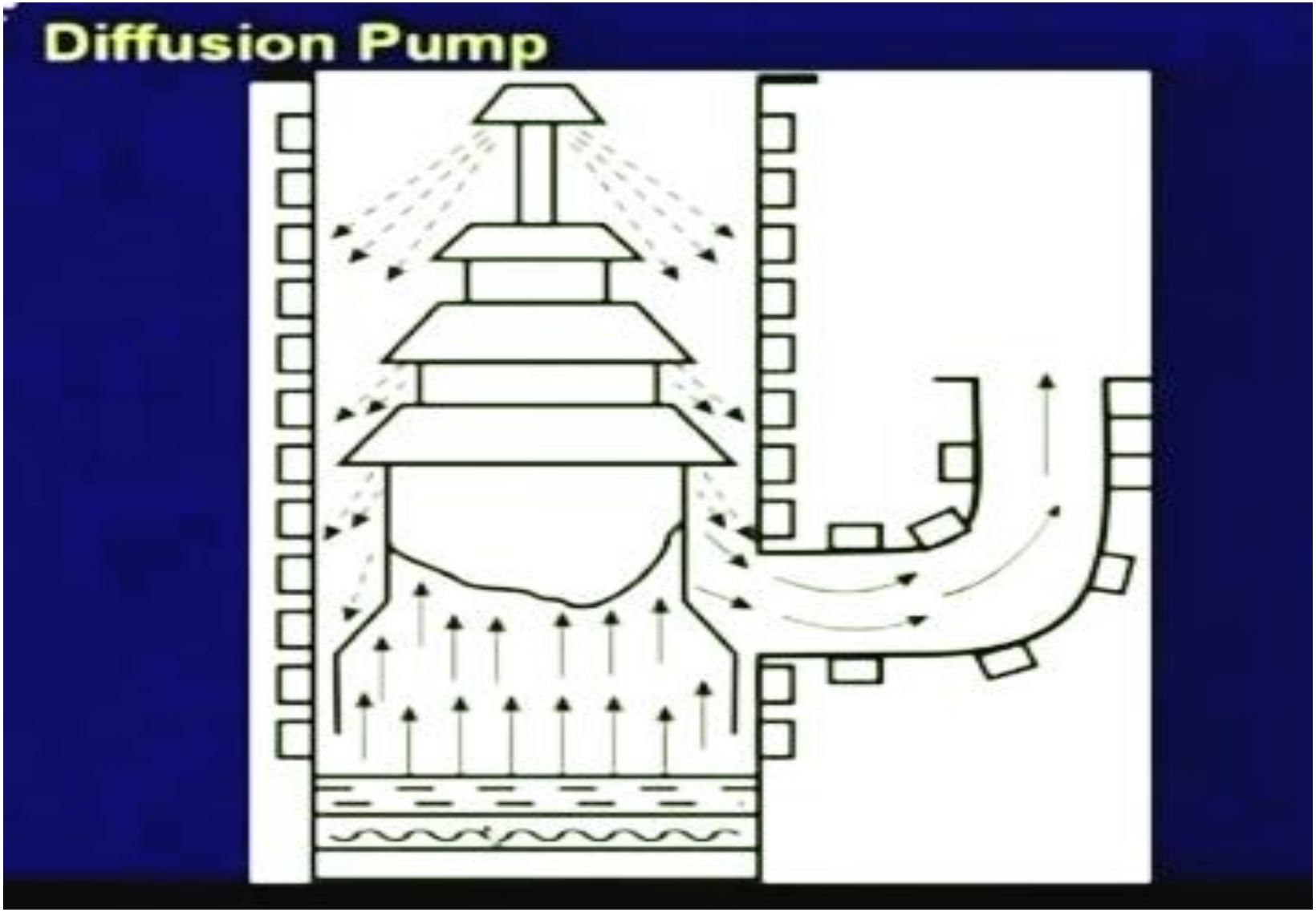
EBM – Modules of Electron Beam Gun

- Cathode cartridge – tungsten or tantalum
- High voltage supply
- Bias Grid – (pulsed) to get pulse mode operation
- Anode
- Magnetic Lens
- Aperture
- Electromagnetic Coils
- Deflector Coils
- Lighting System & Telescope for Alignment
- Rotating Slotted Discs
- Vacuum pumps – Diffusion Pump

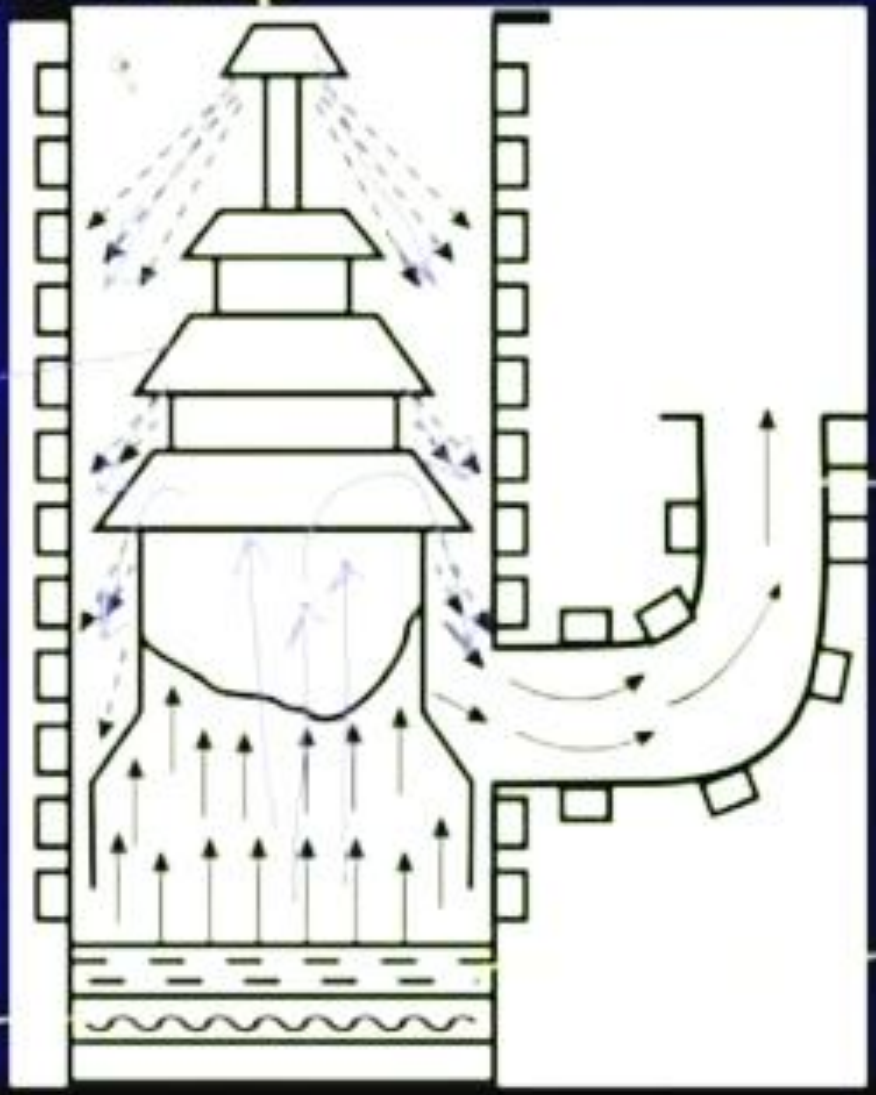
EBM – Modules of Electron Beam Gun

- Cathode cartridge – tungsten or tantalum filament
- High voltage supply → Cathode –ve
- Bias Grid – (pulsed) to get pulse mode operation
- Anode
- Magnetic Lens
- Aperture — stray electron → focussed/ concentrated beam
- Electromagnetic Coils → focussing lens.
- Deflector Coils
- Lighting System & Telescope for Alignment
- Rotating Slotted Discs
- Vacuum pumps – Diffusion Pump

