ATME College of Engineering

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DEPARTMENT OF MECHANICAL ENGINEERING - ATME -

Introduction to Non-Traditional Machining BME405A

Laser Beam Machining (LBM)

Dr. Chethan S
Associate Dean Academics
Associate Professor & HoD,
Dept. of Mechanical Engineering,
ATMECE, Mysuru

Module - 5

LASER BEAM MACHINING (LBM)

- Introduction, generation of LASER
- Equipment and mechanism of metal removal
- LBM parameters and characteristics
- Applications, Advantages & limitations.

ELECTRON BEAM MACHINING (EBM)

- Introduction & Principle of EBM
- Equipment and mechanism of metal removal
- Applications, advantages and limitations.

Principle of Laser Beam Machining (LBM)

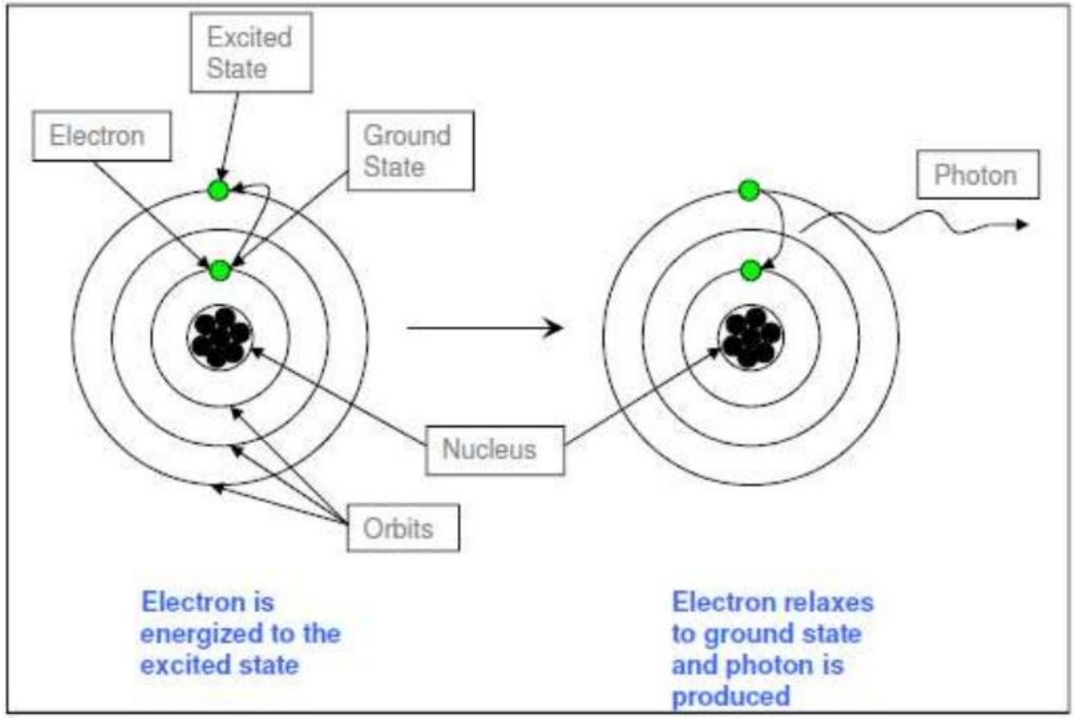
- Laser beam machining is a thermal material removal process that utilizes a high-energy, monochromatic beam of light to melt and vaporize particles on the surface of metallic and nonmetallic workpieces.
- The machining is achieved by a laser device, which produces a light beam with various characteristics.
- The electrical energy supplied to the laser is converted into light energy and then to thermal (heat) energy. The temperature generated is high enough to melt and vaporize any material.

Principle of Laser Beam Machining (LBM)

- Light energy of a particular frequency could be used to stimulate the electrons in an atom to emit additional light with exactly the same characteristics as the original stimulating light source.
- The light emitted from a laser differs from all other natural and man-made light sources and is able to perform material processing tasks because of its properties of monochromaticity.
- Lasers are mainly used to cut, drill and weld materials. However, they can also be used to mark parts (scribing and marking), heat-treat surfaces and selectively clad materials.

Generation of LASER

- The electrons are charged particles, they carry some energy. The energy related with the orbit in which the electrons revolve.
- Generally the electrons are present in the outer most orbit of the atom take part in the process of energy absorption or emission.

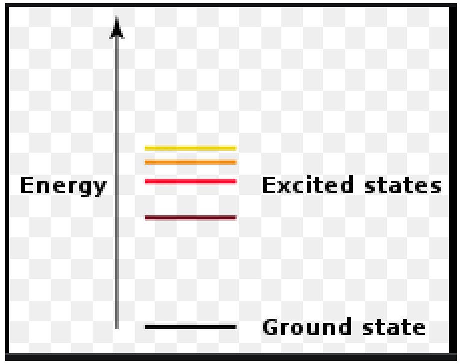


- Ground state, the state with lowest energy is the most stable state for the electrons. After absorbing the energy electron jump to the higher energy state and staying there for some seconds jump to the ground state and release the absorbed energy and supplies the initial electrons ,which accelerated before colliding & ionizing.

Generation of LASER

The jump may be in two stages:-

- Electron from higher state may not come directly to the ground state but may halt for some micro seconds on some intermediate state before finally coming to the ground state.
- The period for which electron stays in a higher energy state is known as the lifetime of that energy state.



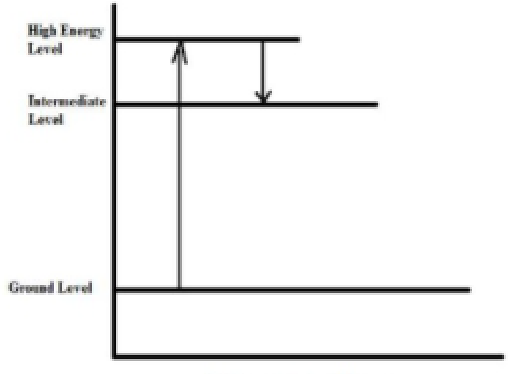
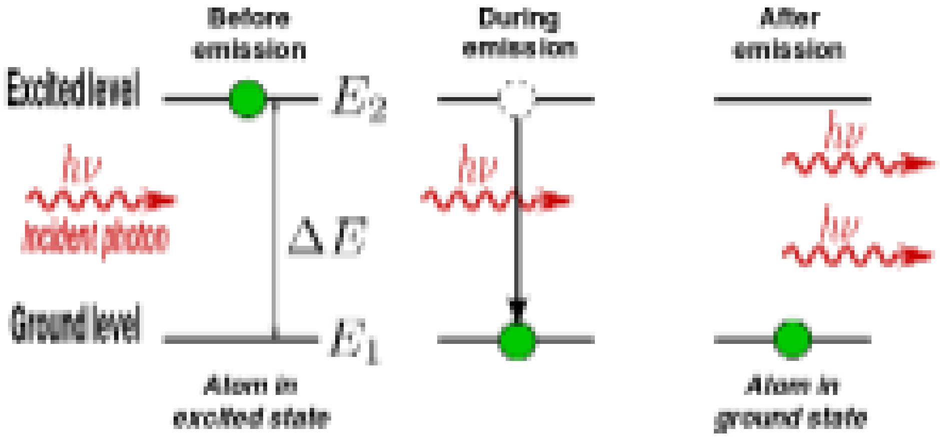


Fig. Energy Levels of Electrons

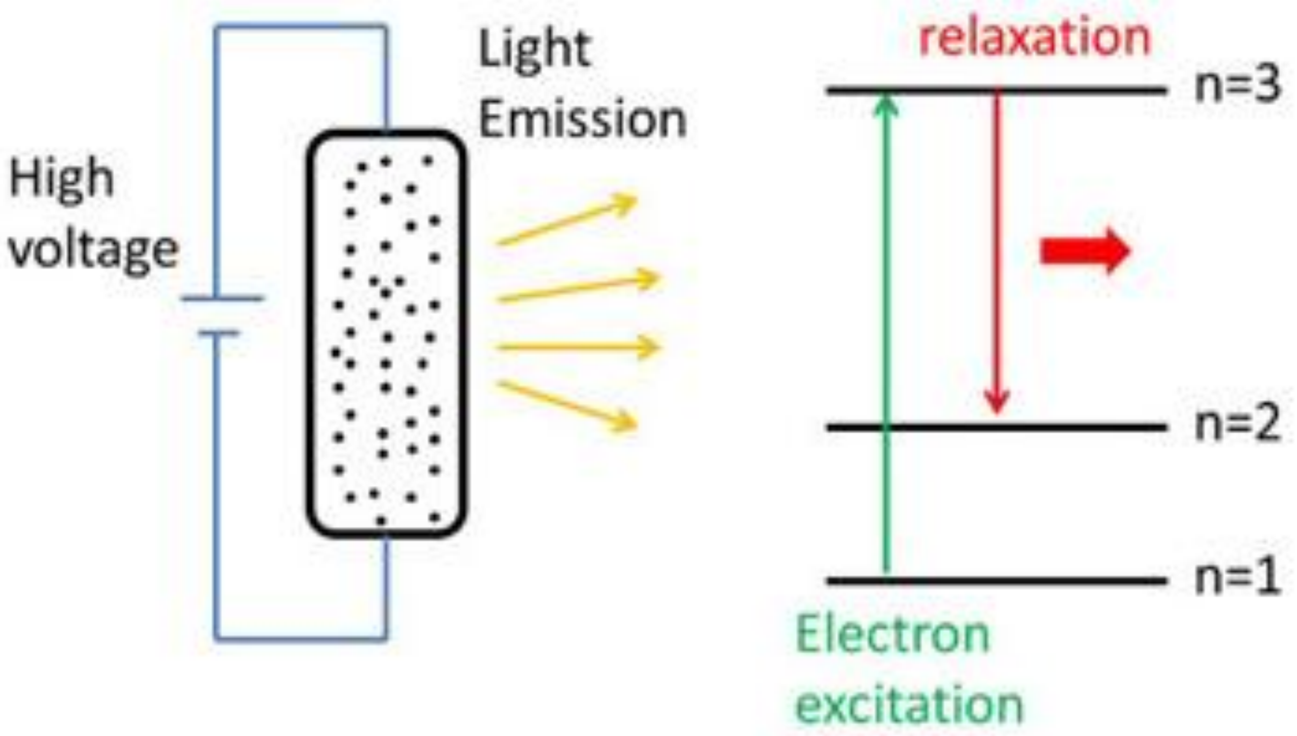


$$E_2 - E_1 = \Delta E = h\nu$$

Generation of LASER

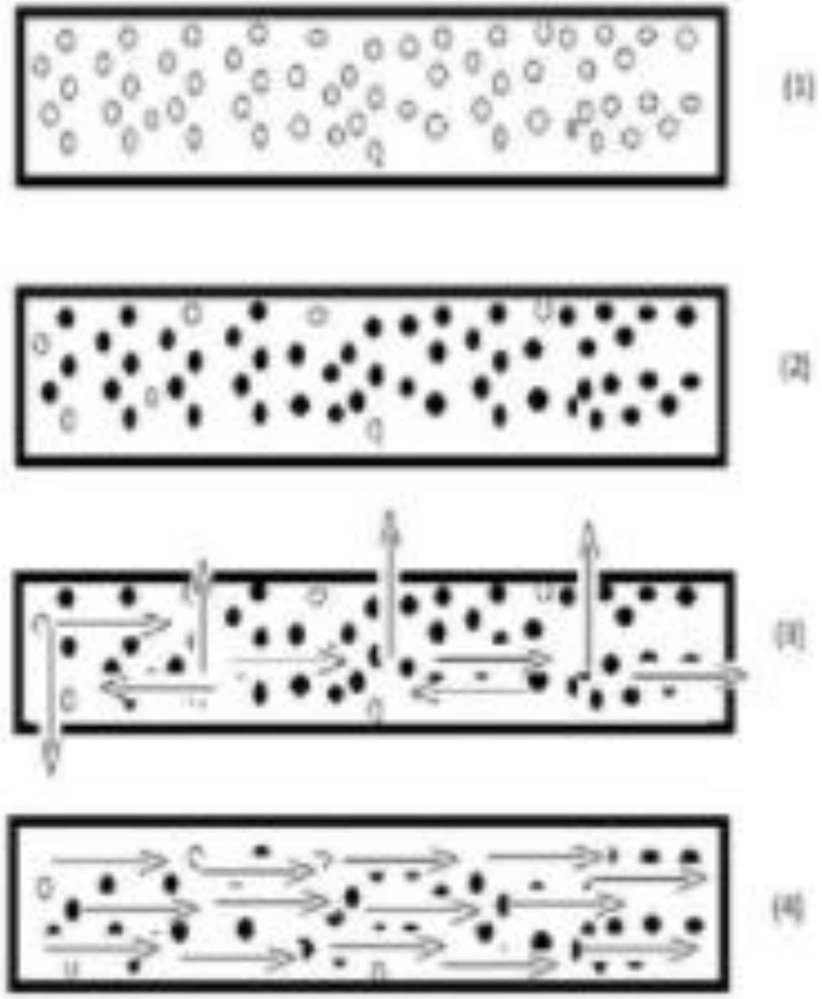
Lasing action

- The emission of photon is not done by only one atom at upper energy level but on the influence of external light, a sort of chain reactions occurs and one after other atoms start emitting photons. Thus whole avalanche dumps down together. This is called lasing action.

