Lecture Unit 06

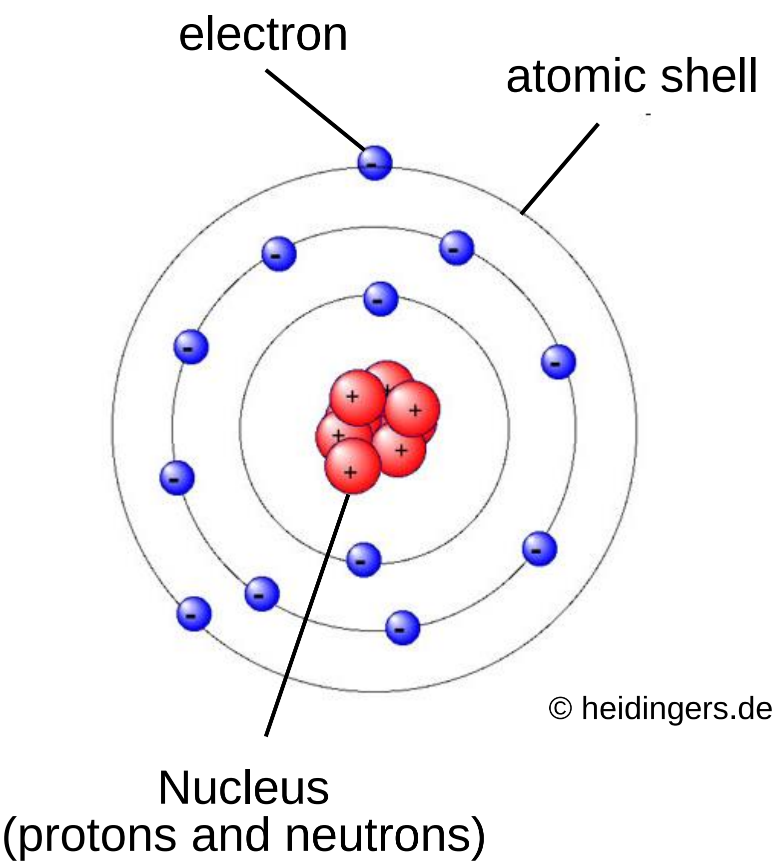
Beam Processing Tools
Electron Beam

Electron Beam Processing Technologies within DIN 8580

Primary Shaping	Forming	Cutting	Joining	Coating	Change of mat. prop
PBF-EB/M	Laser Bending	Water Jet Cutting	Electron Beam Welding	DED-LB/M	Hardening
PBF-LB/M		Laser Beam Cutting	Laser Beam Welding		VPP
DED-LB/M		Laser Beam Drilling			
		Electron Beam Drilling			

Structure of an Atom

- Basic elements of matter
- Smallest parts into which matter can be decomposed with chemical agents or mechanical forces
- Structure:
  - Atomic shell: consisting of electrons on orbits
  - Nucleus: consisting of protons and neutrons
- Various models: e. g. Bohr model

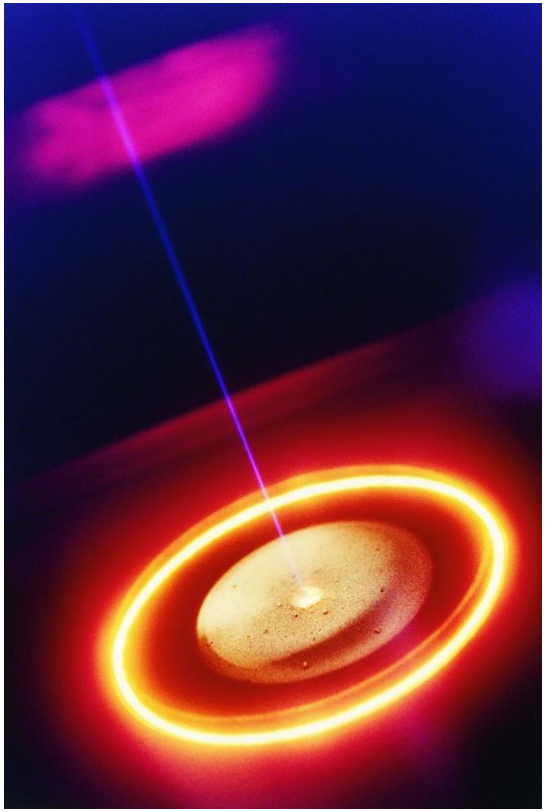


Electron Beam

Basics

Electrons travel straight in one direction

- Flow of electric charges (→ electric current)
- Identical charges → repulsion leads to divergence of the electron beam
- Compensation via electrostatic or magnetic focusing
- Guidance of electron beams via a deflection system



Live-Survey

What can be reduced by the vacuum in the process chamber?

a) spreading of the beam (divergence)
b) generation of X-Rays (bremsstrahlung)
c) direct evaporation of the workpiece (sublimation)

Result

Generation of Electron Beams

- Heating-up of cathode material

→ Emission of electrons (extraction from atomic shell)
→ Formation of an electron cloud