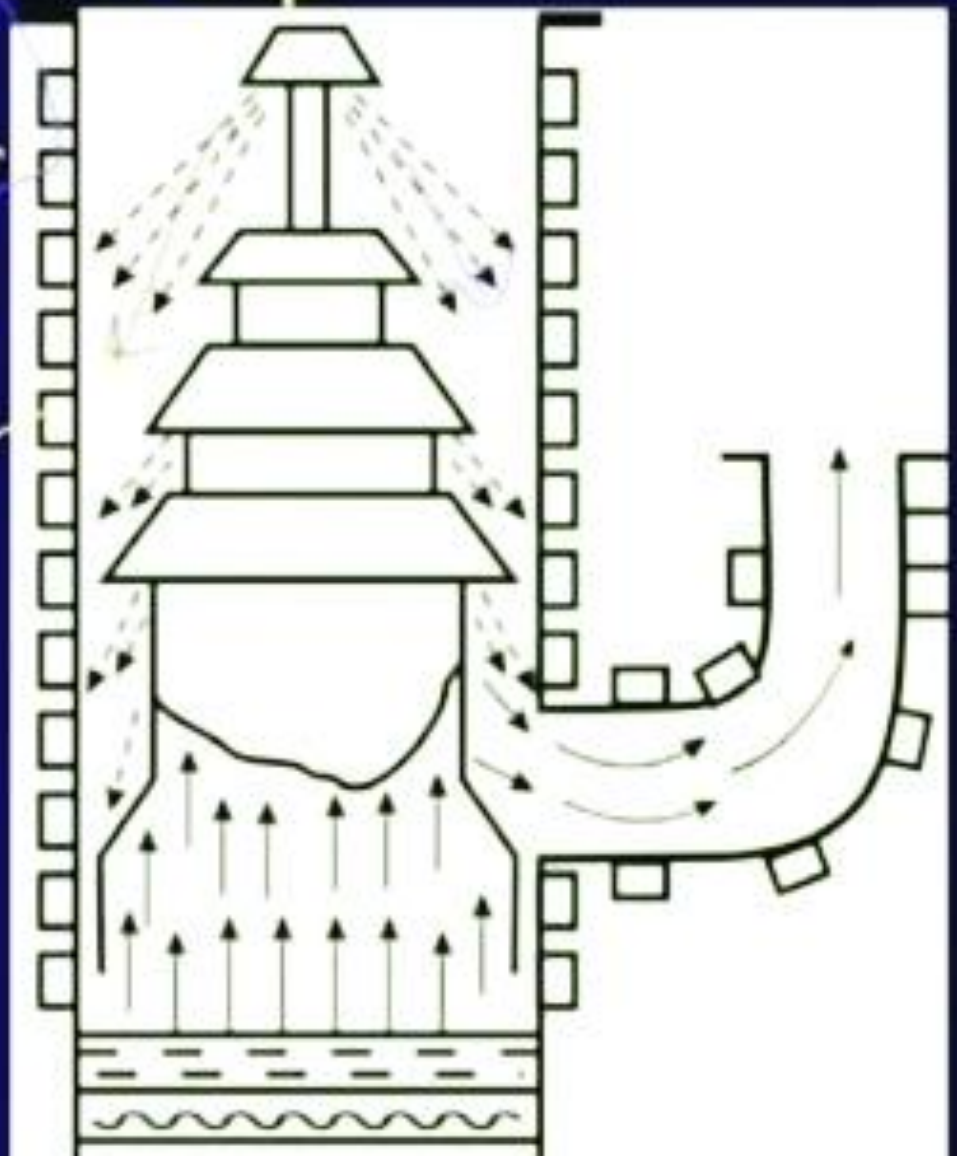
DIFFUSION PUMP



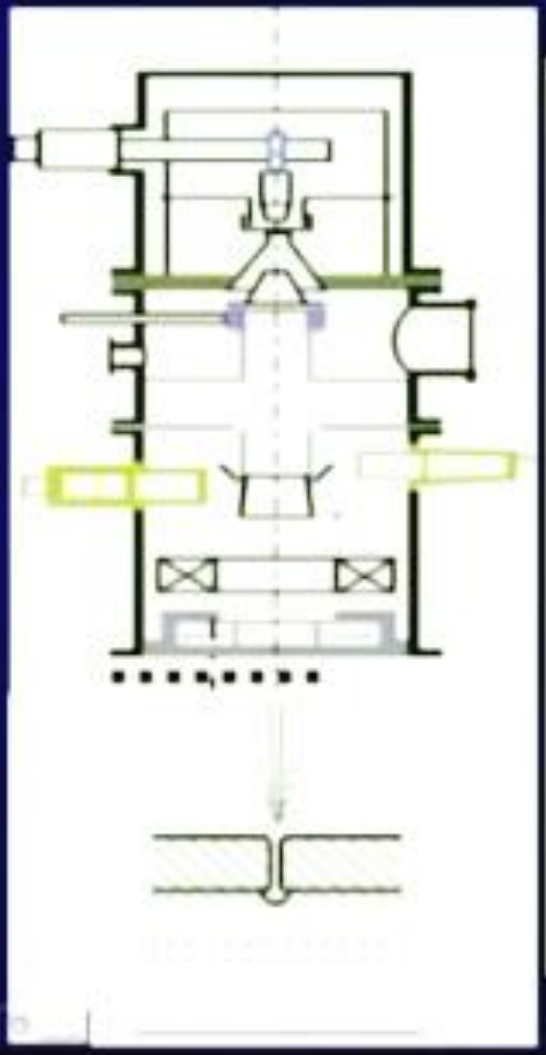
Diffusion Pump



Diffusion Pump

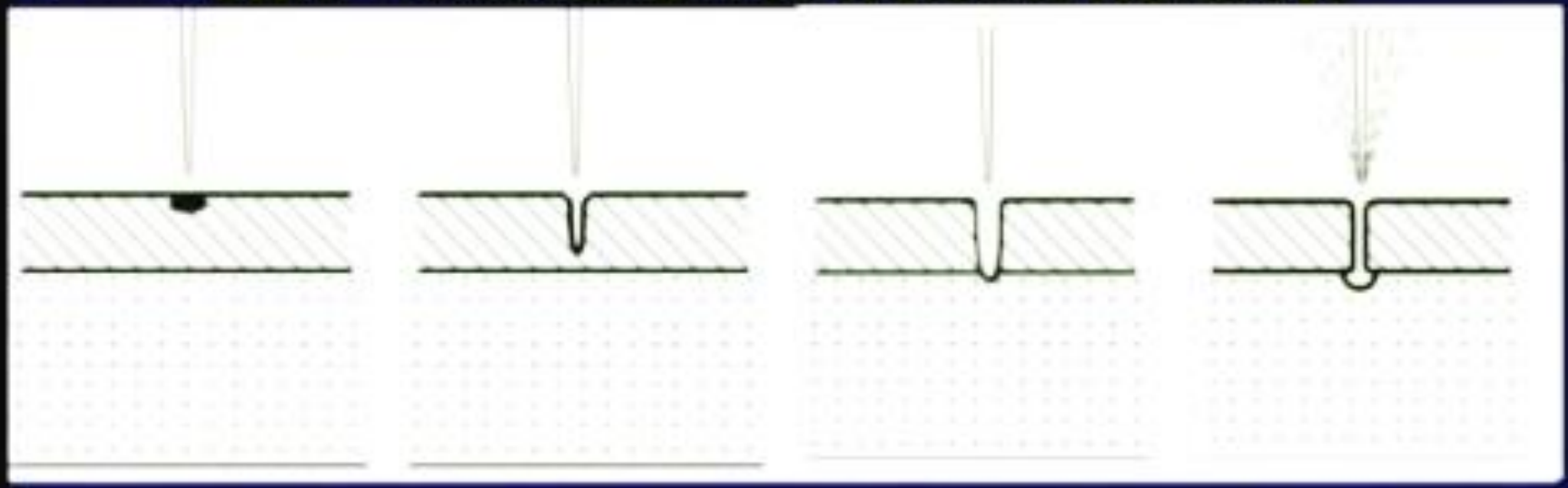


EBM – Mechanism of Material Removal



- Thermo-ionic electrons
- Acceleration of electrons due to anode potential
- High velocity beam of electron
- Shaping and focussing of the electron beam
- Impingement of high velocity electron beam on the work
- Spot size 10 – 100 micron – high energy density
- Heating, melting & vaporisation