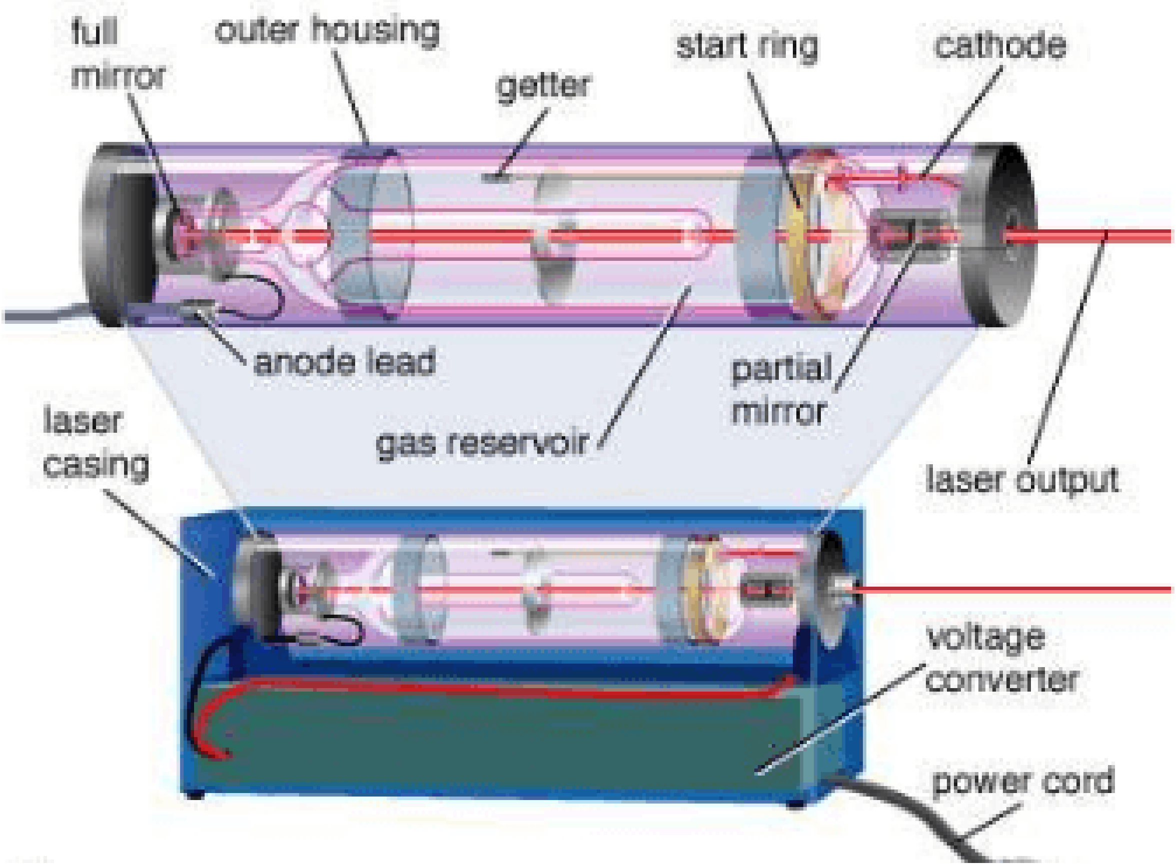


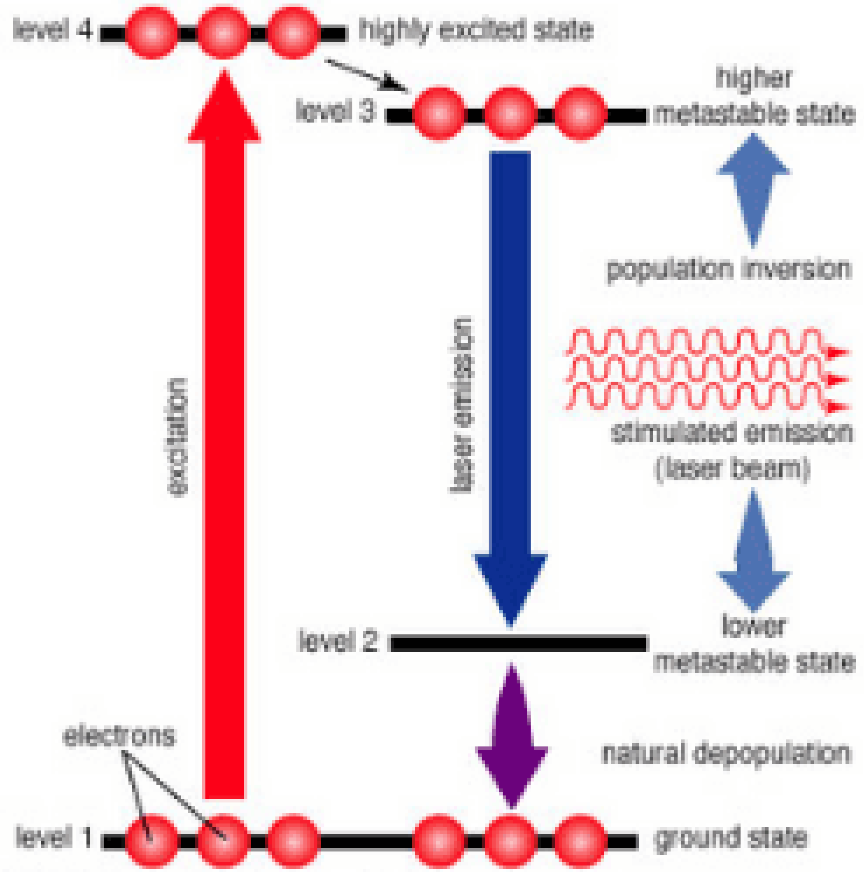
Generation of LASER

- All the materials are not suitable for producing laser beam.
- One of the most common laser materials and also one capable of delivering high power is the chromium on a ruby crystal.
- Crystal ruby is aluminum oxide.
- Generally the ruby rod 1 cm diameter and 10 cm long with ends polished fully is used.

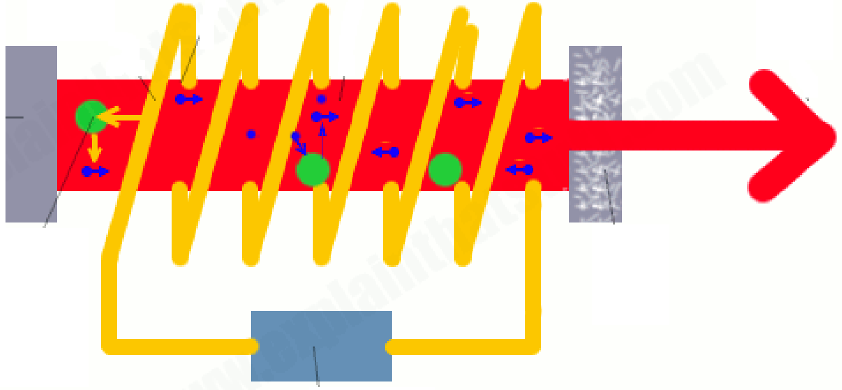


Generation of LASER

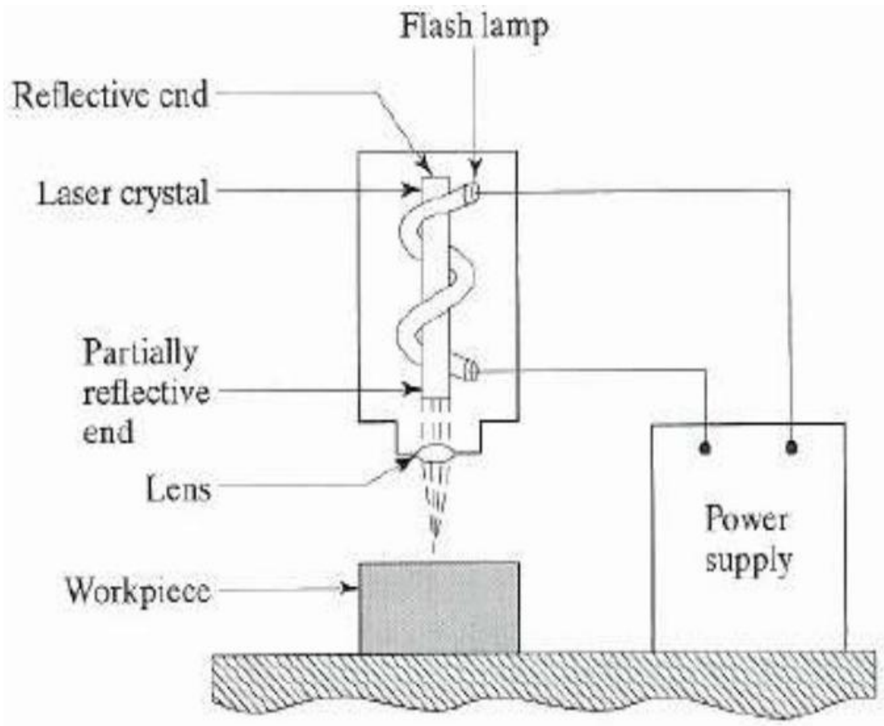


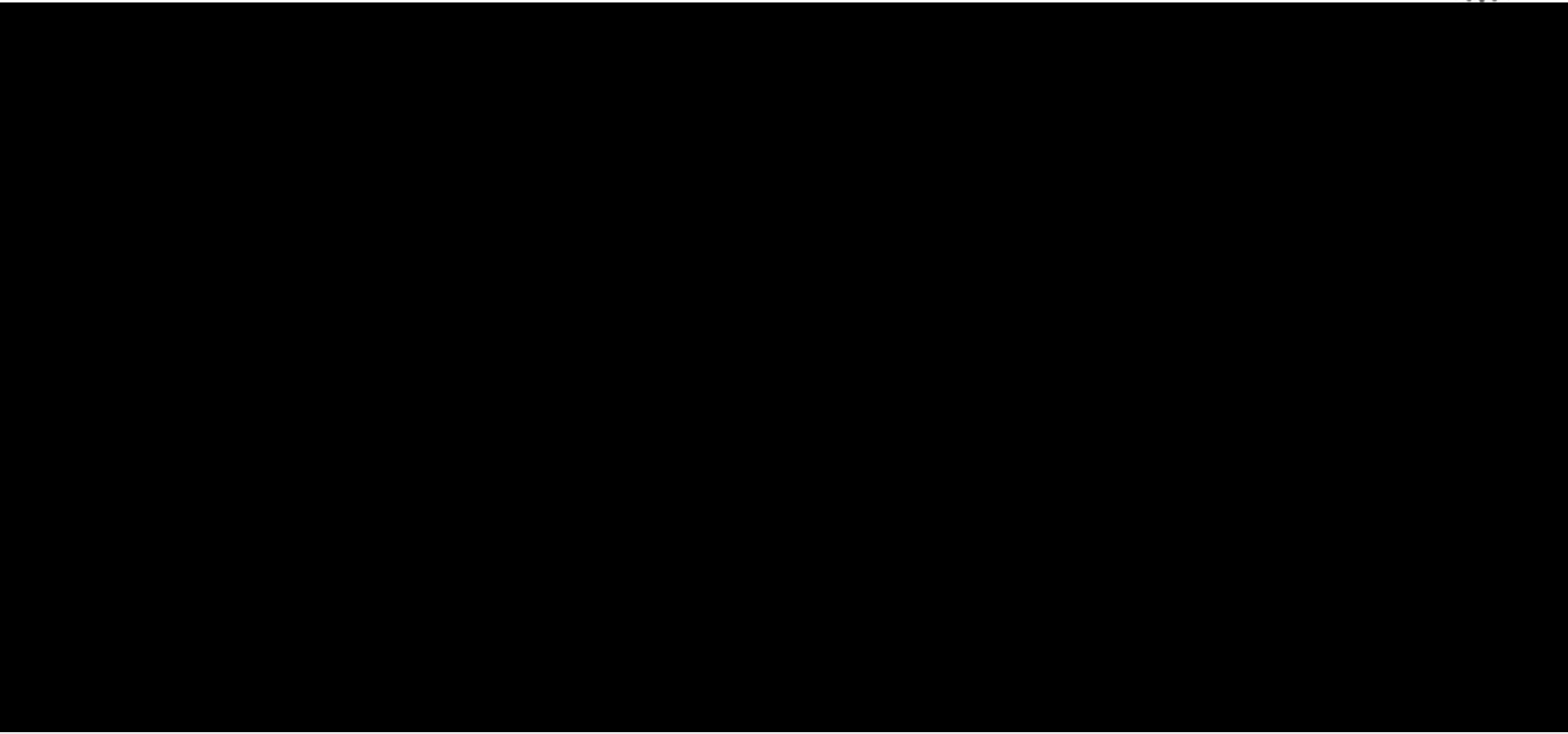


Mechanism of Laser Action



- In the beginning in atom all the crystals are in ground state
- When the light is flash over the crystal, most of the atoms are raised to the excited state. Some light waves incline to the axis of the crystal will leave the box either after only a few reflections or without strike on mirror.
- Some of the waves that travel parallel to the axis of the crystal, will spontaneously emit photon from chromium ions. These photon stimulate another atom to contribute a second photon. This process continues as the photons are reflected to and fro between the mirror.
- At the each reflection a certain loss occurs

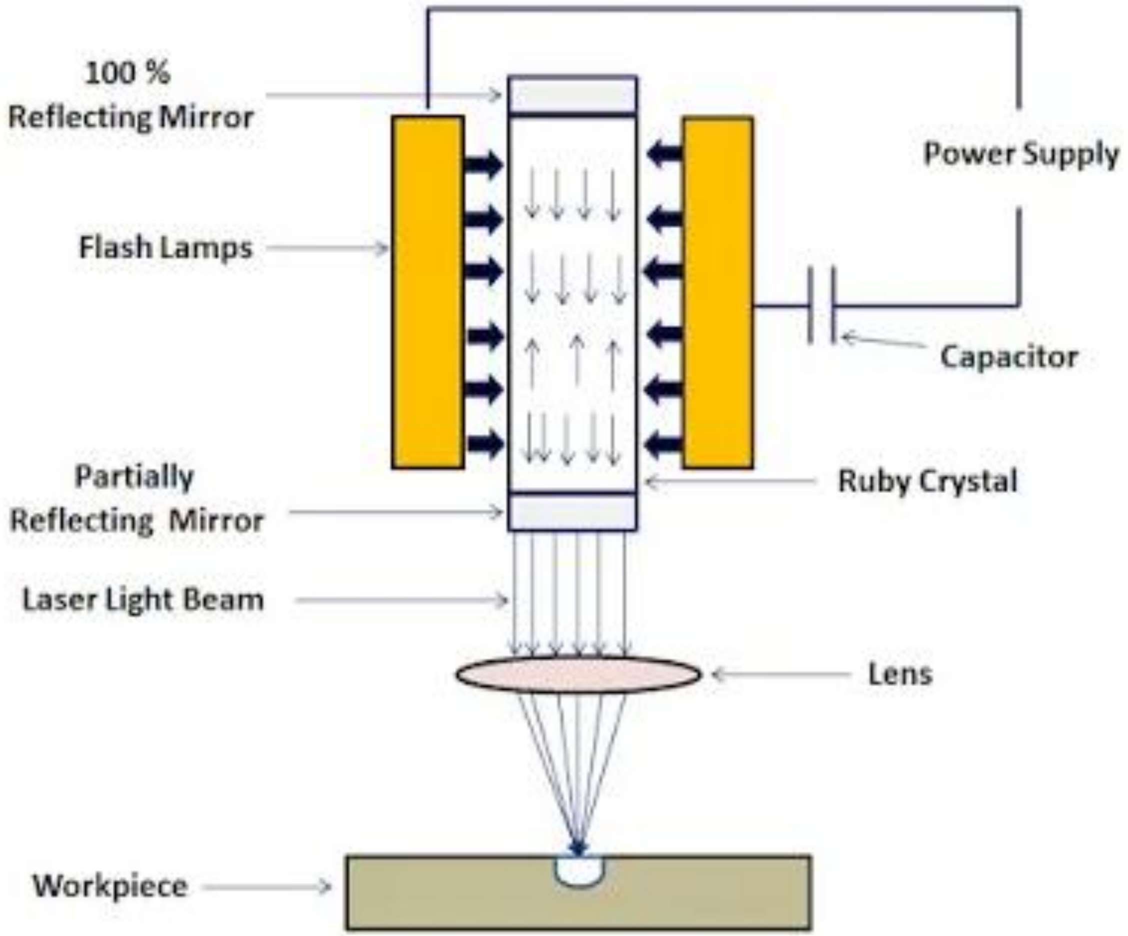




LBM EQUIPMENT

The equipment consists of the following main parts:

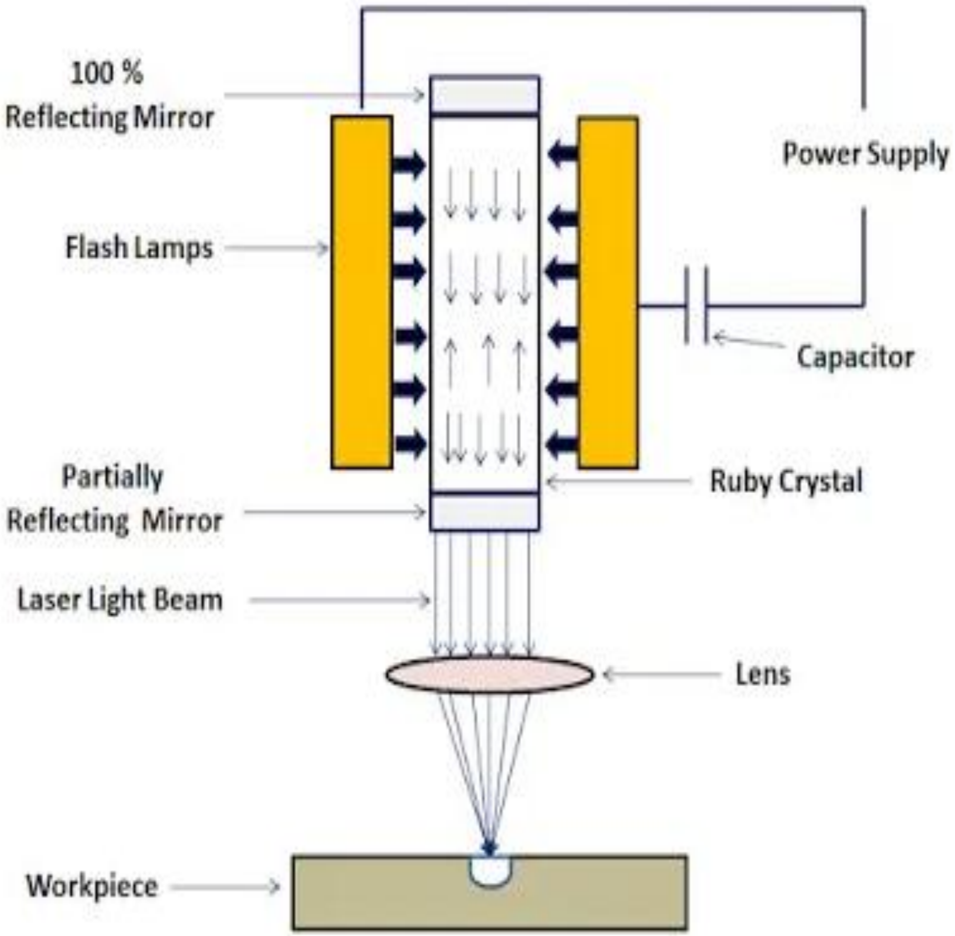
- Ruby crystal
- Xenon flash tube
- Cooling system and
- Focusing lens.



LBM EQUIPMENT

1. Ruby crystal

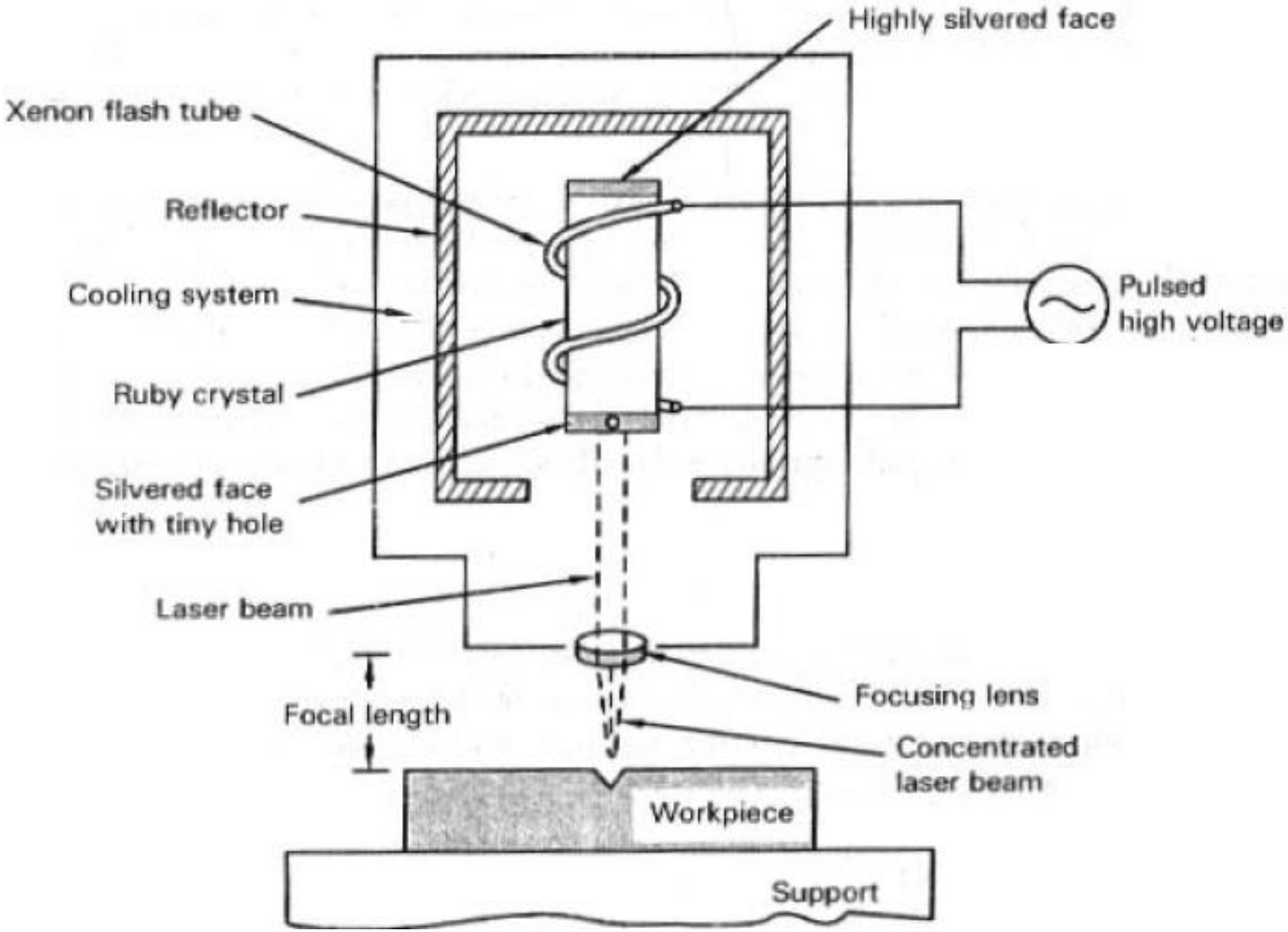
- The cylindrical shaped ruby crystal forms the important part of the laser beam equipment.
- Ruby is aluminum oxide with chromium dispersed throughout it. Both the ends of the ruby crystal are made absolutely parallel to each other.
- One of the end faces of the crystal is highly silvered, so that it reflects nearly 96% of the incident light.
- In order to tap the laser output, the other end face of the crystal is partially silvered and contains a small hole through which the laser beam emerges.



LBM EQUIPMENT

2. Xenon flash tube

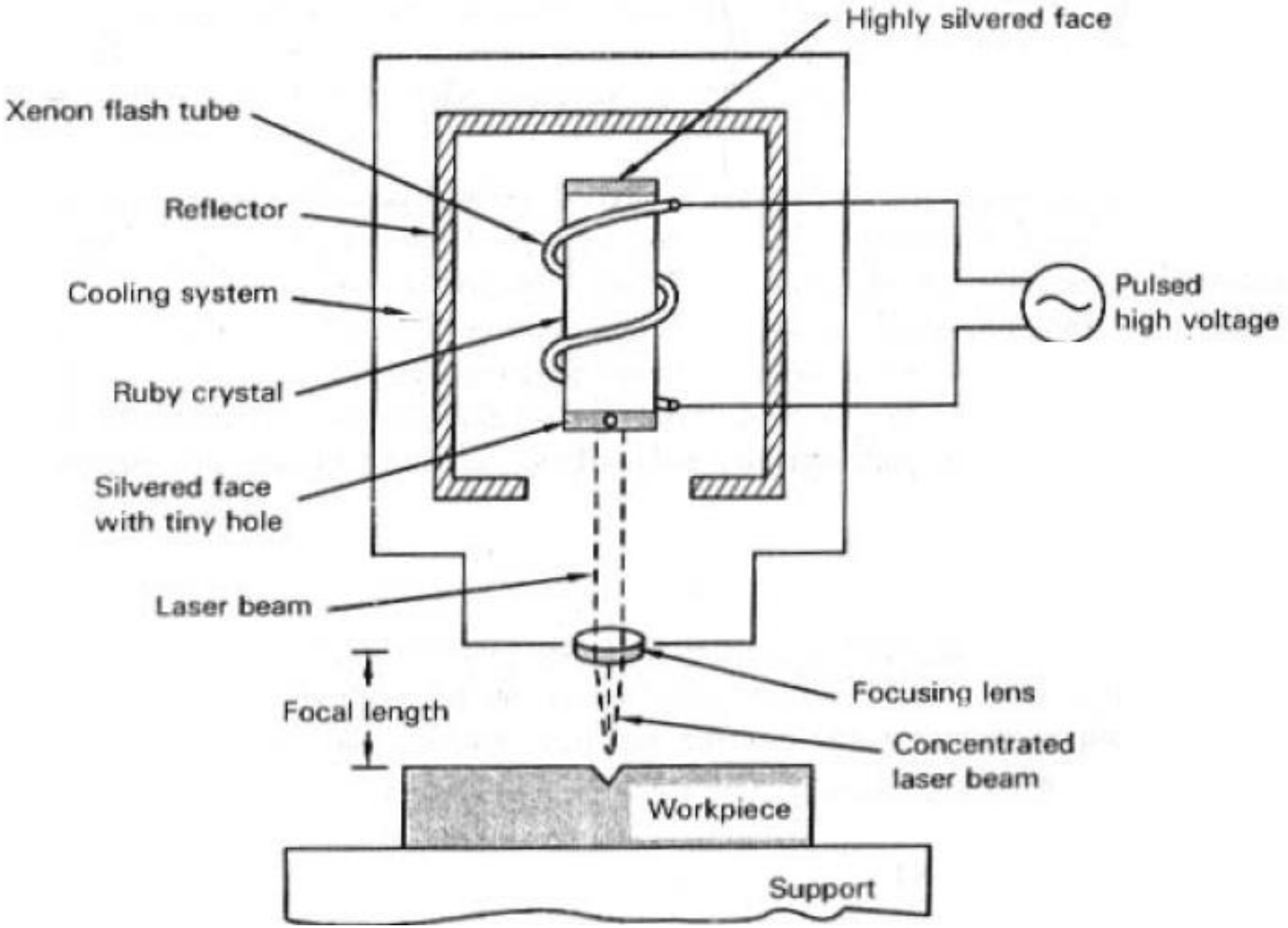
- The ruby crystal is surrounded by a helical flash tube containing inert gas xenon, which itself in turn is surrounded by a reflector, to maximize the intensity of the incident light on the ruby crystal.
- The xenon tube is connected to a pulsed high voltage source by which the xenon transforms the electrical energy into light flashes (light energy) .



LBM EQUIPMENT

3. Cooling system

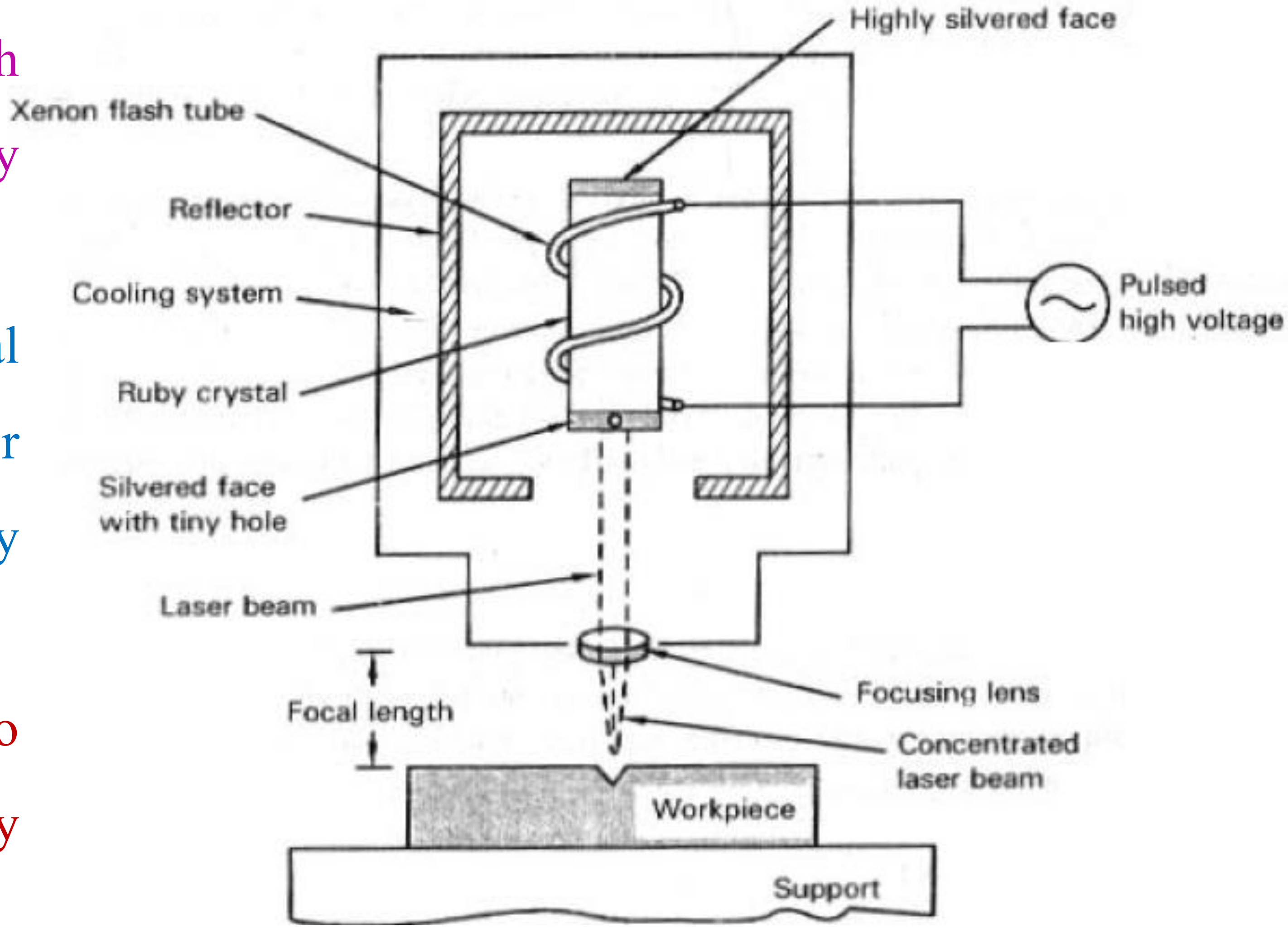
- A cooling system, which utilizes water, air or liquid nitrogen, is provided to protect the ruby crystal* from the enormous amount of heat generated.