- Applying of a high voltage between cathode and anode (acceleration voltage)

→ Acceleration of the electrons

→ Kinetic energy

- In ambient air: collisions of the electrons with air molecules

→ Divergence of electron beam

→ Vacuum in the electron generation chamber necessary, and usually also in the working chamber where the workpiece is located

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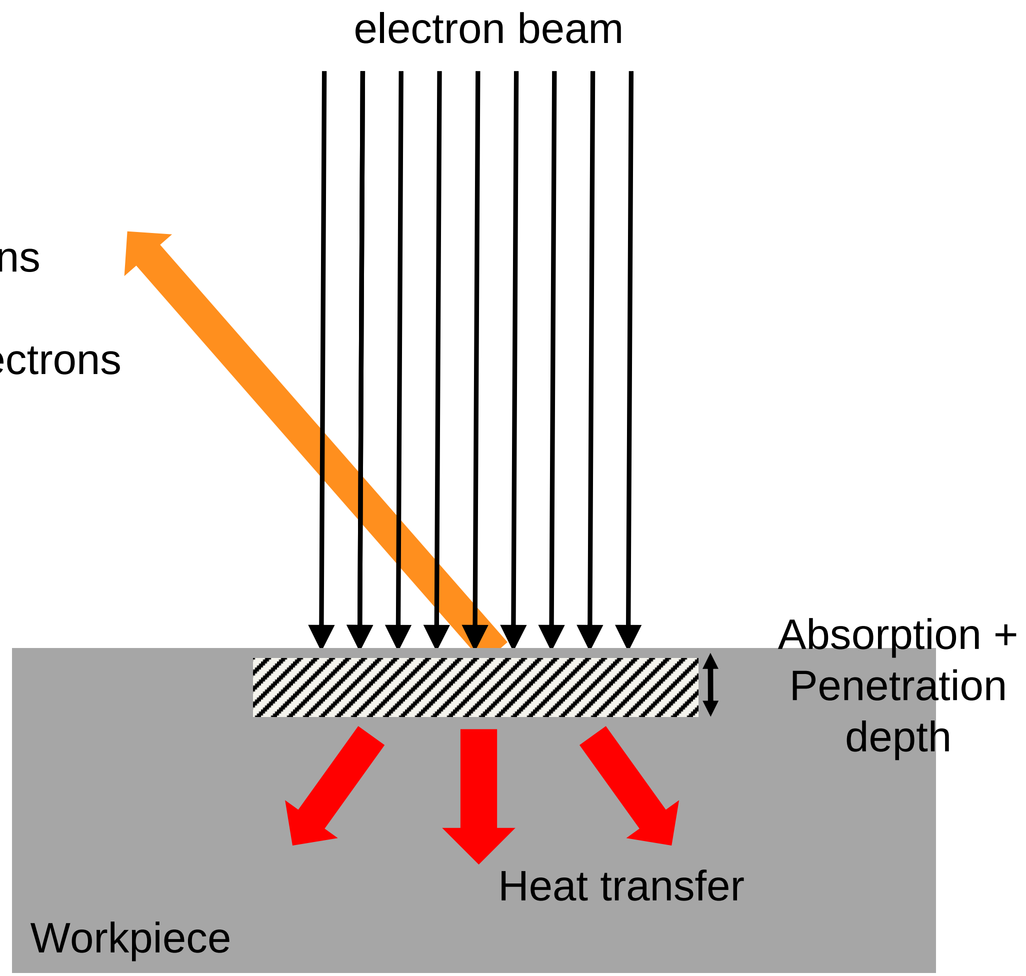
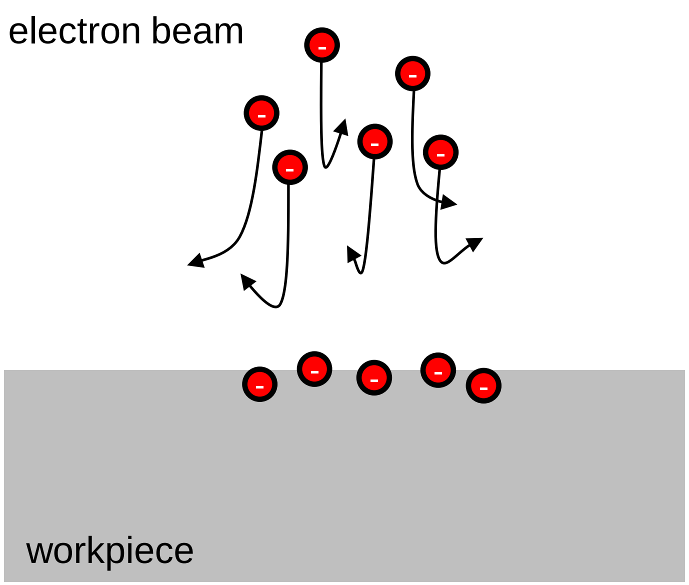
Energy Transfer into the Workpiece

Energy loss:
- Heat radiation
- Secondary electrons
- X-Rays
- Back-scattered electrons