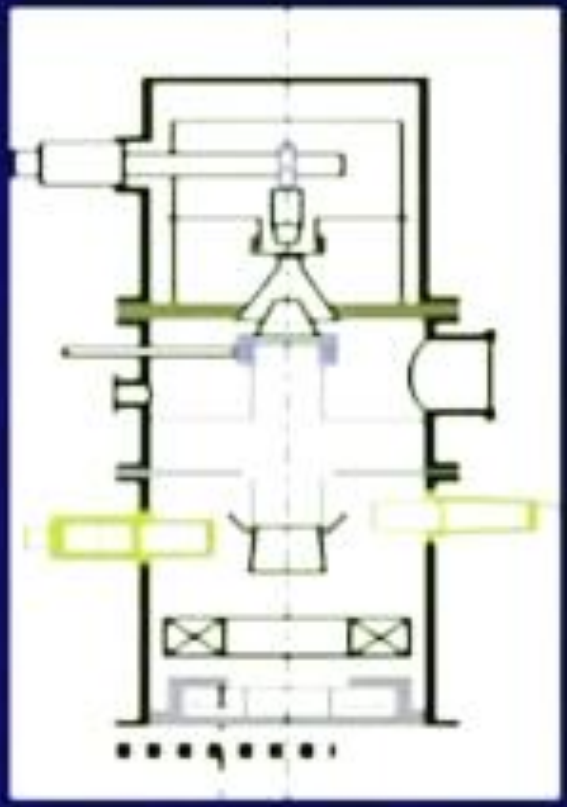
EBM – Mechanism of Material Removal



- Localised heating by focussed electron beam
- Gradual formation of hole by penetration of melt-vaporisation front
- Penetration till auxiliary support
- Expulsion of any molten material at the top by high vapour pressure of auxiliary material

EBM – Process Parameters

- Accelerating voltage
- Beam current – 250 μA – 1A
- Pulse duration – 50 μs – 50 ms
- Energy per pulse – 100 J/pulse
- Power per pulse
- Lens current
- Spot size – 10 μm – 500 μm
- Power density



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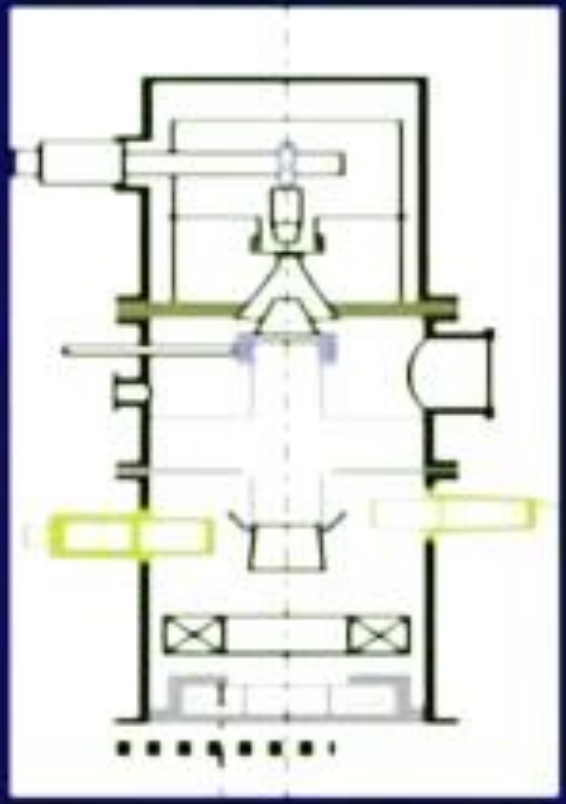
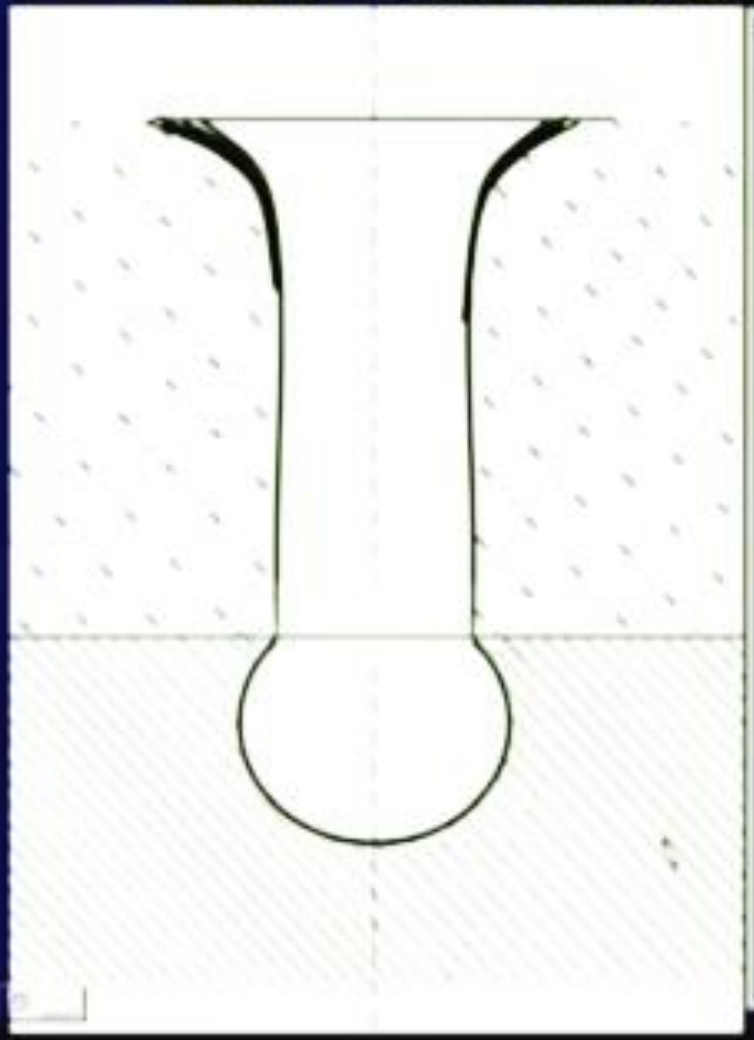


$$P_d = \frac{\frac{1}{2} m_e v_e^2}{\pi/4\, d_s^2} = \frac{V_a I_b t_{on}}{\pi/4\, d_s^2}$$

EBM – Hole characteristics



- Plane of focussing
- Reverse Tapering
- Auxiliary Support
- Recast layer
- No Burr Formation
- Minimum HAZ
- 100 μm – 2mm diameter
- L/d ratio – 10 ~ 15
- Almost any material
- Shallow angle drilling - 20^0

EBM – Hole characteristics

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- Reverse Tapering
- Auxiliary Support
- Recast layer
- No Burr Formation
- Minimum HAZ
- 100 μm – 2mm diameter
- L/d ratio – 10 ~ 15
- Almost any material
- Shallow angle drilling - 20^0

EBM – Advantages

- very high drilling rates when small holes with large aspect ratio are to be drilled.
- machine almost any material irrespective of their mechanical properties.
- applies no mechanical cutting force, work holding and fixturing cost is very less.
- fragile and brittle materials can also be processed.
- heat affected zone in EBM is rather less due to shorter pulses.
- holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