LBM EQUIPMENT

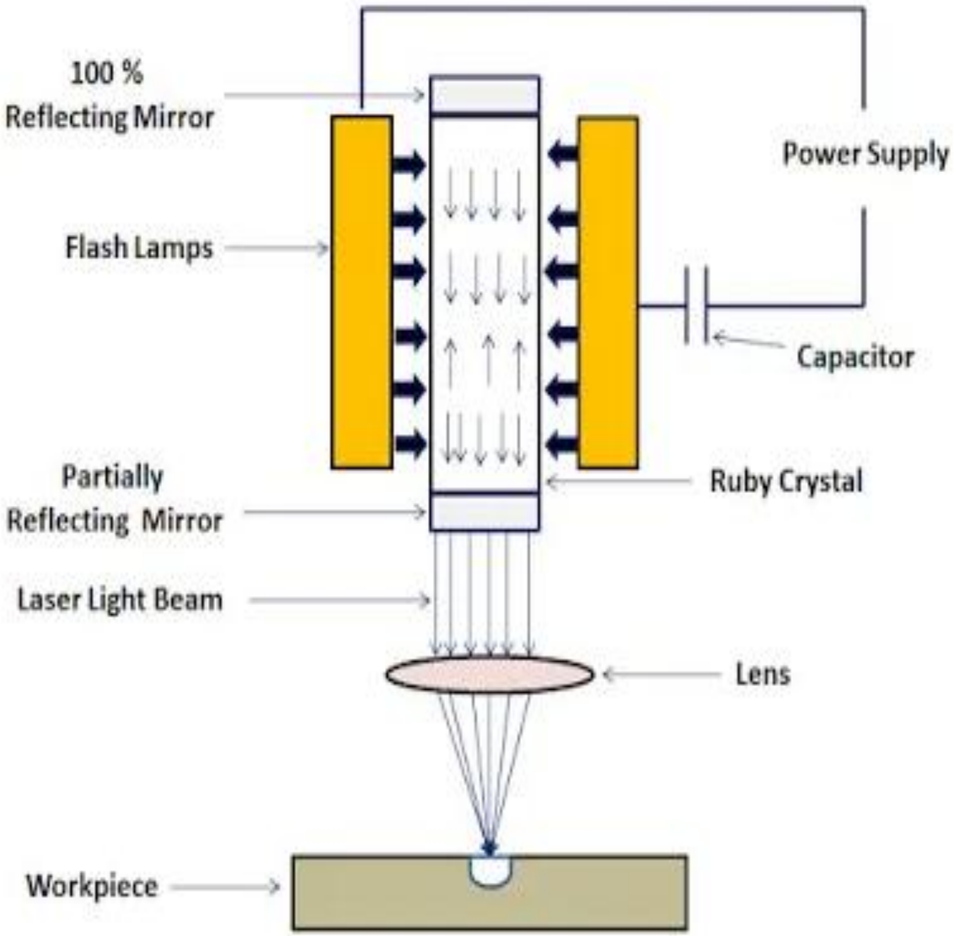
4. Focusing lens

- The light beam or laser beam, which escapes through the tiny hole of the ruby crystal possess low power densities.
- The beam is useless for material processing applications until its power density is increased. This is achieved by means of a focusing lens.
- The lens focuses the laser beam to converge to a narrow spot thereby increasing its power density.



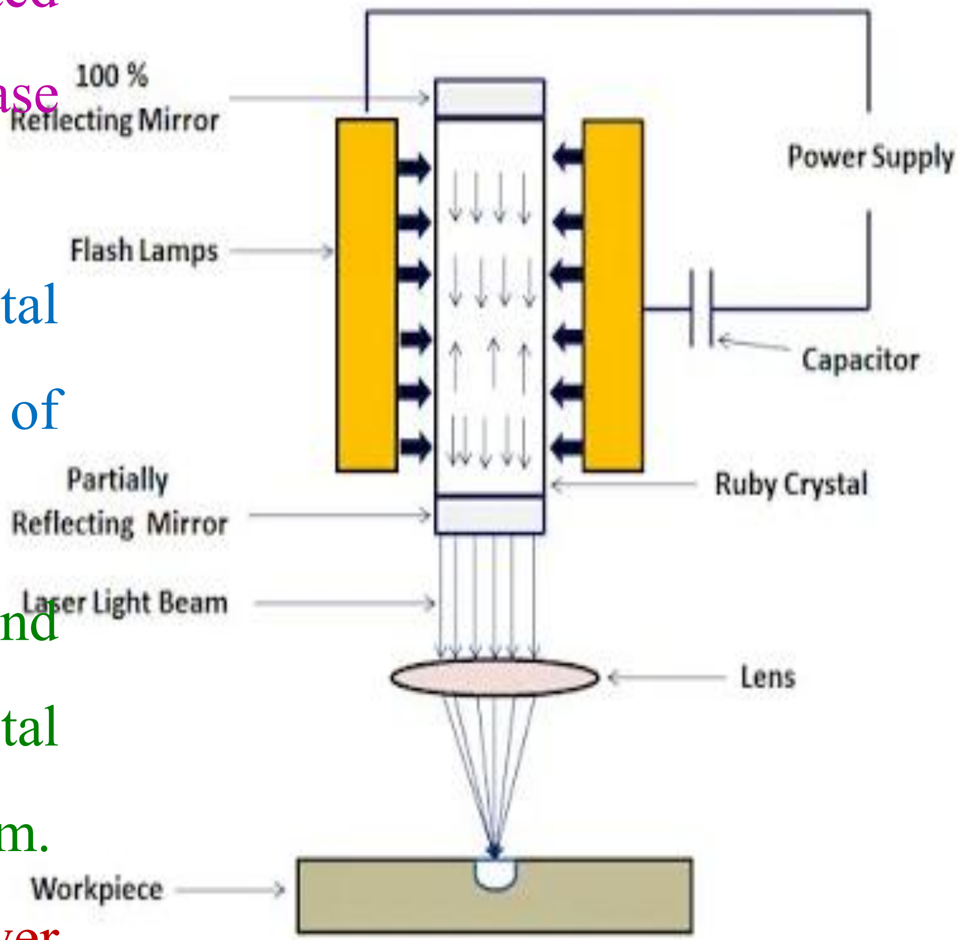
LBM OPERATION

- In operation, when the xenon flash tube is connected to a pulsed high voltage source, the inert gas xenon transforms the electrical energy into white light flashes (light energy).
- The ruby crystal is exposed to the intense light flashes, the chromium atoms of the crystal are excited and pumped to a high-energy level.
- These chromium atoms immediately drop to an intermediate energy level with the evolution of heat and eventually drop back to their original state with the evolution of a discrete quantity of radiation in the form of red fluorescent light.



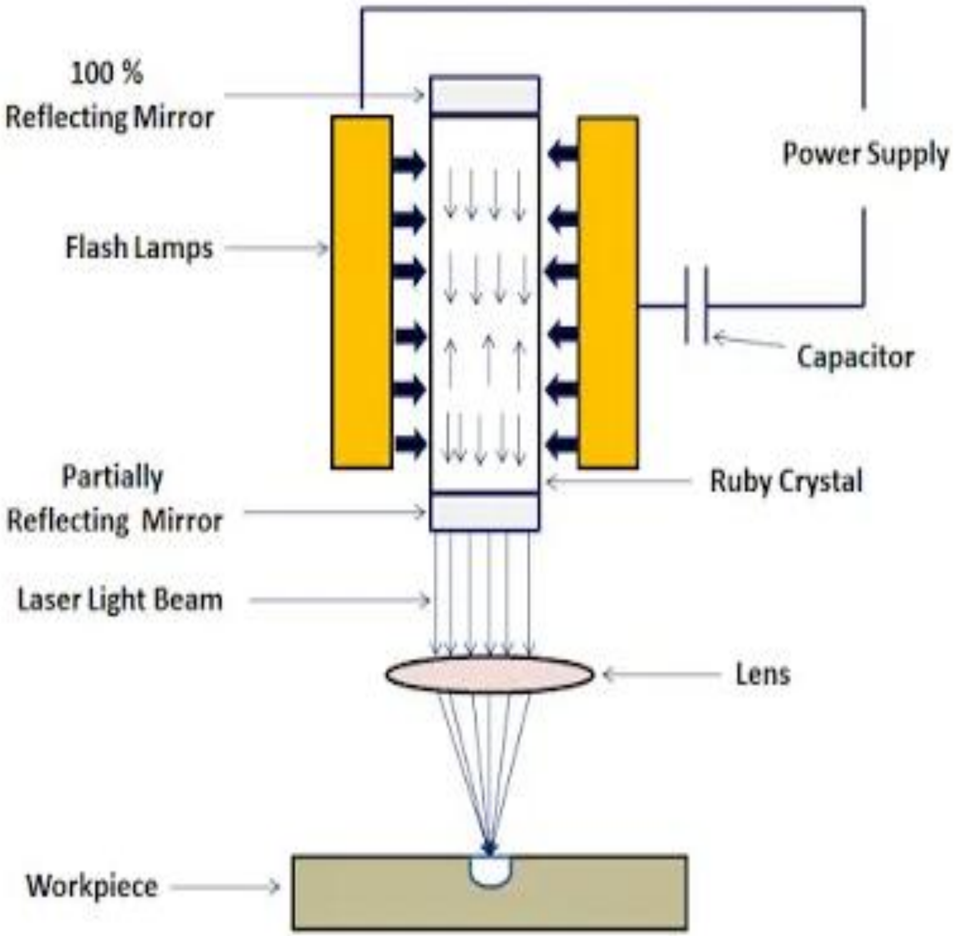
LBM OPERATION

- The red light emitted by one excited atom hits another excited atom, the second atom gives off red light, which is in phase with the colliding red light wave.
- The effect is enhanced as the silvered ends of the ruby crystal cause the red light to reflect back and forth along the length of the crystal.
- The chain reaction collisions between the red light wave and the chromium atoms become so numerous that, finally the total energy bursts and escapes through the tiny hole as a laser beam.
- The beam is focused with a simple lens to obtain high power densities in small areas of the worksurface.



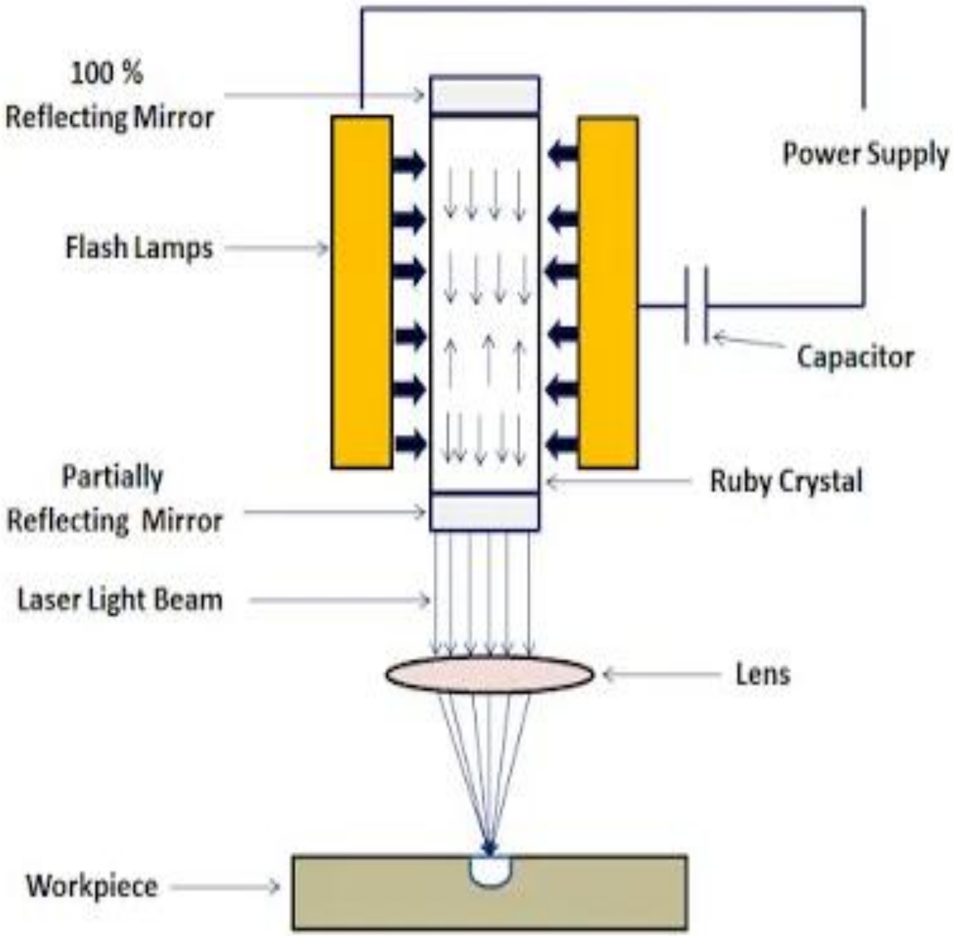
LBM OPERATION

- The intense heat of the laser beam is used to melt and, or evaporate the workpiece material being cut. A stream of gas, like oxygen, nitrogen or argon is often used to blow the molten metal through the cut, cool the workpiece and minimize the heat affected zone.
- The table carrying the workpiece can be moved in three dimensions with respect to the laser beam to obtain the desired profile of cut on the workpiece.