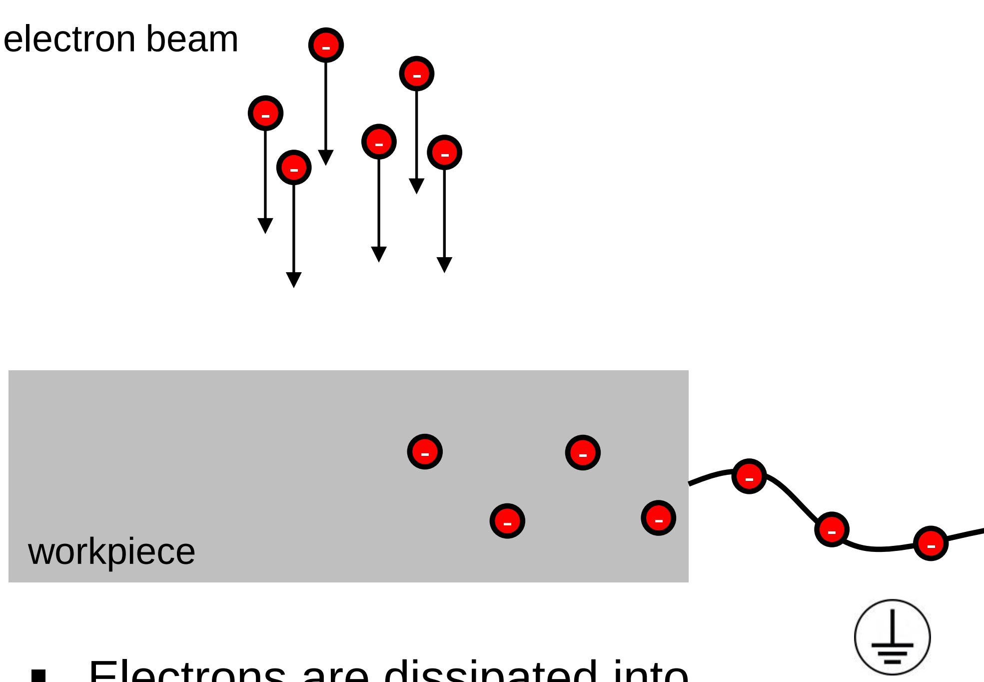
Electron Beam: Grounding of Workpiece

no grounding/conductivity:



- Electrons accumulate at surface
  → redirection of incoming electrons
- no efficient energy input possible

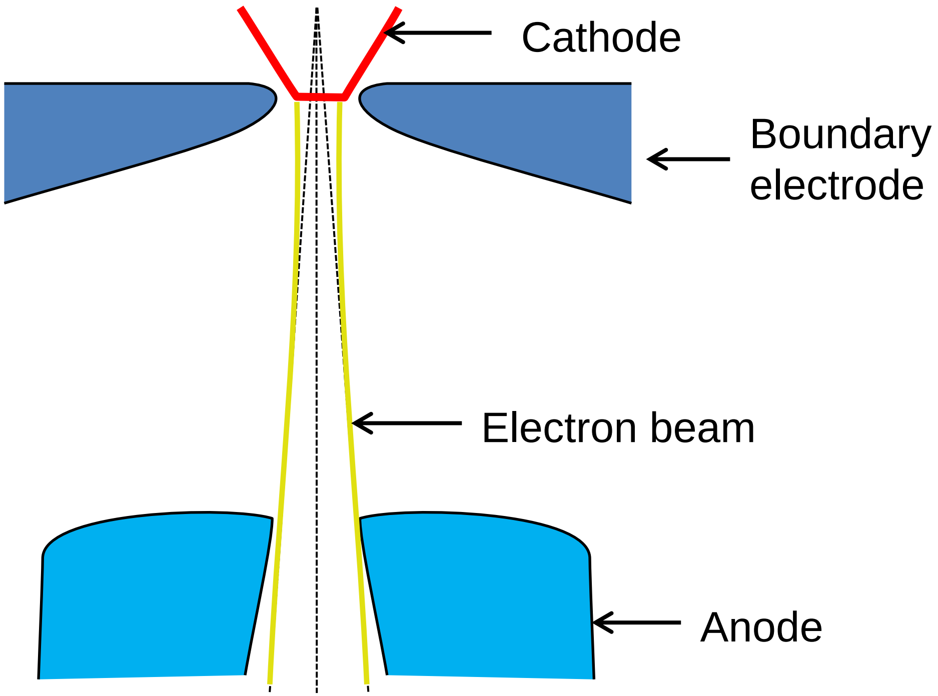
with grounding:



- Electrons are dissipated into ground
- High energy input possible

Schematics of a Diode Beam Generator

- Acceleration of the electrons due to voltage between anode and cathode
- Boundary electrode without electric field → beam shaping
- Very thin electron beam waist
- Cathode current → Controlling of beam current