EBM – Limitations

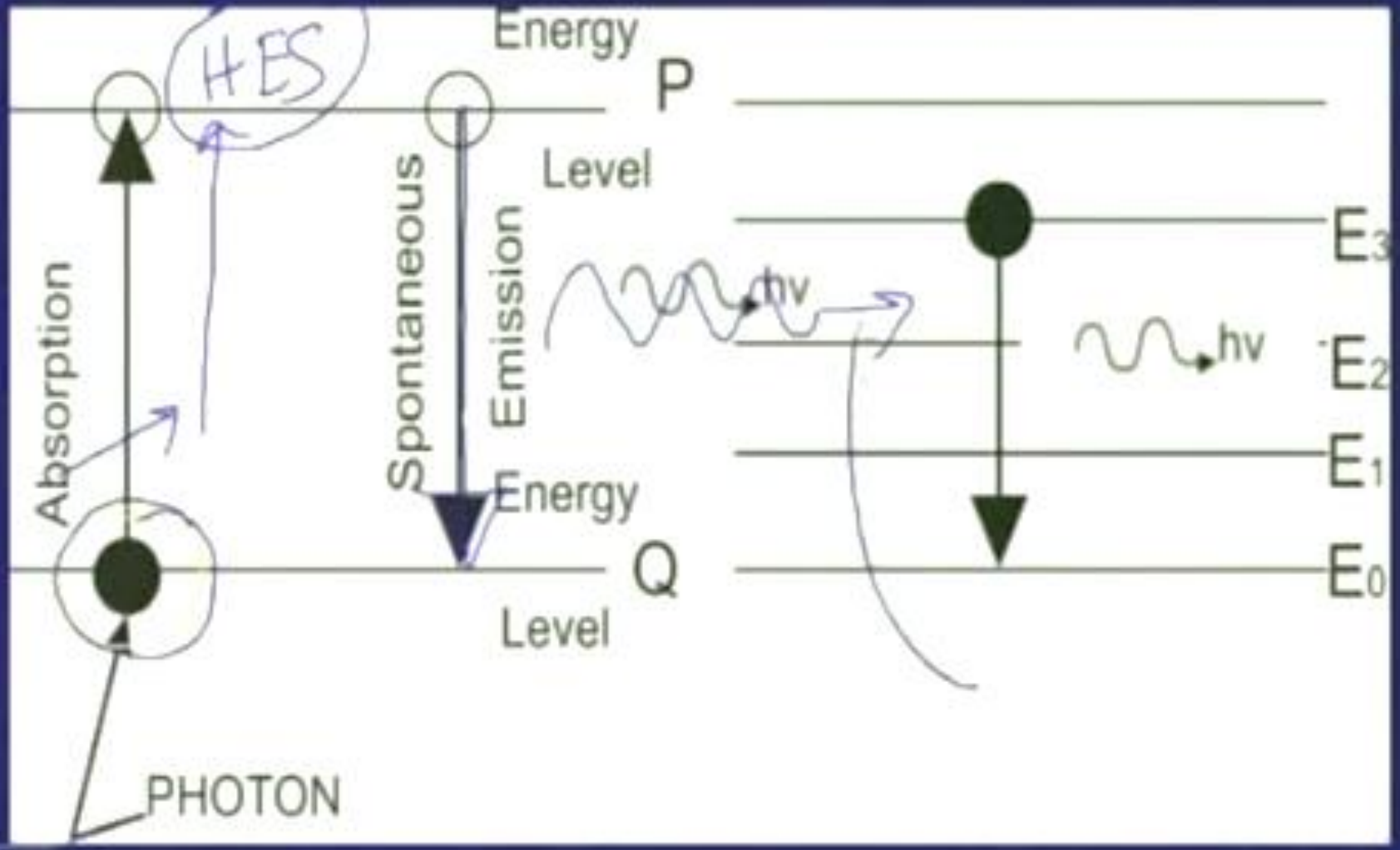
- high capital cost of the equipment and necessary regular maintenance applicable for any equipment using vacuum system.
- non-productive pump down period for attaining desired vacuum. However this can be reduced to some extent using vacuum load locks.
- heat affected zone is rather less in EBM but recast layer formation cannot be avoided.

LASER BEAM MACHING

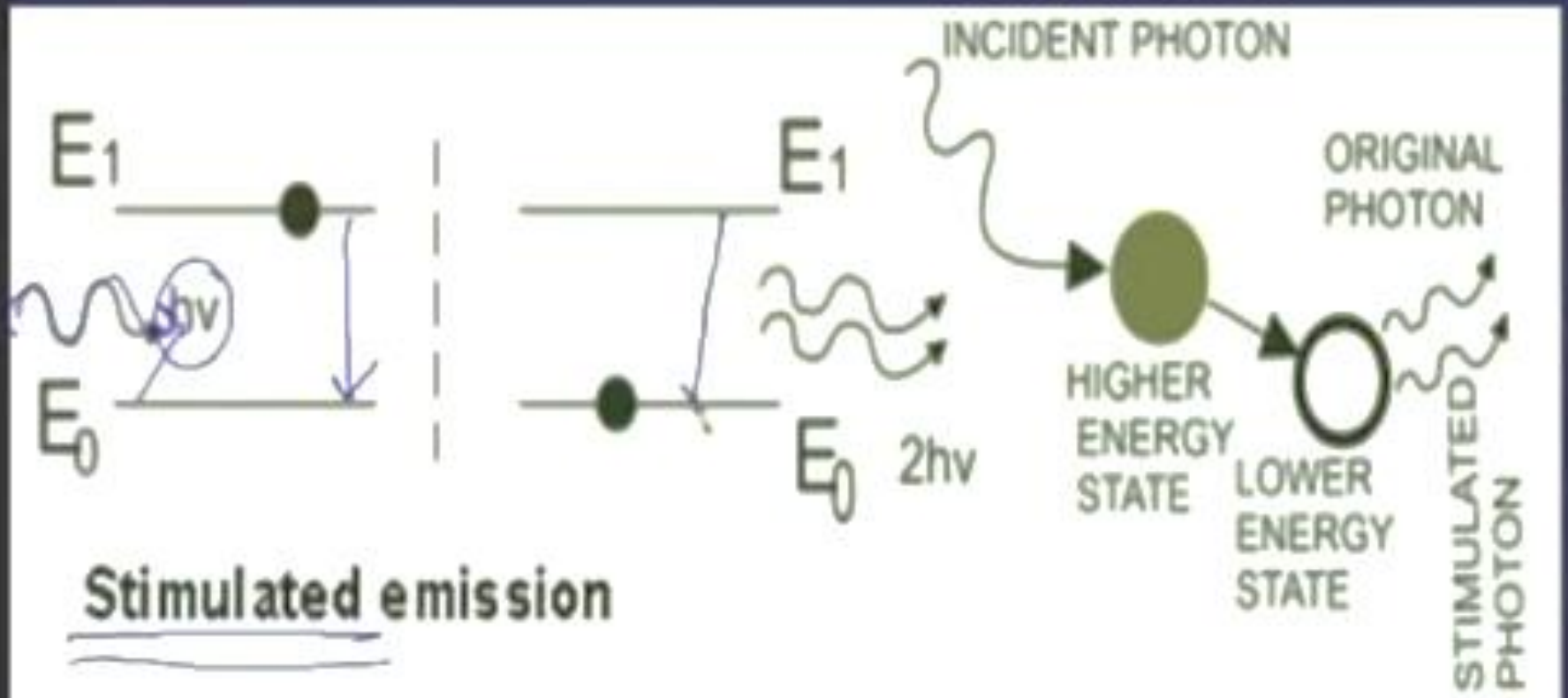
LBM – Working Principle of Laser

- Spontaneous absorption
- Spontaneous emission
- Time duration – ns
- Stimulated absorption
- Meta-stable state of electron
- Time Duration – micro to ms
- Population inversion
- Stimulated emission
- Phase coherency – temporal and spatial