LBM Mechanism of Material Removal

- Metal removal by a laser beam is achieved through a combination of melting and evaporation, although with some carbon based materials and certain ceramics, the mechanism is purely one of evaporation.
- When a high energy density laser bream is focused on a small work surface, the thermal energy is absorbed, which heats and transforms the work volume into a molten, vaporized state that can easily be removed by the flow of high pressure assisted gas jet, which accelerates the transformed material and ejects it from the machining zone



TYPES of LASERS USED in LBM

01

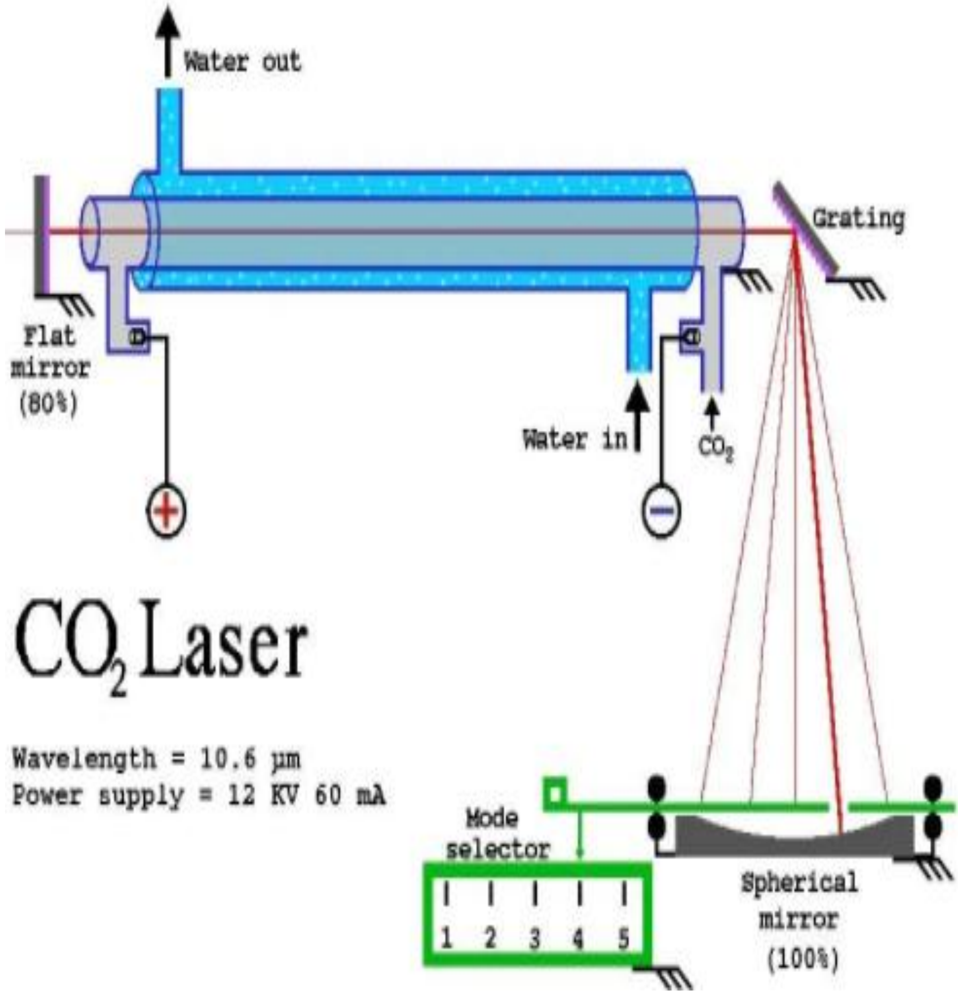
CO_2 laser
(gas laser)

02

Nd-YAG
(neodymium yitrium-aluminum garnet)
solid state type of laser

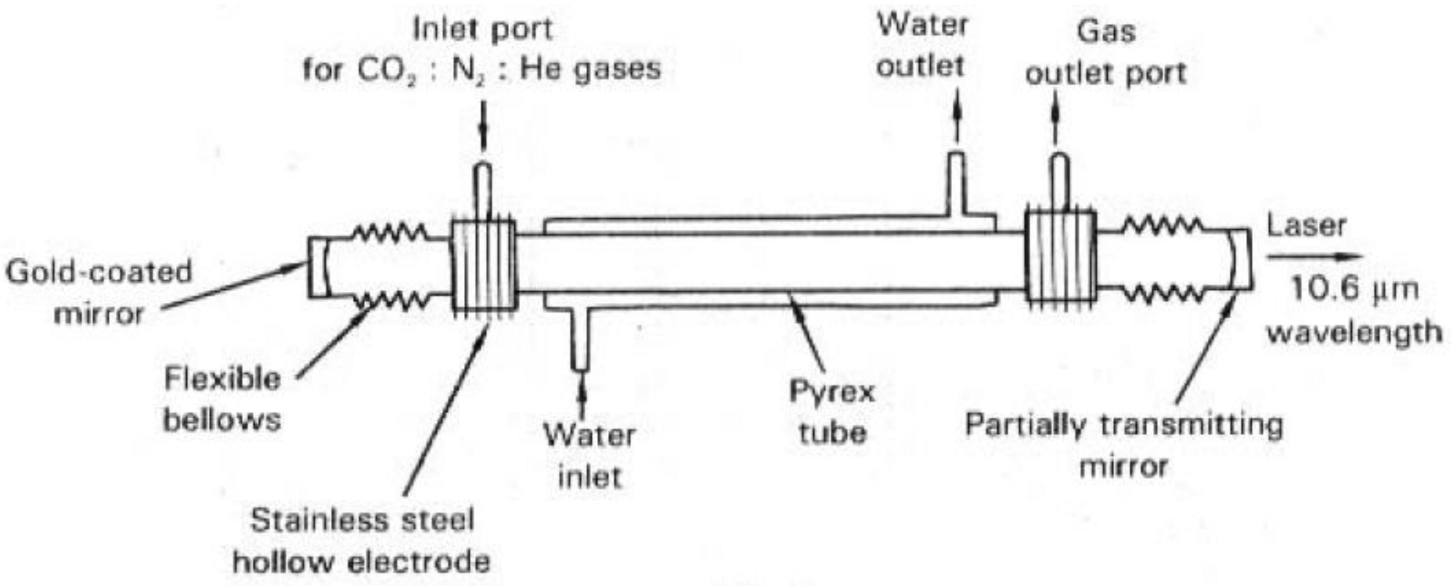
CO_2 Laser

- CO_2 lasers are commonly pumped (producing active atoms) by passing a current through the gas mix (DC-excited) or using radio frequency energy (RF-excited).
- A high voltage is applied at both the ends of the laser that leads to discharge and formation of gas plasma.
- Energy of this discharge leads to population inversion and lasing action.
- At the left end of the laser there is a 100% reflector, and on the right end, a partial reflector.



CO_2 Laser

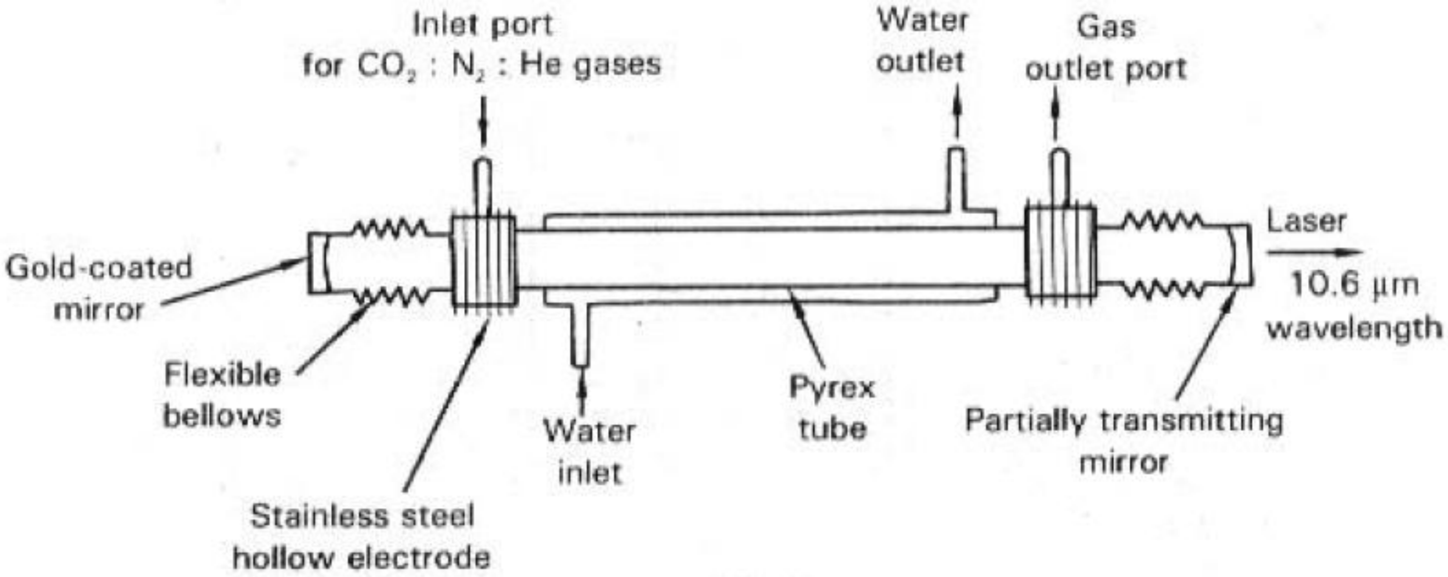
- The 100% reflector redirects the photons inside the gas tube, while the partial reflector allows a part of the laser beam that can be used for material processing.
- Typically the laser tube is cooled externally as well. Due to its high power efficiency, CO2 laser is used for cutting thick metals, and also in welding process



CO_2 laser

CO_2 Laser

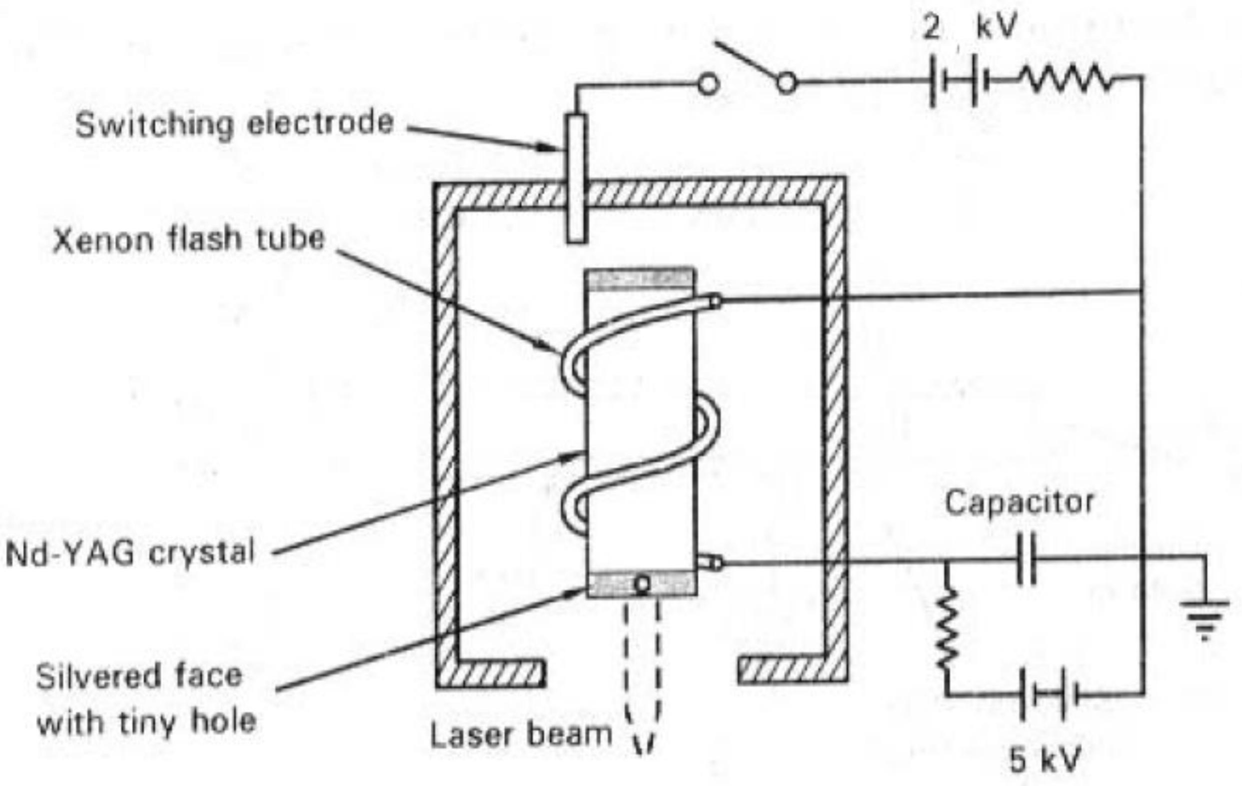
- In a CO_2laser, a mixture of CO_2, N, and He are continuously circulated through the gas tube so as to minimize consumption of gases.
- CO2 acts as the main lasing medium, whereas nitrogen helps in sustaining the gas plasma, and helium helps in cooling the high temperature gases.



CO_2 laser

Nd-YAG (neodymium yitrium-aluminum garnet)

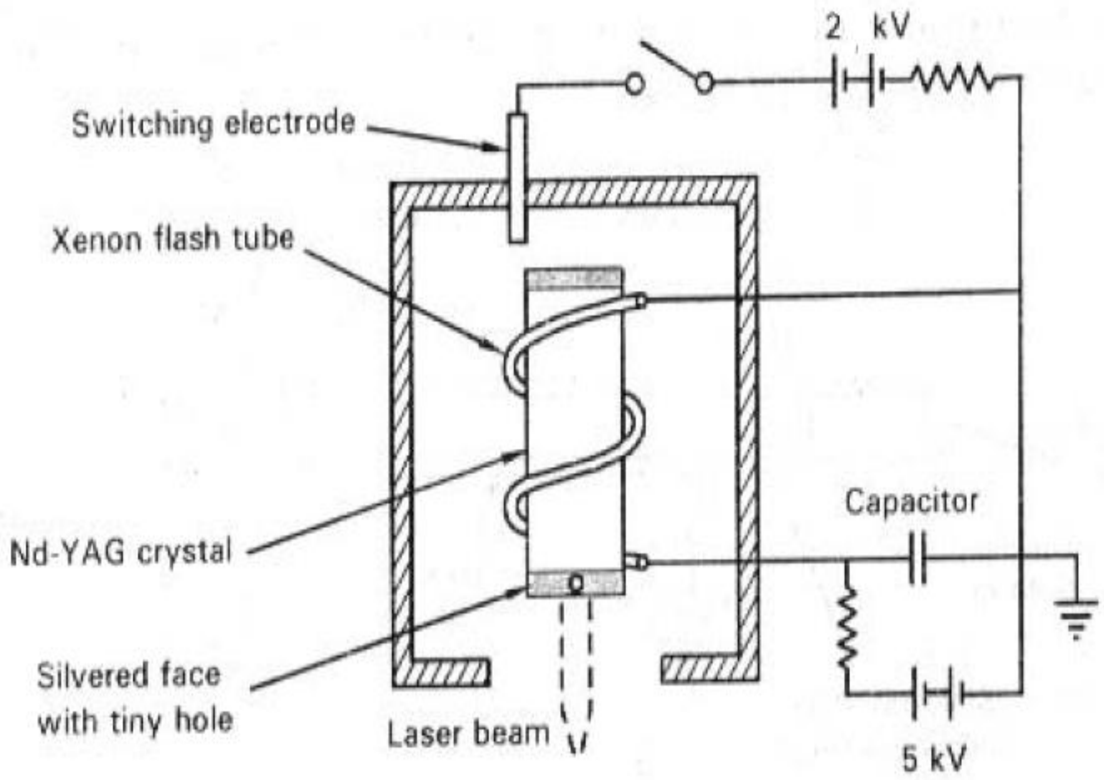
- Nd-YAG is a crystal that is used as a lasing medium for solid-state lasers.
- Nd-YAG laser is pumped using xenon flash tube of helical form. The lasing material (crystal) is at the focal plane of the flash tube. The flash tube is operated in pulsed mode by charging and discharging of the capacitor.
- Nd-YAG lasers produce infrared light at a wavelength of 1.064 micrometers.