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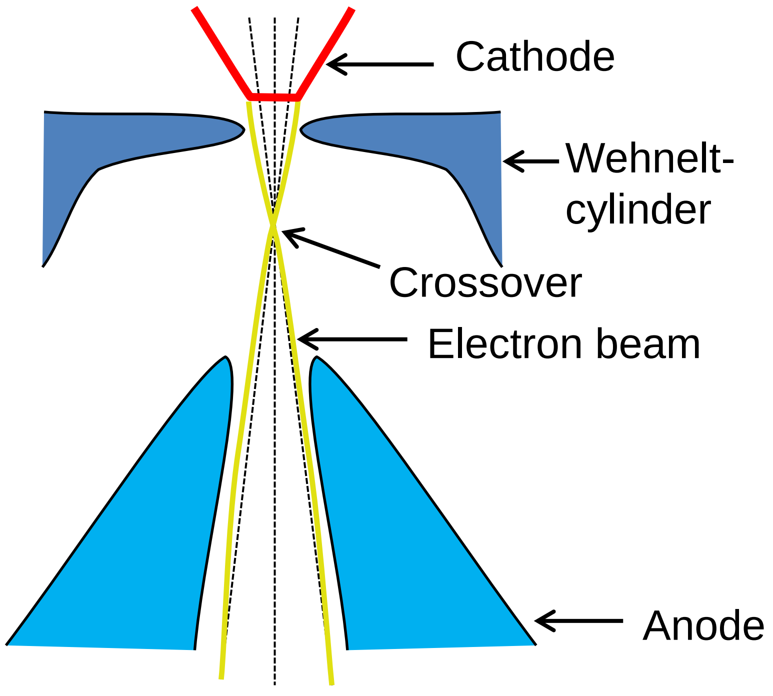
→ Focused electron beam

Schematics of a Triode Beam Generator

- Applying a voltage at the boundary electrode (Wehnelt cylinder)
- Controlling the electron cloud
- First focus of the electron beam between cathode and anode (crossover)
- Application: e. g. if high accuracy beam controlling is required



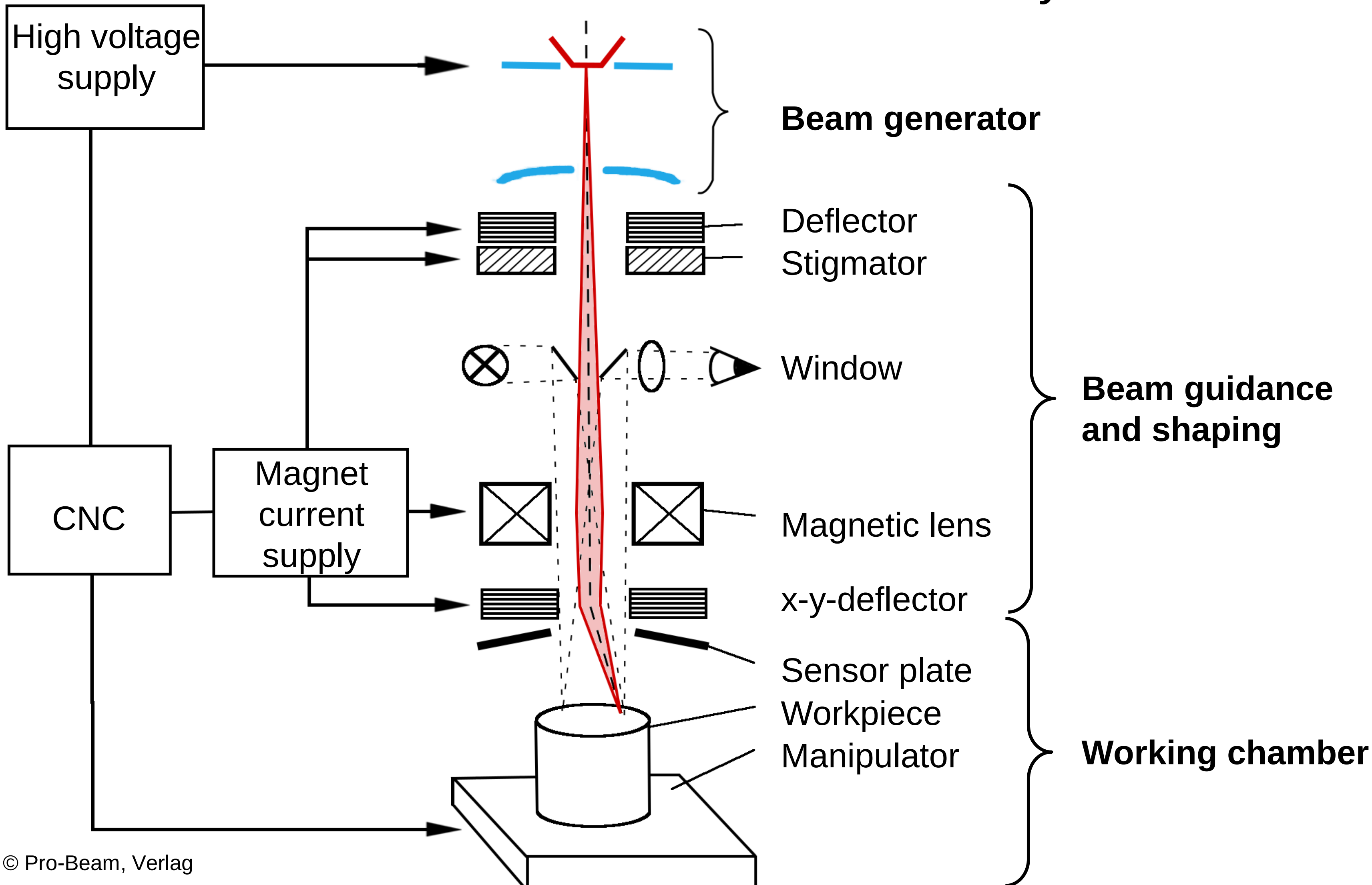
By what can an electron beam be deflected?