LBM – Spontaneous Absorption & Emission

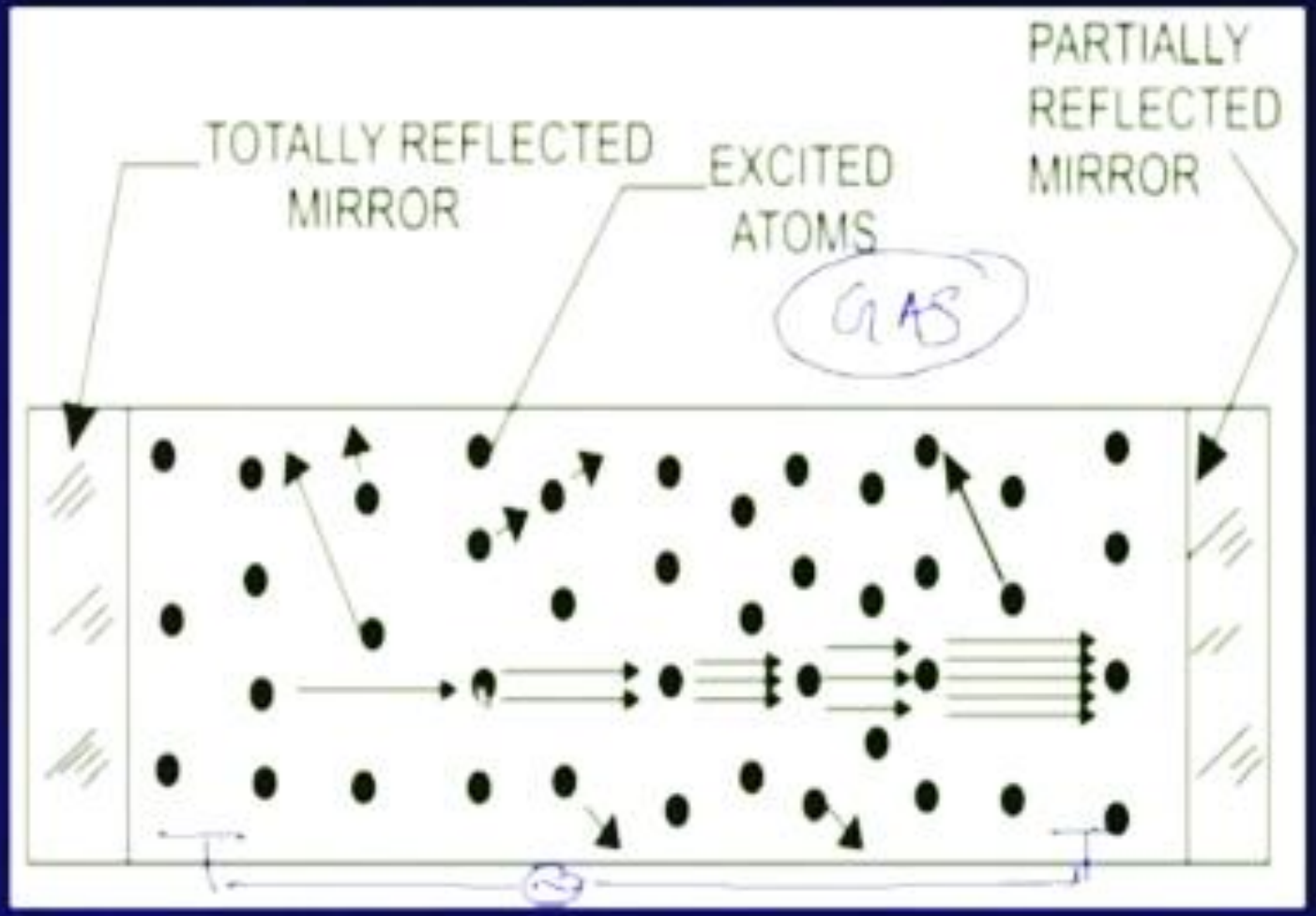


LBM – Stimulated Emission



Stimulated emission

LBM – Working Principle of Laser

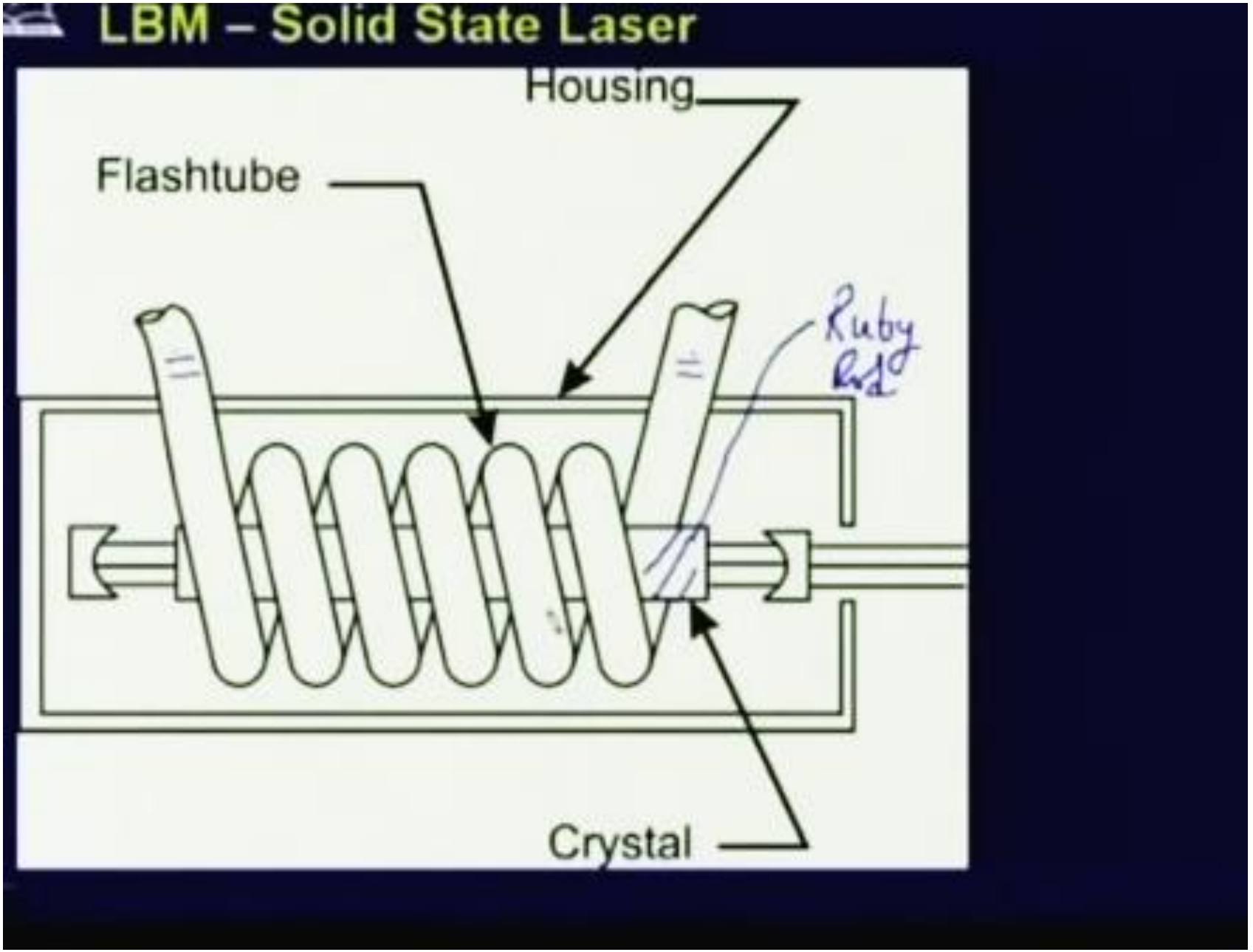


LBM – Laser Types and Lasing Medium

- Gas Lasers
  - Helium – Neon
  - Argon
  - CO_2 etc. – wave length 10.6 μm

- Solid State Lasers
  - Ruby which is a chromium – aluminium alloy having a wavelength of 0.7 μm
  - Nd-glass lasers having a wavelength of 1.64 μm
  - Nd-YAG laser having a wavelength of 1.06 μm

LBM – Solid State Laser



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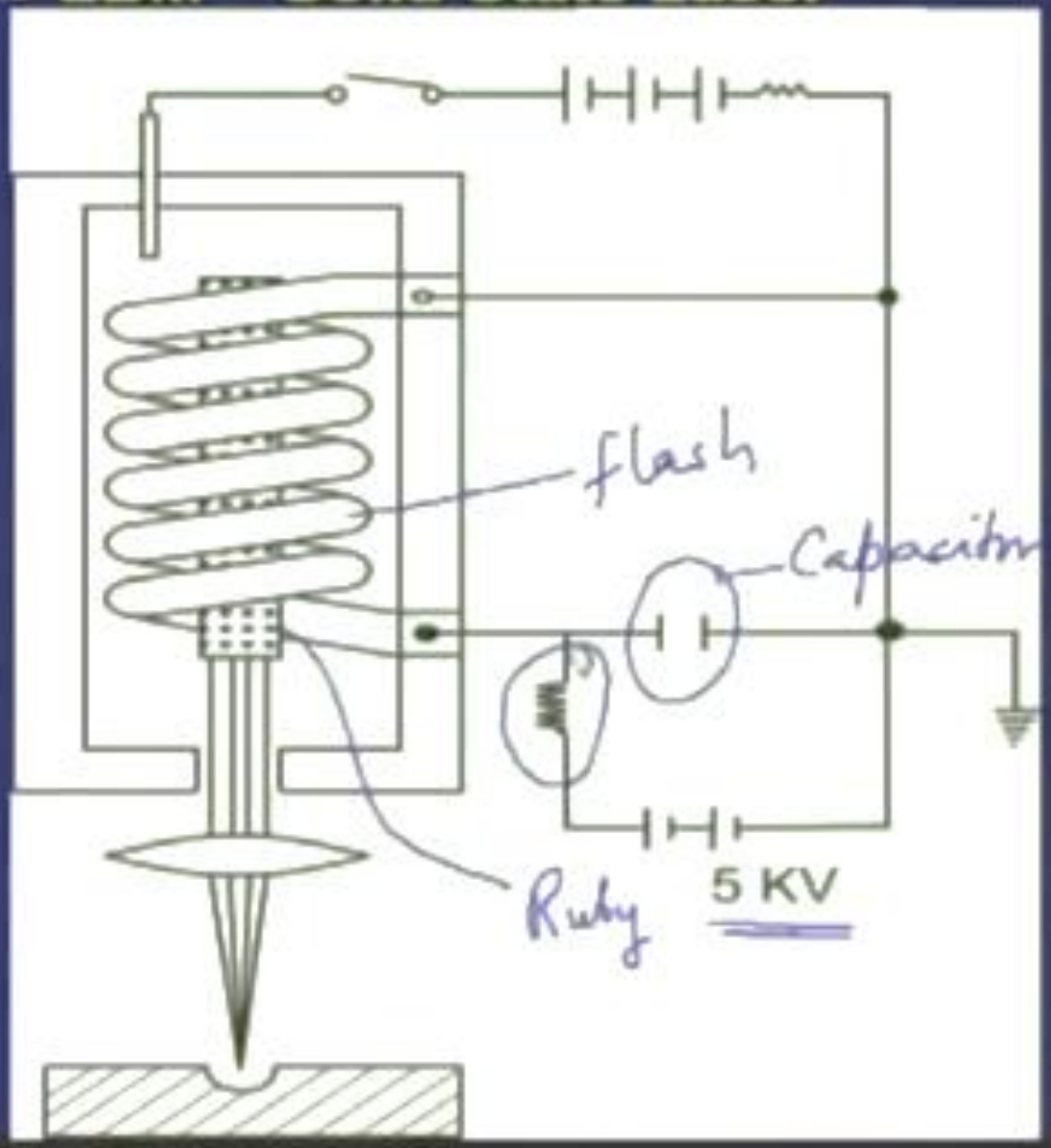