Nd-YAG laser

Nd-YAG (neodymium yitrium-aluminum garnet)

- Higher dopant concentration is used for pulsed lasers; lower concentration is suitable for continuous wave lasers.
- Nd-YAG Laser is not as powerful as a CO_2 laser, However, a YAG laser can drill a hole to a depth of six times the diameter of its beam.
- Besides machining and welding operations, industries commonly employ YAG lasers for etching, engraving and marking operations.



Nd-YAG laser

PROCESS PARAMETERS of LBM

- Power density and laser beam-workpiece interaction time are the most important variables determining whether the beam will weld, cut, mark or heat treat.
- For rapid heating of a surface without melting, a highly focused beam producing power densities of only 1.5×10^2 to 1.5×10^4 W/cm² is used.
- If melting is desired, as in the case of welding or cladding applications, power densities ranging from 1.5×10^4 to 1.5×10^5 W/cm² is used.
- Cutting and drilling action will occur for power densities ranging from 1.5×10^6 to 1.5×10^8 W/cm²

Advantages of LBM

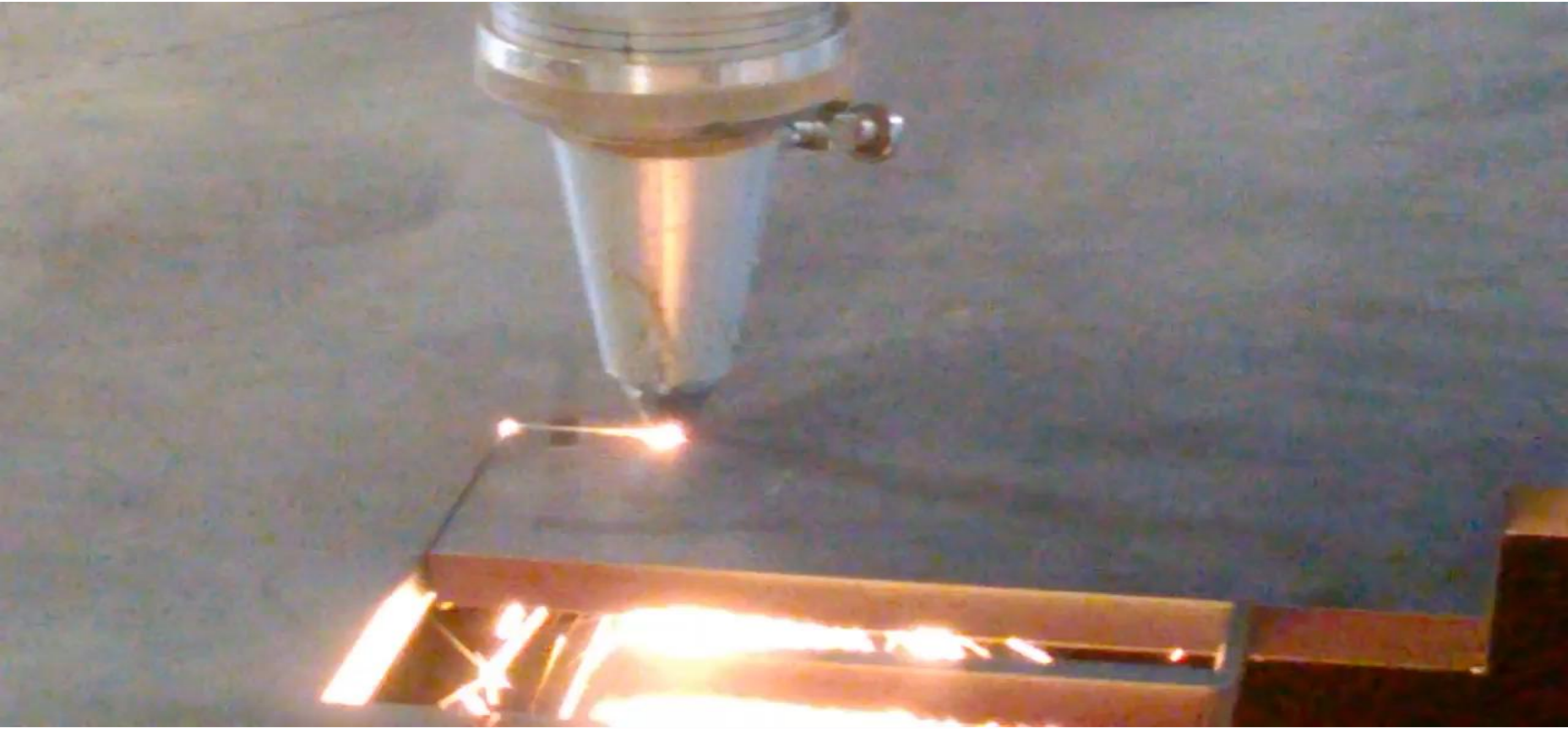
- Any material, including non-metals, and irrespective of their hardness and brittleness can be machined by laser
- Apart from cutting, drilling and welding materials, lasers can also be used for marking, scribing heat-treating of surfaces and selectively clad materials.
- The process can be easily automated.
- It can remove material in very small amounts.
- Laser beam machining is a force-less machining process. This allows very thin and fragile parts to be easily cut.
- Operating cost is low.
- Machining is extremely rapid and the set-up times are economical.

Limitations of LBM

- High equipment cost.
- Low thermal efficiency.
- Low metal removal rates.
- Process is limited to thin parts.
- High reflectivity materials are difficult to machine.
- Difficult to drill exact round holes. Tapers are nominally encountered during drilling.
- A blind hole of precise depth is difficult to achieve with laser beam.
- The thickness of the material that can be laser drilled is mm.

Applications of LBM

- The laser beam machining is mostly used in automobile, aerospace, shipbuilding, electronics, steel and medical industries for machining complex parts with precision.
- In heavy manufacturing industries, it is used or drilling and cladding, seam and spot welding among others.
- In light manufacturing industries, it is used for engraving and drilling other metals.
- In the electronic industry, it is used for skiving (to join two ends) of circuits and wire stripping.
- In medical industry, it is used for hair removal and cosmetic surgery.



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ELECTRON BEAM MACHINING (EBM)

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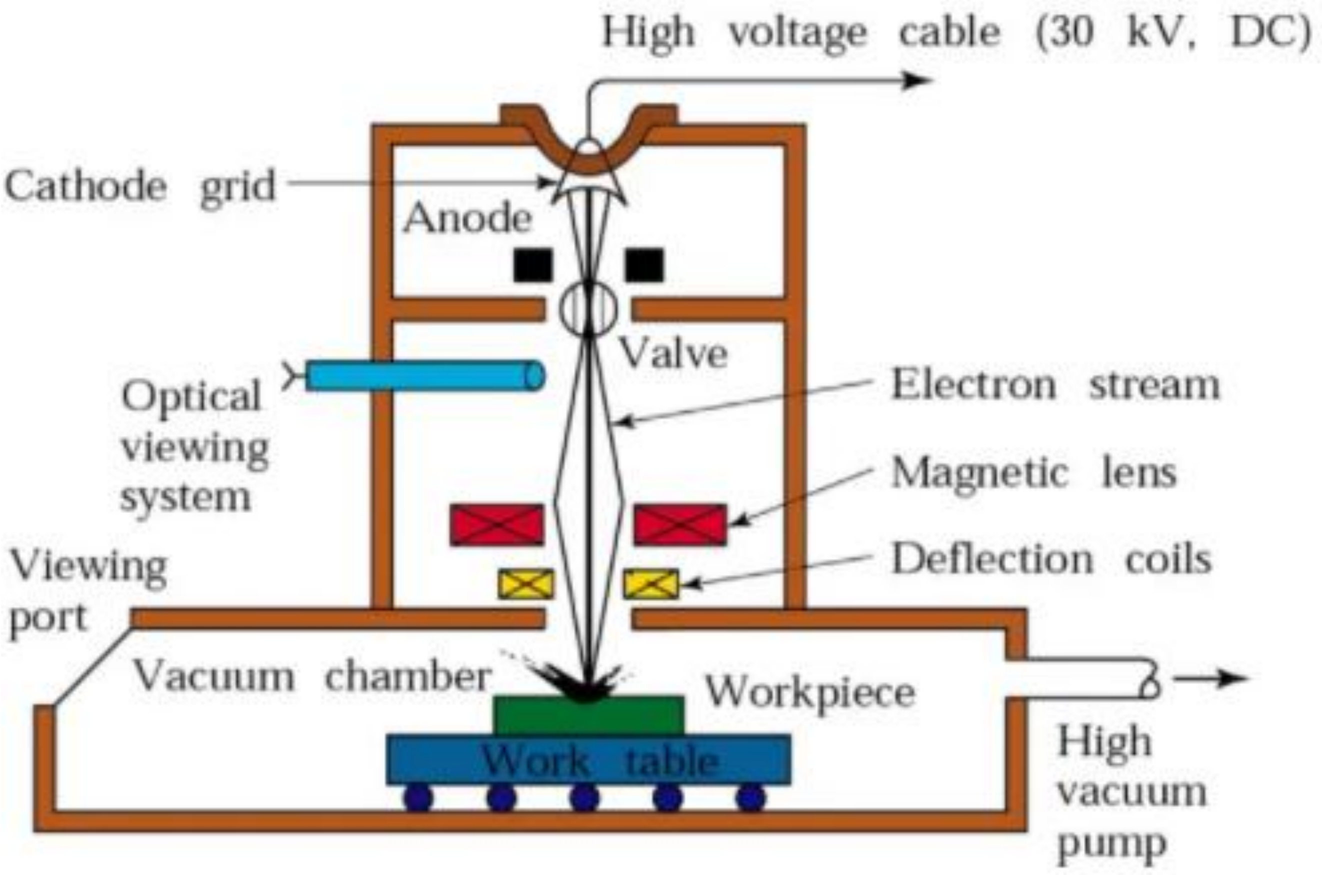
Principle of Electron Beam Machining (LBM)

- Electron Bearn is a controlled stream of electrons (negatively charged particles) that are generated and accelerated to move at between 30-70% the speed of light, providing the energy to heat and melt the metal.
- A heated tungsten filament is used to emit the electrons.

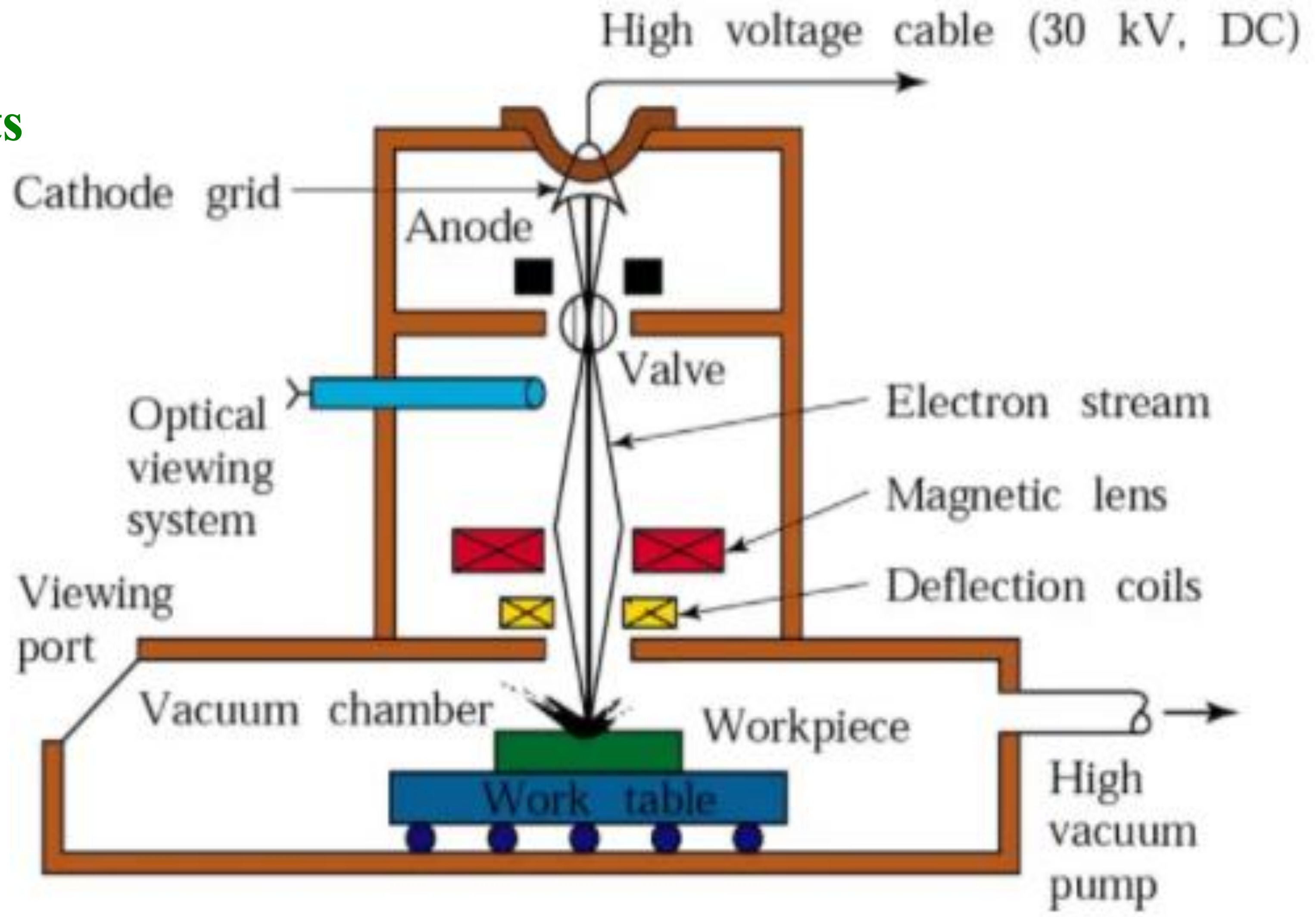
Principle of Electron Beam Machining (EBM)

- In electron beam machining, the stream of electrons (electron beam) generated is directed against a precisely limited area of the workpiece; on impact the kinetic energy of the electrons is converted into thermal energy that melts and vaporizes the material to be remoted, thereby forming holes or cuts.
- The process is performed in a vacuum chamber, as the electrons would lose energy by collision with the air molecules in atmosphere.