a) electric field
b) magnetic field
c) both

Result

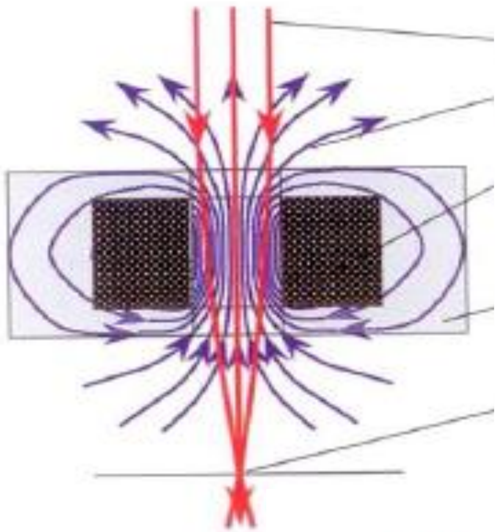
Electron Beam Generator

Schematics of an Electron Beam System

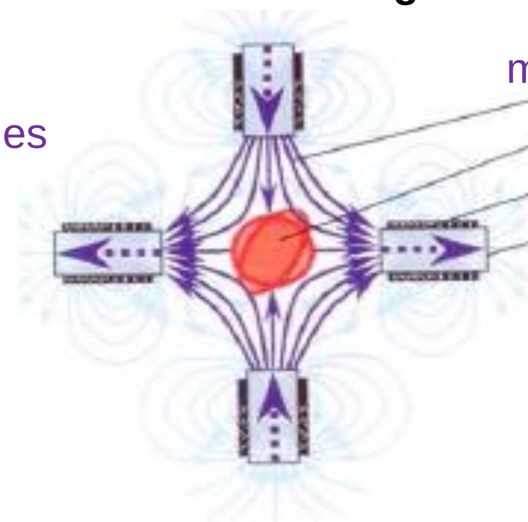


Focusing and Deflection of the Electron Beam

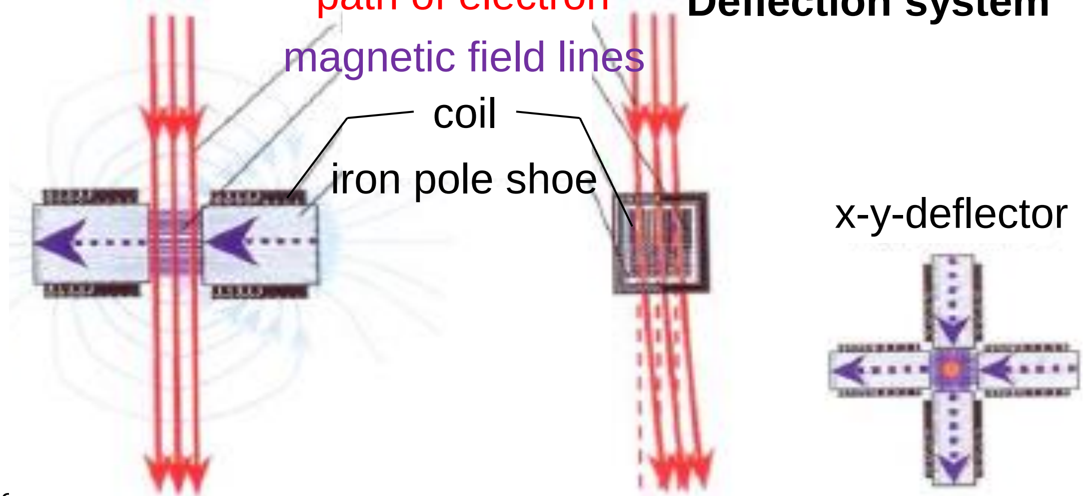
Electromagnetic lens



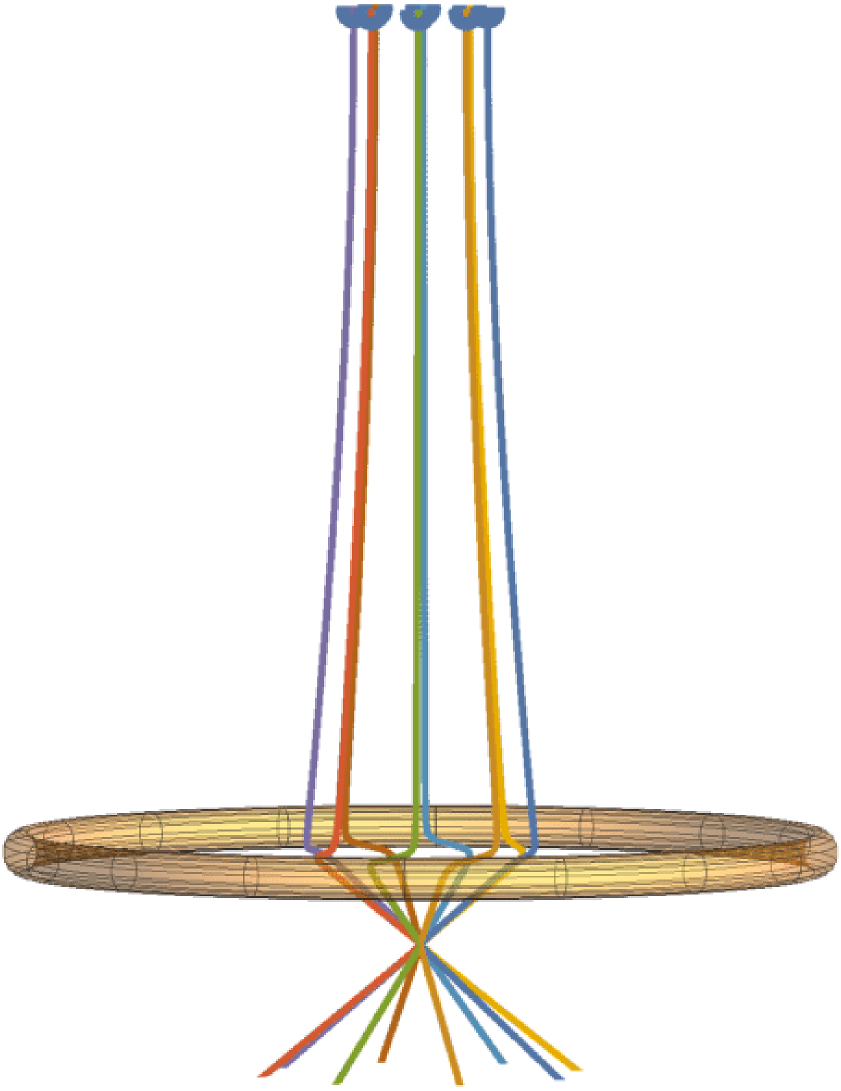
Stigmator



Deflection system



Focusing and Deflection of the Electron Beam



Fields of Application for the Electron Beam

Intensity W/cm²	Field of Application	Class of Material
10^2 - 10^3	Polymerization	Plastics
10^4 – 10^5	Annealing	Metals
10^5 – 10^6	Welding, Remelting	Metals
10^5 – 10^7	Perforating	Metals
10^7– 10^9	Drilling, Milling	Metals
10^8	Engraving	Metals
>10^8	Sublimation	Metals

After Klocke, F. Fertigungsverfahren

Advantages and Disadvantages of the Electron Beam

Advantages

- Low energy input into the workpiece due to high intensity
- Vacuum in the working chamber

  → No reactions with the atmosphere (no oxidation)

  → Protection of the melt from contamination
- Higher efficiency ~70% than laser based processes
- Large aspect ratio of the melt pool (deep penetration welding)

Disadvantages

- Processing of electrically conducting materials only
- Working distance depending on the quality of the vacuum
- High investment and operational costs (e. g. due to the permanent usage of vacuum pumps)
- Limited flexibility

  → Selection of the vacuum chamber size according to the part geometry
- Generation of X-rays → Shielding necessary

Live-Survey

Which threshold intensity is necessary to evaporate metallic materials?