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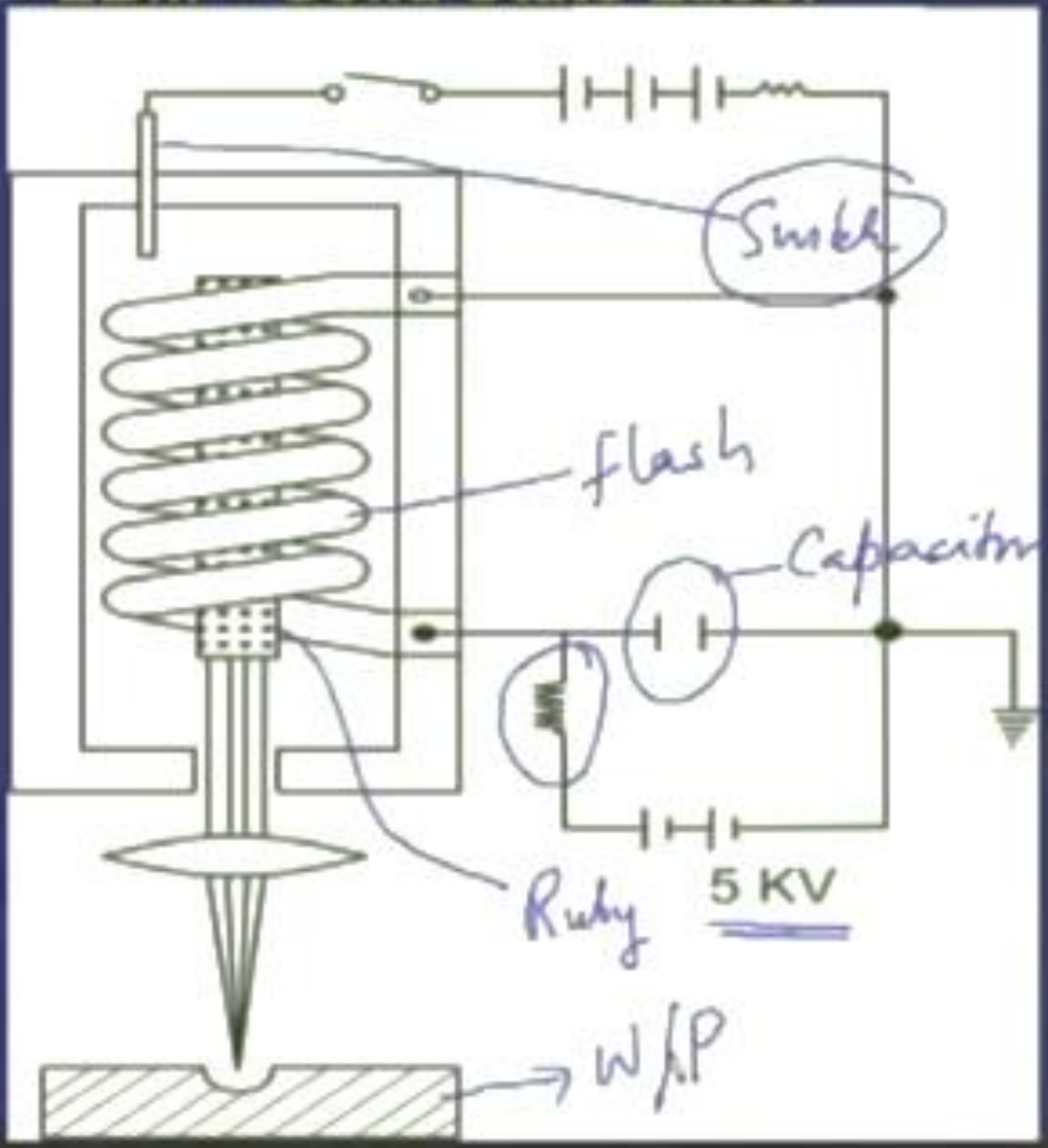
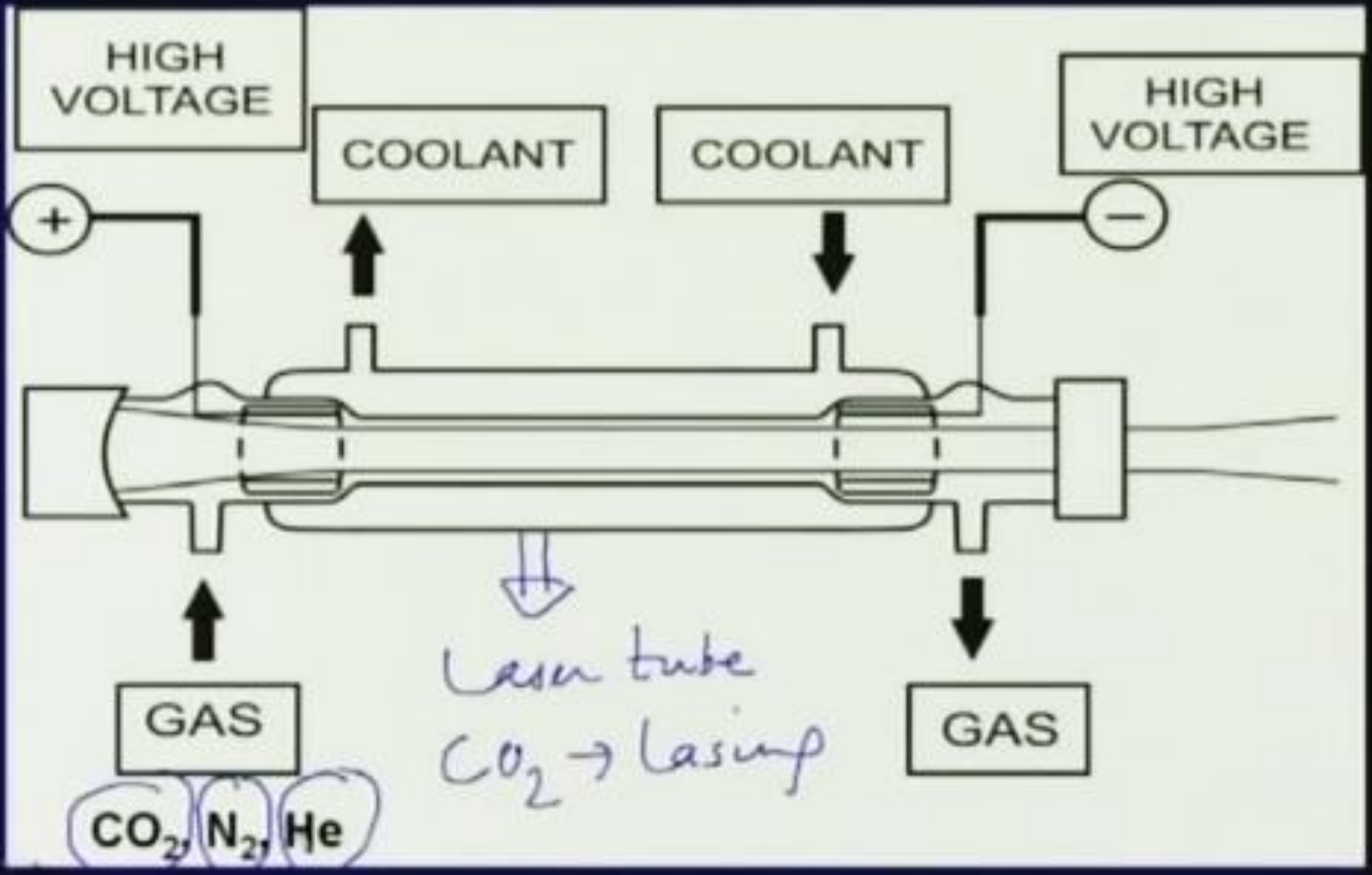
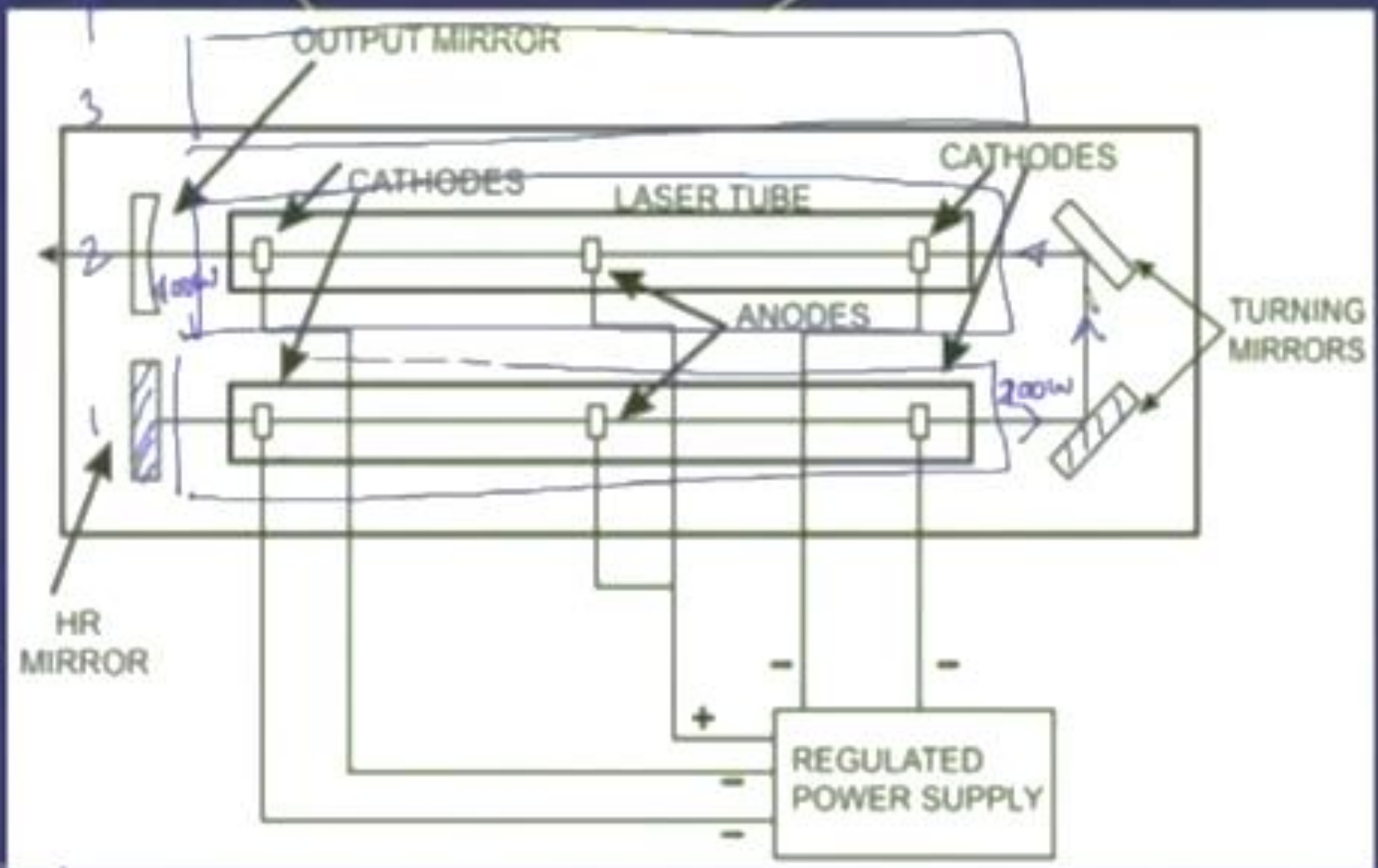