Equipment of Electron Beam Machining

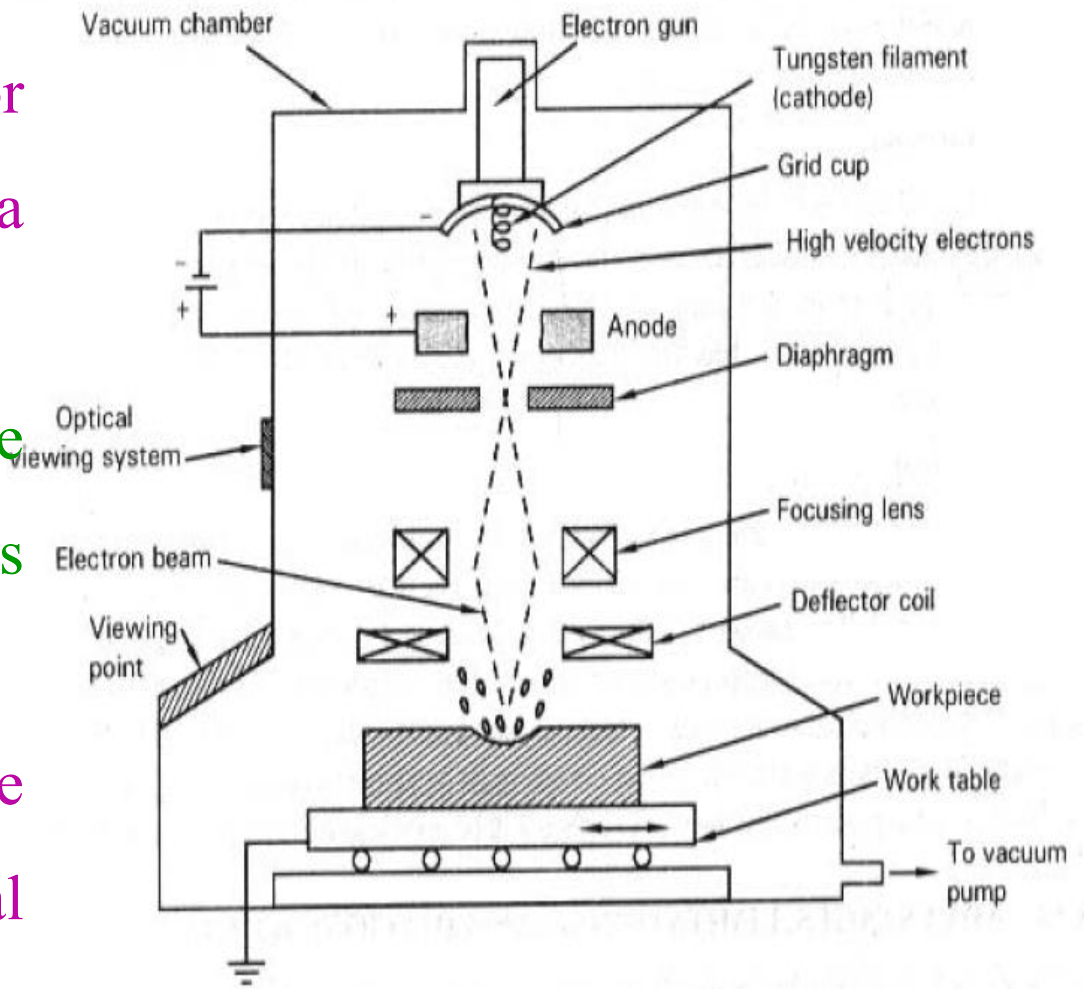
- A typical EBM equipment consists of the following:
  1. Electron Beam Gun
  2. Magnetic Deflection Coil
  3. Vacuum Chamber



Equipment of Electron Beam Machining

1. Electron Beam Gun

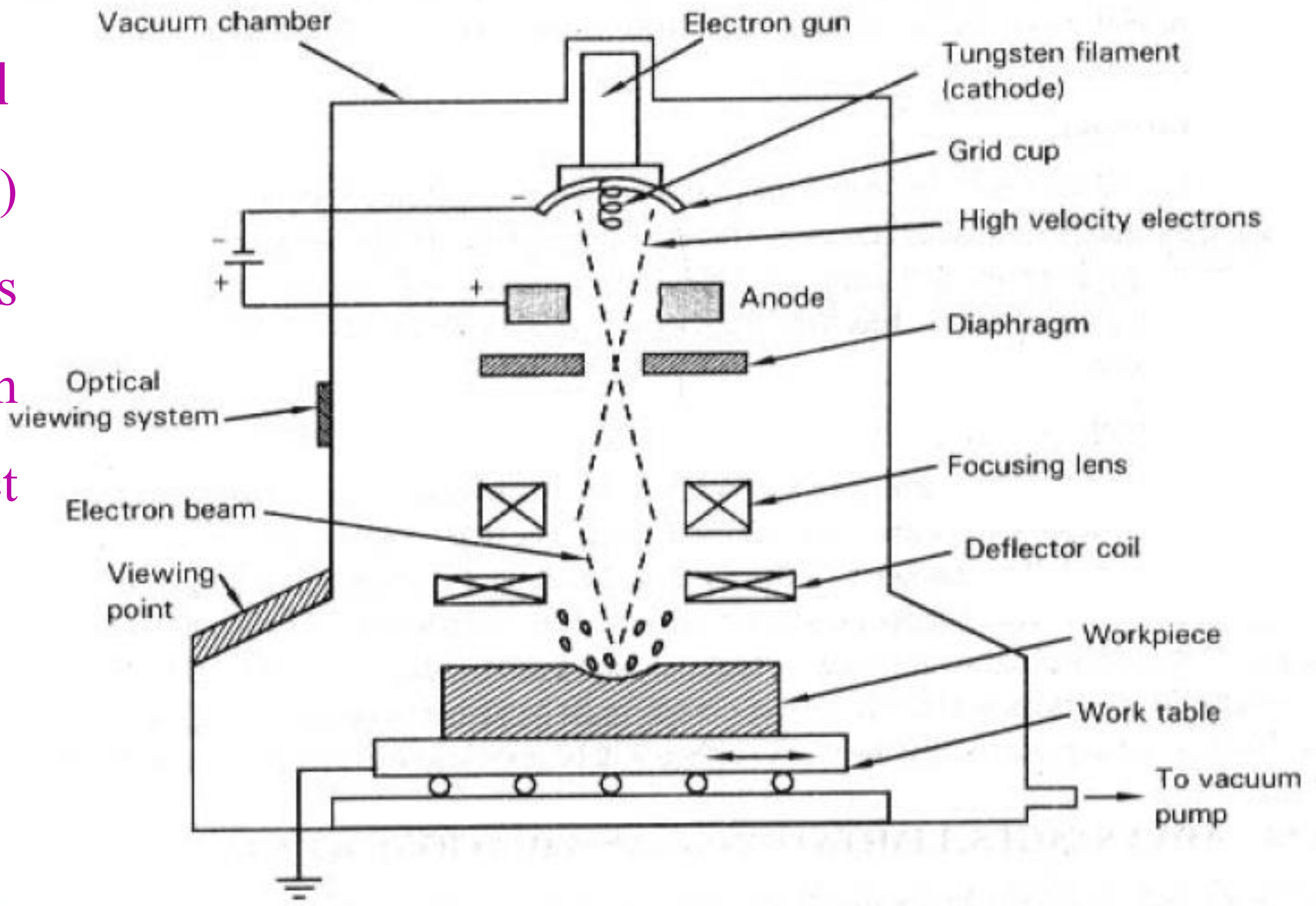
- The electron gun, which is mainly responsible for emission of electrons, consists of three parts: a tungsten filament, grid cup, and anode.
- The tungsten filament is connected to the negative terminal (cathode) of the power supply and is acts as a source for electrons.
- The grid cup is negatively biased with respect to the filament. The anode part is kept at ground potential and through it, the high velocity electrons passes



Equipment of Electron Beam Machining

2. Magnetic deflection coil

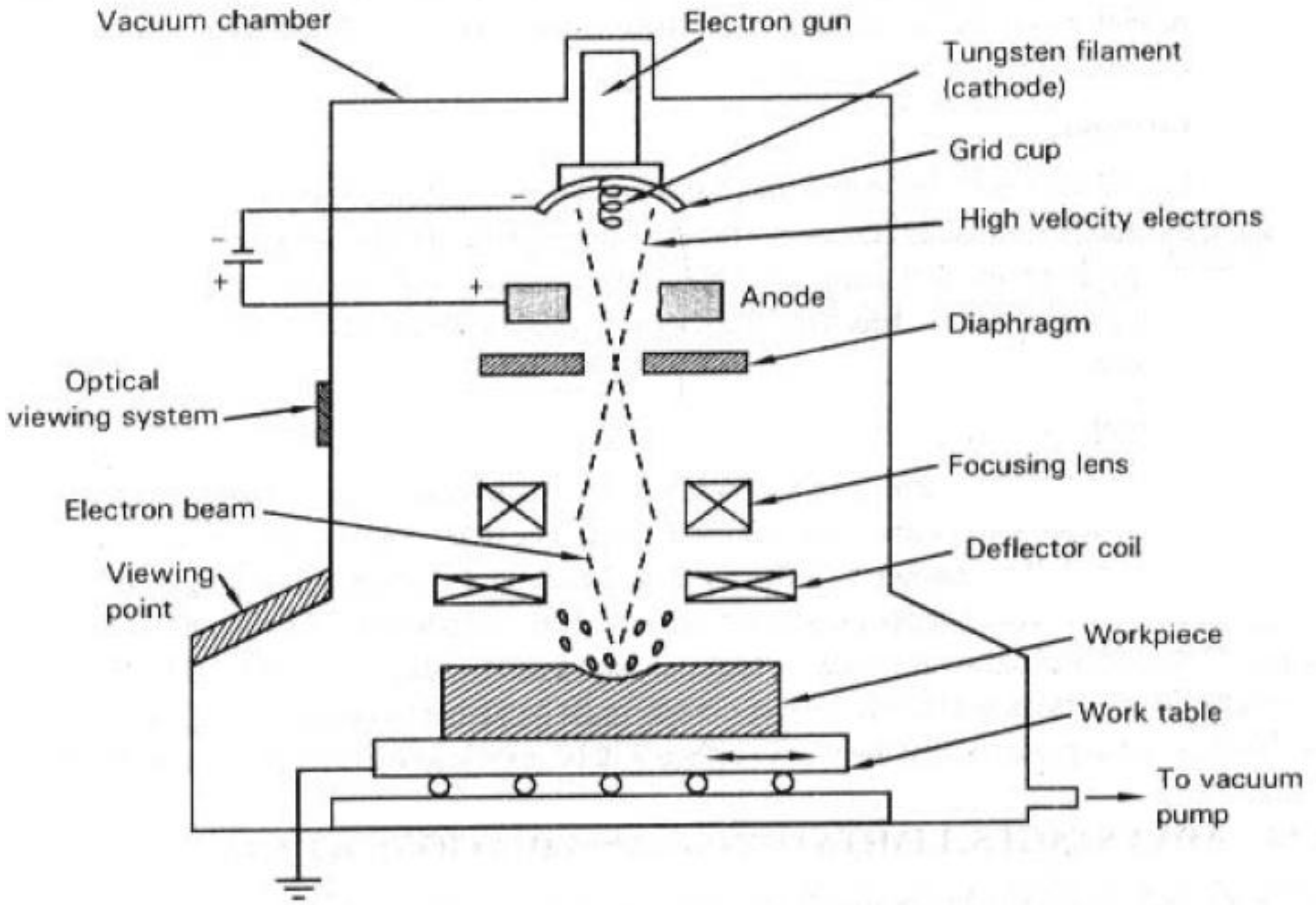
- A magnetic deflection coil (lens) fitted below the electron gun is used to make the electron beam circular in cross-section and deflect it anywhere on the work surface.