a) ~10^6 W/cm²

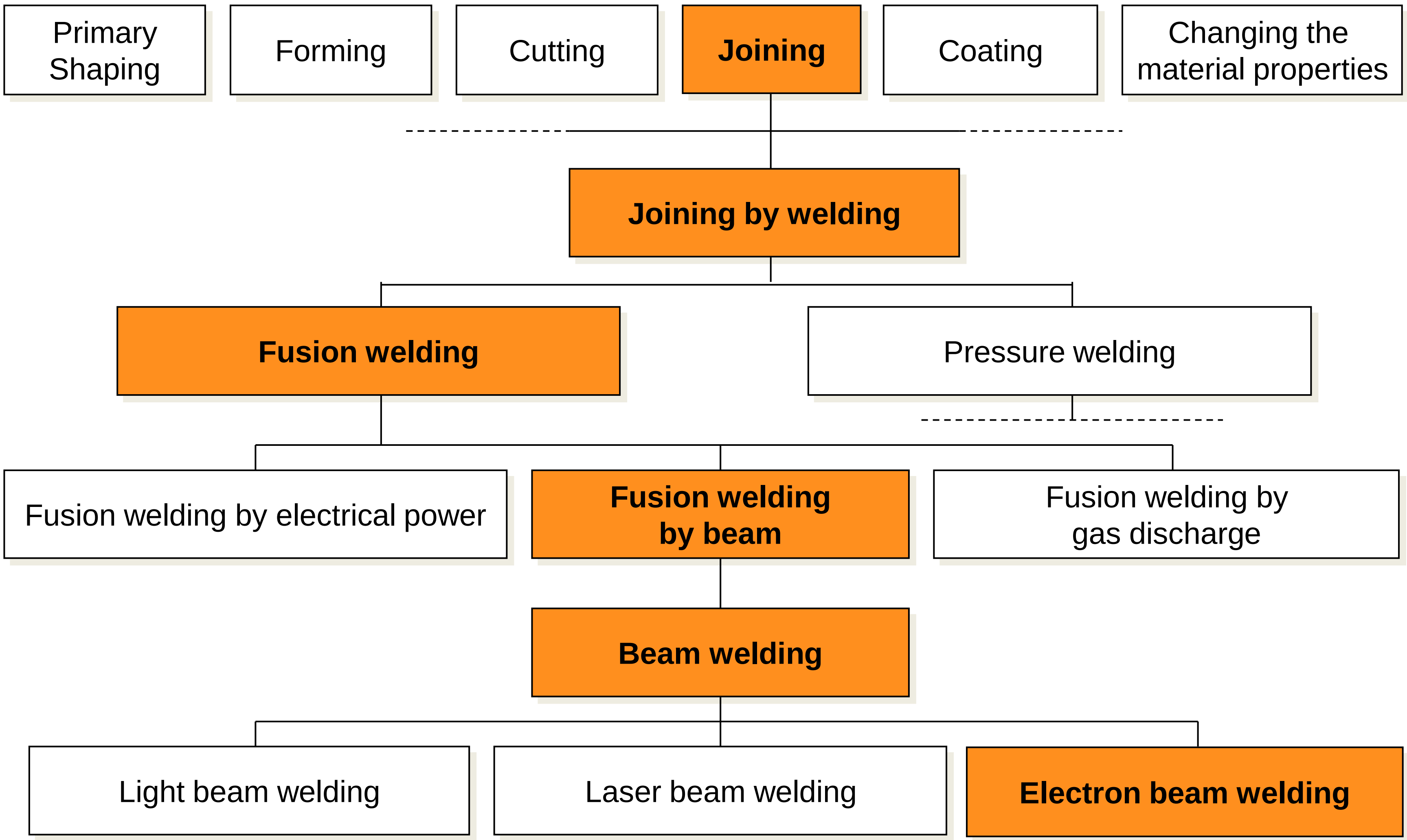
b) ~10^5 W/cm²

c) ~10^3 W/cm²

Result

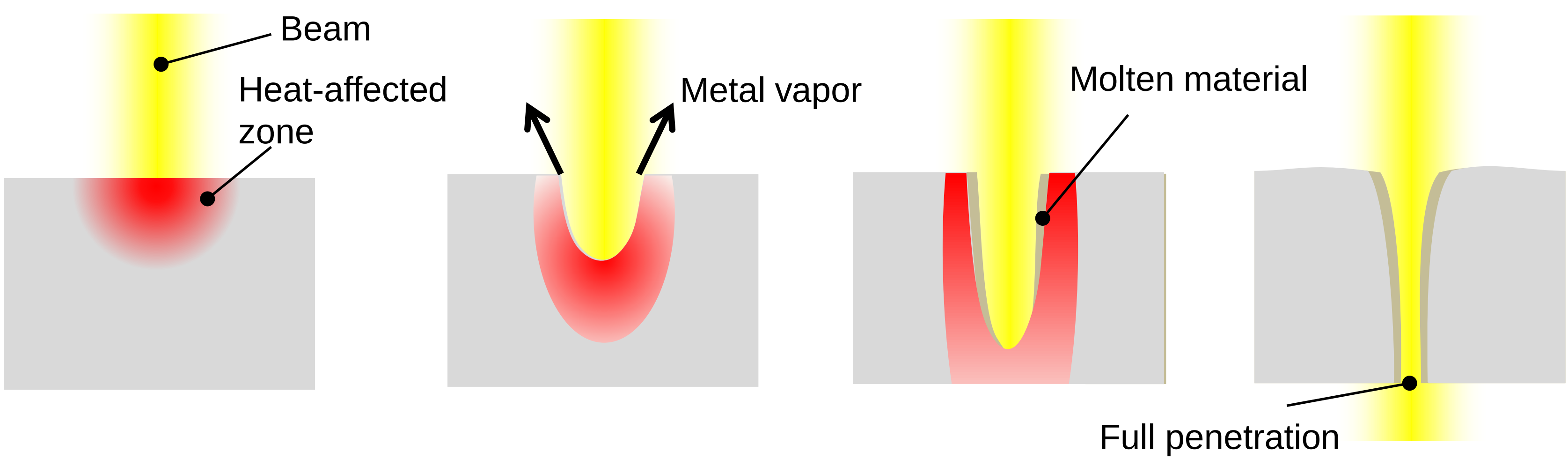
Electron Beam Welding

Classification of Electron Beam Welding according to DIN 8580 and 1910



Deep Penetration Welding

- Absorption of electron beam
- Melting of the material and rapid vaporization in the center of the beam
- Pressure of the vaporizing material displaces molten material and compensates the ambient pressure
  - → Keyhole evolves with high aspect ratio (depth to width) and surrounded by molten material
  - → Electron beam can further penetrate into the material
- Intensity > 10^6 W/cm² (Evaporation of metallic materials)
- Full penetration of the workpiece for sufficient energy input