LBM – Gas Laser

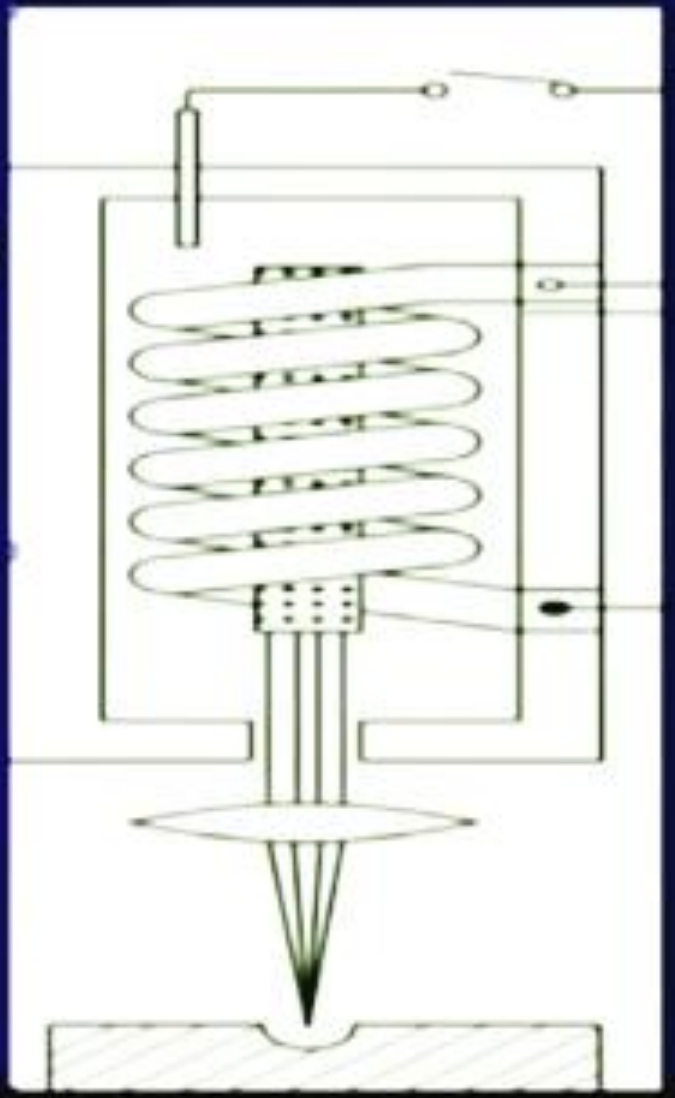


LBM – Folded Gas Laser



LBM – Mechanism of Material Removal

- Absorption of Laser Energy
- Rapid rise in Temperature
- Melting & Evaporation
- Material Removal
- Gas Assist



Laser – Characteristics

Materials	Nd-YAG	CO_2
Type	Solid state	Gas
Composition	1% Nd doped Yttrium – Aluminium-Garnet	CO_2+He+N_2 (3:8:4)
Wavelength	1.064 μm	10.6 μm
Efficiency	2%	10-15%
Beam mode	Pulsed	CW
Spot size	0.015 mm	0.075 mm
Pulse rate	1-300 pps	CW
Beam output	10-1000 W	0.1 – 10 kW
Peak power	400 kW	100 kW

LBM – Application

- Material Removal – drilling, cutting, trepanning
- Welding
- Cladding
- Alloying
- Bending
- Laser Drilling – Pulsed and Continuous Laser