Equipment of Electron Beam Machining

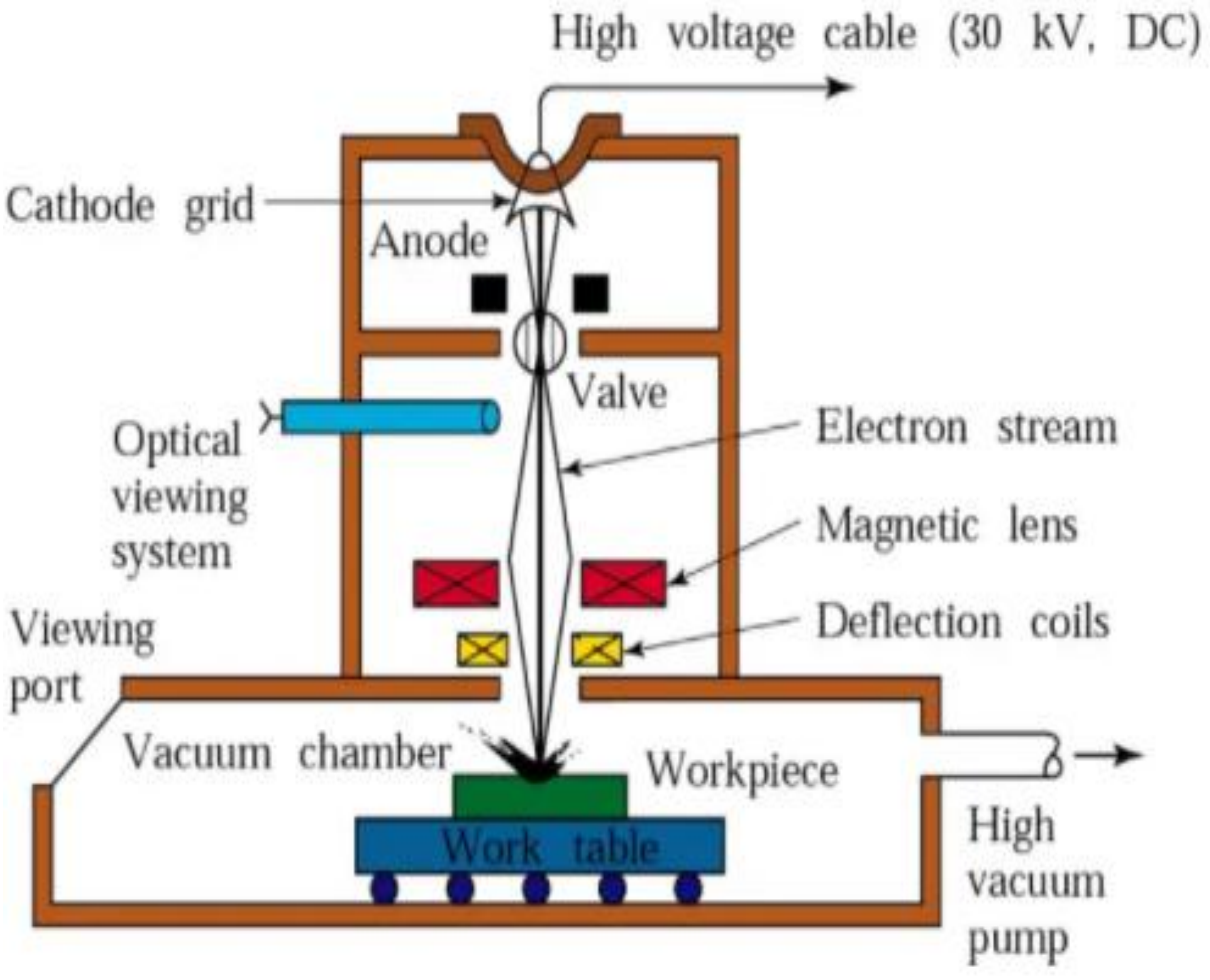
3. Vacuum chamber

- The vacuum chamber encloses all the parts, and is required for following reasons:
  - The emitter (filament) would rapidly oxidize when incandescent and
  - The electrons would lose energy by collision with air molecules in the atmosphere.



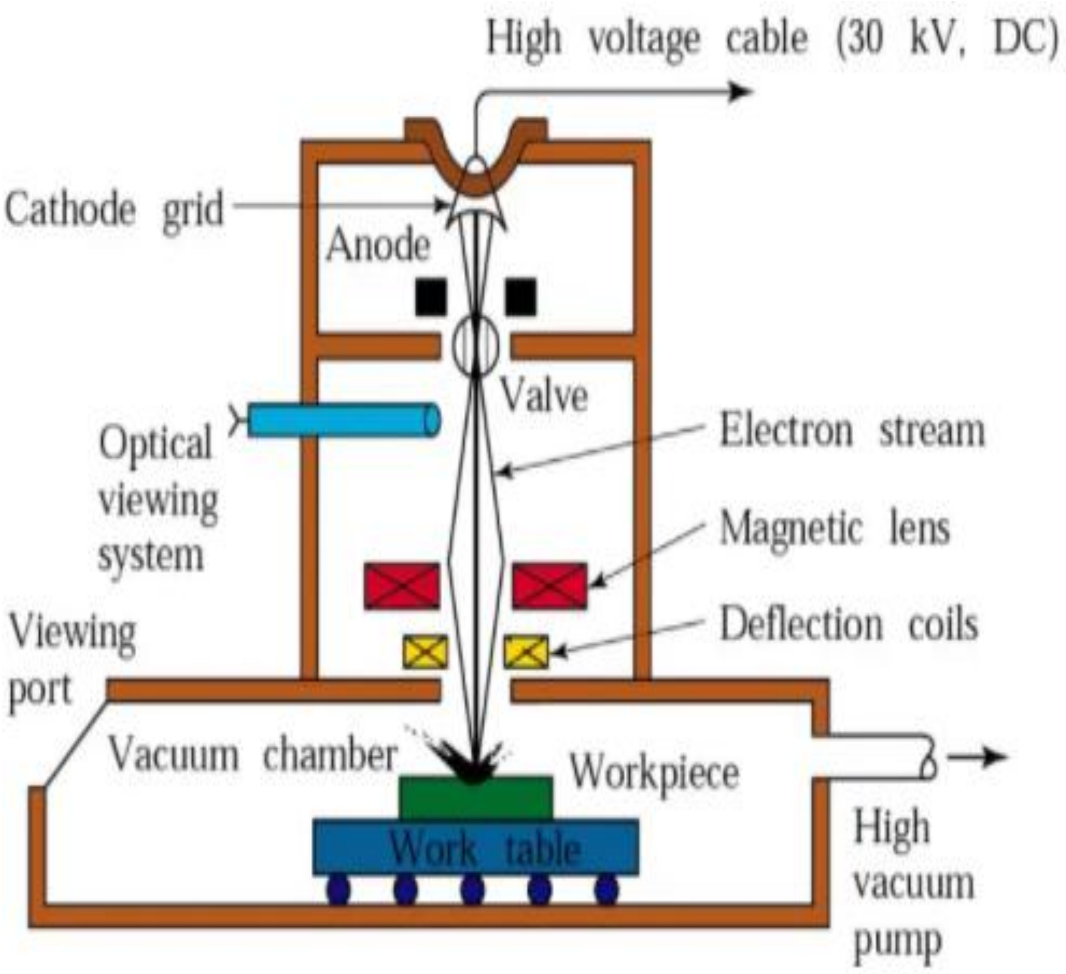
EBM Operation

- The tungsten filament is electrically heated in vacuum to about 2500°C, due to which a cloud of electrons are emitted by the filament.
- The electrons are guided by the grid cup to travel downwards, towards the anode. The flow of electrons is controlled by the negative bias applied to the grid cup.
- The electrons passing through the anode are accelerated to achieve as high a velocity as around 2/3 of light.



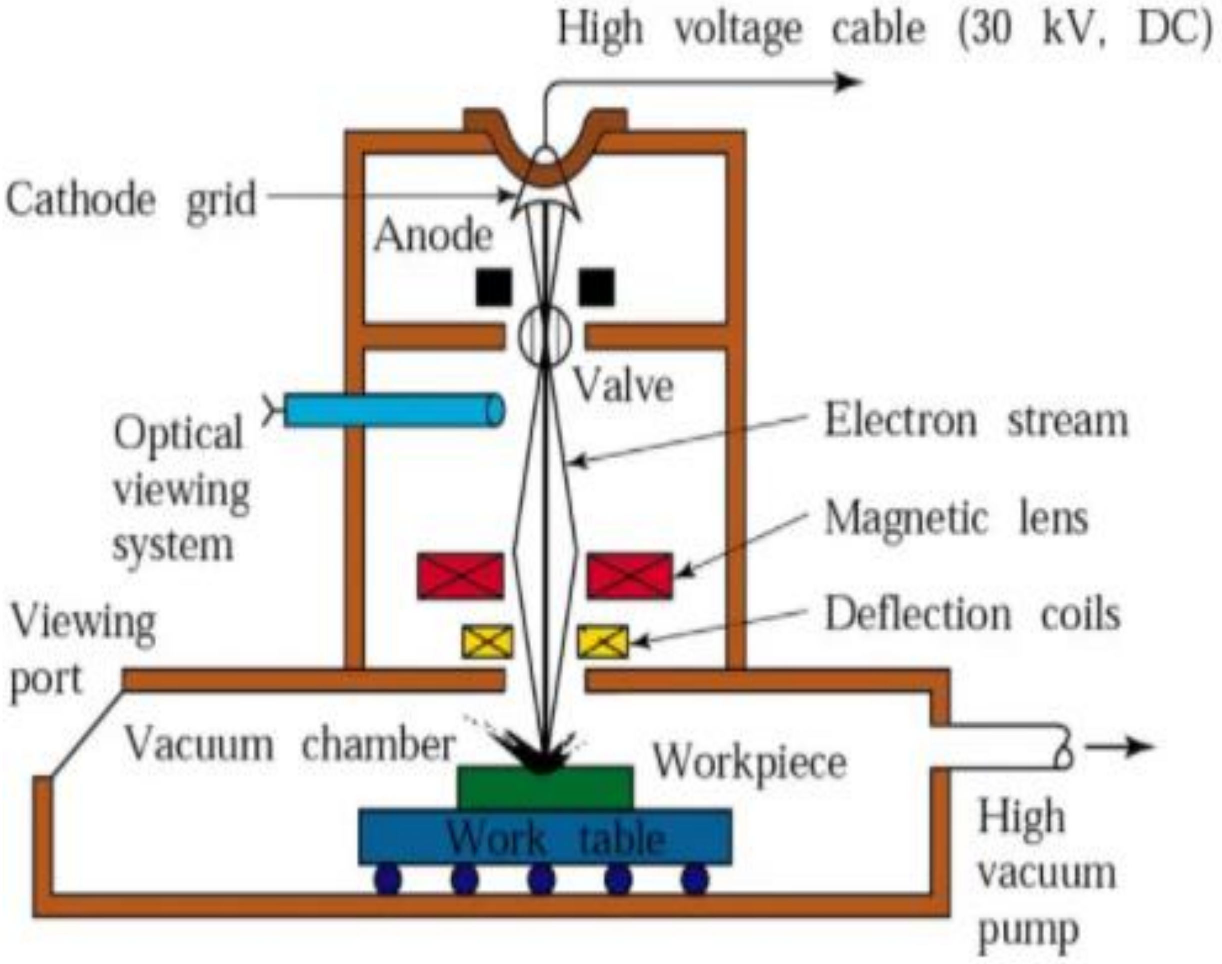
EBM Operation

- This high velocity stream of electrons are collected into a concentrated beam by means of diaphragm and focusing lens, and further directed towards the workpiece with the help of magnetic forces resulting from the deflector coils.
- The high velocity beam of electrons impinges on the workpiece where its kinetic energy is converted into heat energy.
- The concentrated heat raises the temperature of the workpiece material to its melting point, and vaporizes a small amount of it, resulting in removal of metal from the workpiece.



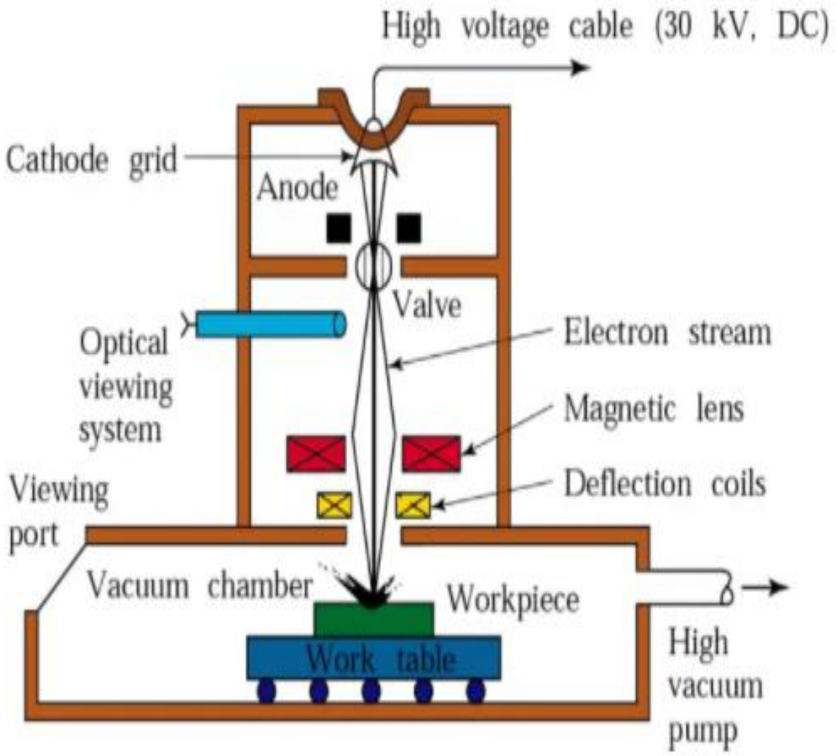
EBM Operation

- The table on which the workpiece is mounted can be traversed to feed the workpiece as needed.
- Alternately, by focusing and turning off the beam in a specific direction, the cutting process can be continued till the desired profile is achieved.
- A suitable viewing device is usually incorporated so as to enable the operator to observe and control the progress of the machining operation,



Mechanism of Material Removal in EBM

- In electron beam machining, the electrons impinge on the worksurface with velocities exceeding one-half the speed of light; their kinetic energy is transformed into thermal energy (heat energy).
- The focused beam penetrates the workpiece and the mechanisms involved is complex.
- However, it has been justified that the workpiece surface is melted by a combination of electron pressure and surface tension.
- The melted liquid metal on the worksurface is rapidly ejected and vaporized to effect material removal.



PROCESS PARAMETERS of EBM

1. Beam current

- Beam current is directly related to the number of electrons emitted by the cathode. Beam current can range from 200 A to 1 A.
- Increasing the beam current directly increases the energy per pulse delivered to the workpiece.
- Electron beam machining can generate pulse energies in excess of 120 Joules/pulse, a value which is 200 to 400% greater than that available in laser drilling system.
- This extreme high energy pulse helps the process to rapidly drill very deep and large-diameter holes.

PROCESS PARAMETERS of EBM

2. Pulse duration

- Pulse duration affects both the depth and the diameter of the hole.
- Increase in pulse duration (reducing the number of pulses) enhances the energy per pulse.
- High-energy pulses can machine larger and deeper holes on thick plates.
- Shorter pulse duration will allow less interaction time for thermal effects to materialize.
- Electron beam systems can generate pulses as short as 50 μsec or as long as 10 msec

PROCESS PARAMETERS of EBM

3. Lens current

- Lens current is used as the parameter to determine the working distance between the focal point and the electron beam gun.
- It also determines the spot size of the focused part of the beam on the workpiece material. The diameter of the focused beam spot dictates the diameter of the hole produced.
- It must be noted that the power density must be higher to generate a high beam power, else heating and vaporization of the work surface will be poor leading to inefficient machining.

Advantages of EBM

- Any material, hard or soft, can be successfully machined.
- No tool wear problems
- Heat can be concentrated on a particular spot. Hence, effective machining.
- EBM does not apply any cutting forces on the workpiece material. Hence, simple work holding device is sufficient. This also helps to machine thin and fragile work parts
- Workpiece is not subjected to any physical or metallurgical damage.
- EBM can machine holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.

Limitations of EBM

- High investment cost
- Skilled operator is required for machining
- Vacuum requirement tend to limit the workpiece size and production rate. Also regular maintenance is required when using such a facility.
- Suitable for small and fine cuts only
- Low metal removal rate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