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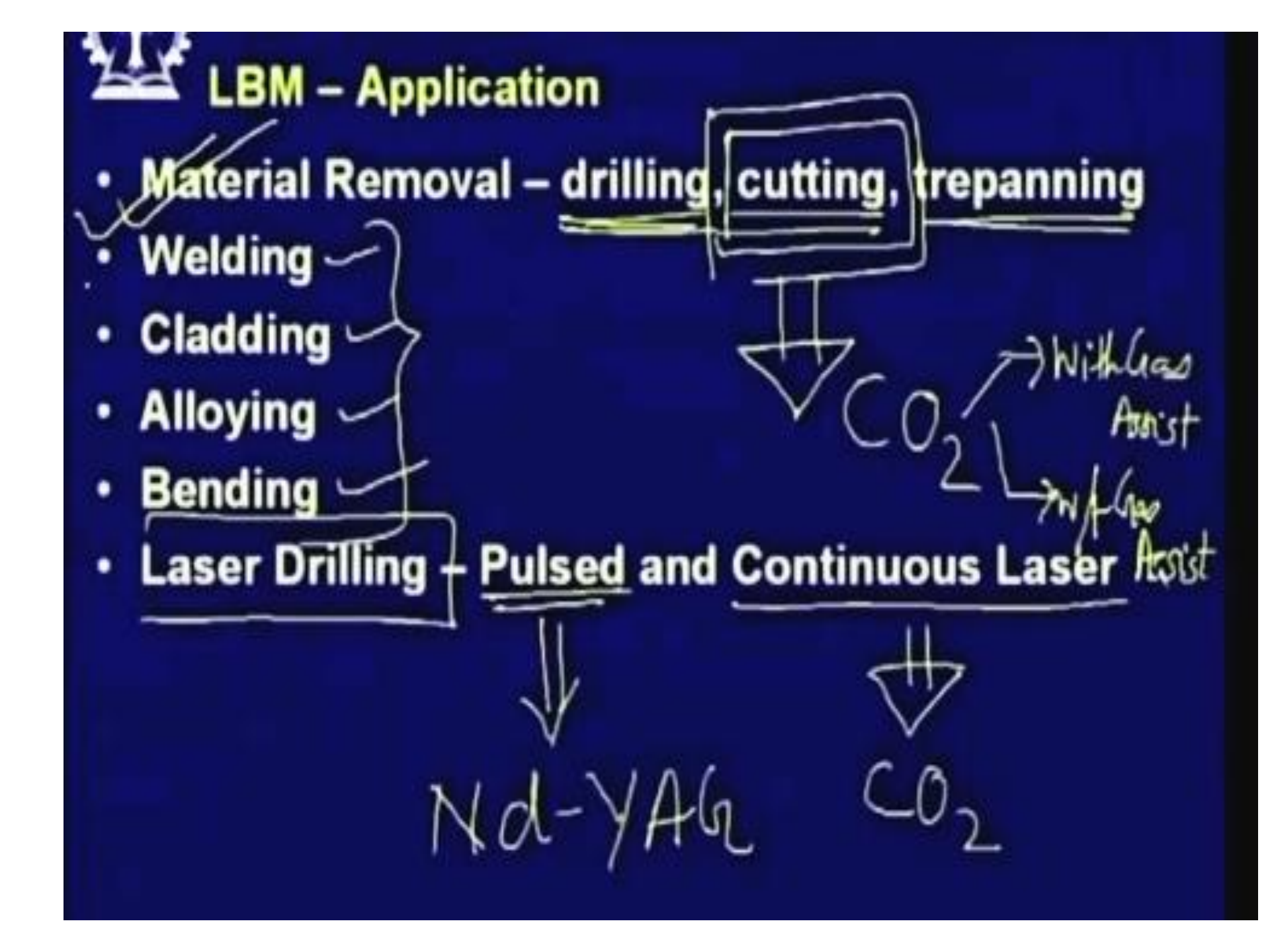

LBM – Application

Application	Type of Laser
Holes upto 1.5 mm dia.	Ruby, Nd-Glass, Nd-YAG
Trepanned Holes	Nd-YAG, CO_2
Holes – dia. less than 0.25 mm	Ruby, Nd-Glass, Nd-YAG
Drilling – punching	Nd-YAG, Ruby
Thick cutting	CO_2 with gas assist
Thin slitting of metals	Nd-YAG
Thin slitting of plastics	CO_2
Plastics	CO_2
Metals	Nd-YAG, ruby, Nd-glass
Organics, Non-metal	Pulsed CO_2
Ceramics	Pulsed CO_2, Nd-YAG

LBM – Advantages

- Micro-holes can be drilled in difficult – to – machine materials
- Though laser processing is a thermal processing but heat affected zone specially in pulse laser processing is not very significant due to shorter pulse duration.
- In laser machining there is no physical tool. Thus no machining force or wear of the tool takes place.
- Large aspect ratio in laser drilling can be achieved along with acceptable accuracy or dimension, form or location

LBM – Limitations

- High initial capital cost
- High maintenance cost
- Not very efficient process
- Presence of Heat Affected Zone – specially in gas assist CO_2 laser cutting
- Thermal process – not suitable for heat sensitive materials

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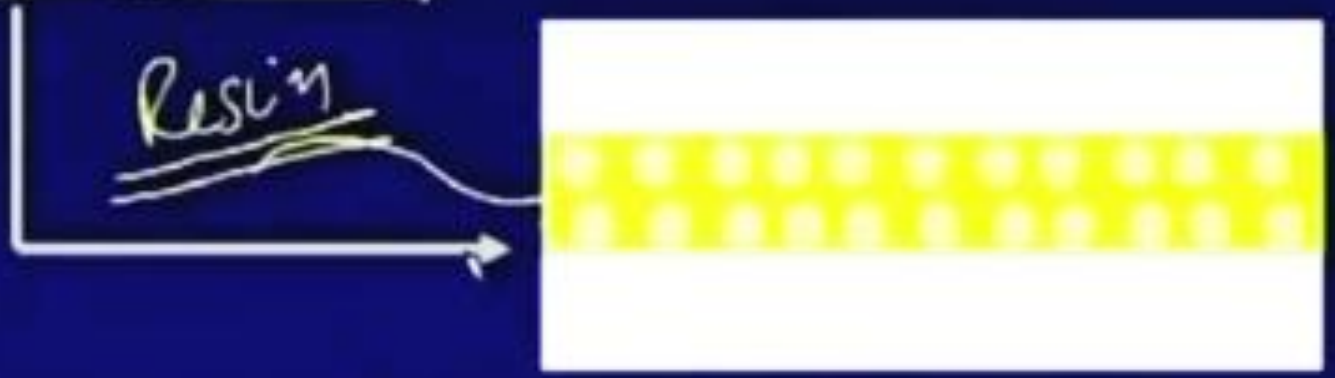

Summary

- Major components of EBM & LBM equipment
- Working principle of EBM & LBM equipment
- Drawing of EBM & LBM equipment
- Process parameters of EBM & LBM
- Basic mechanism of material removal in EBM & LBM
- Applications of EBM & LBM
- Advantages of EBM & LBM
- Limitations of EBM & LBM

Quiz

1. Mechanism of material removal in Electron Beam Machining is due to

   a) Mechanical erosion due to impact of high of energy electrons
   b) Chemical etching by the high energy electron
   c) Sputtering due to high energy electrons
   d) Melting and vaporisation due to thermal effect of impingement of high energy electron

Answer – (d)

Quiz

2. Mechanism of material removal in Laser Beam Machining is due to

a) Mechanical erosion due to impact of high of energy photons
b) Electro-chemical etching
c) Melting and vaporisation due to thermal effect of impingement of high energy laser beam
d) Fatigue failure

Answer – (c)

Quiz

3. Generally Electron Beam Gun is operated at

a) Atmospheric pressure
b) At 1.2 bar pressure above atmosphere
c) At 10 – 100 mTorr pressure
d) At 0.01 – 0.001 mTorr pressure

Answer – (d)

Quiz

4. Laser Beam is produced due to

a) Spontaneous emission
b) Stimulated emission followed by spontaneous emission
c) Spontaneous emission followed by Spontaneous absorption
d) Spontaneous absorption leading to "population inversion" and followed by stimulated emission

Answer – (d)