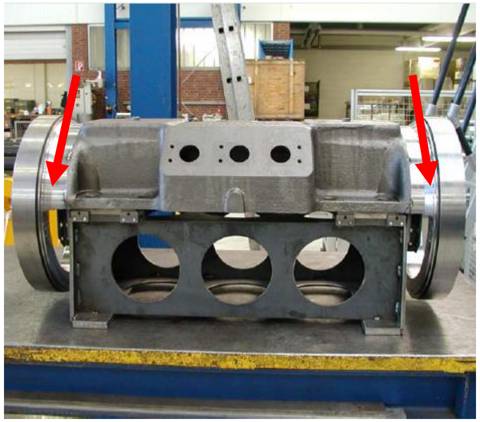
Applications of Electron Beam Welding (1)

Hollow drive shaft
Sports airplane

Membrane reservoir

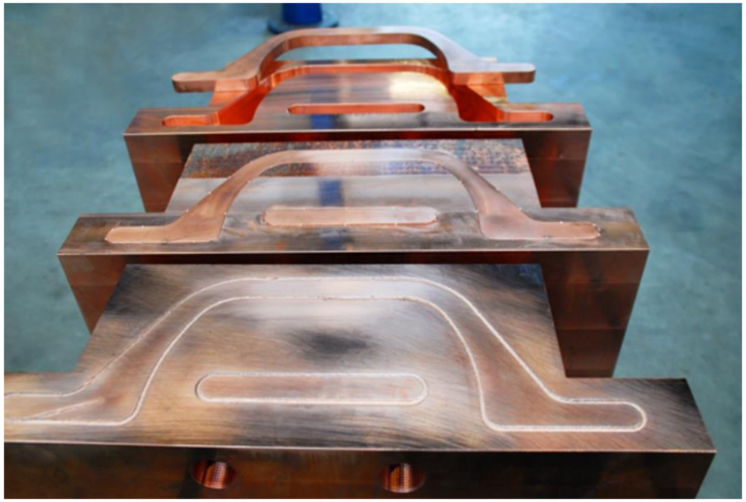
Gearbox components

Bearing housing of a wheel set
of electric locomotive, welded casting steel

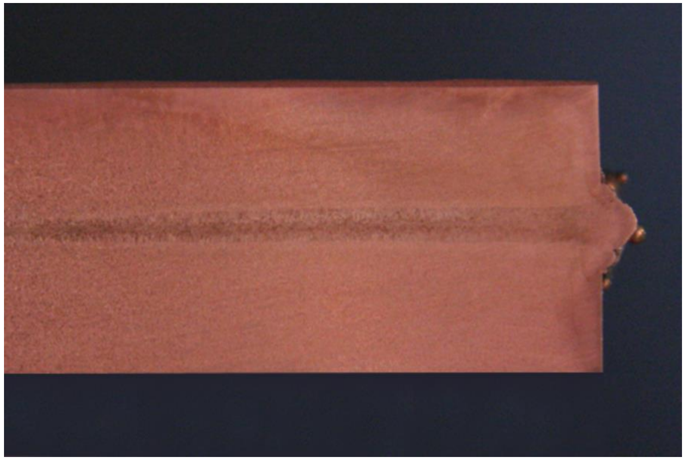


Applications of Electron Beam Welding (2)

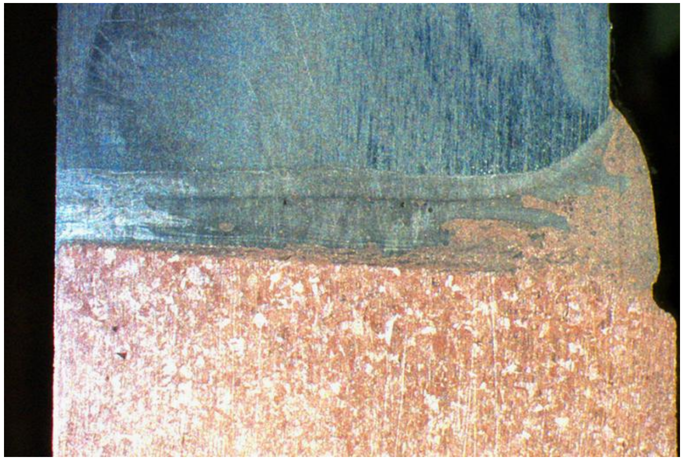
Copper mold for the steel industry



Copper pot



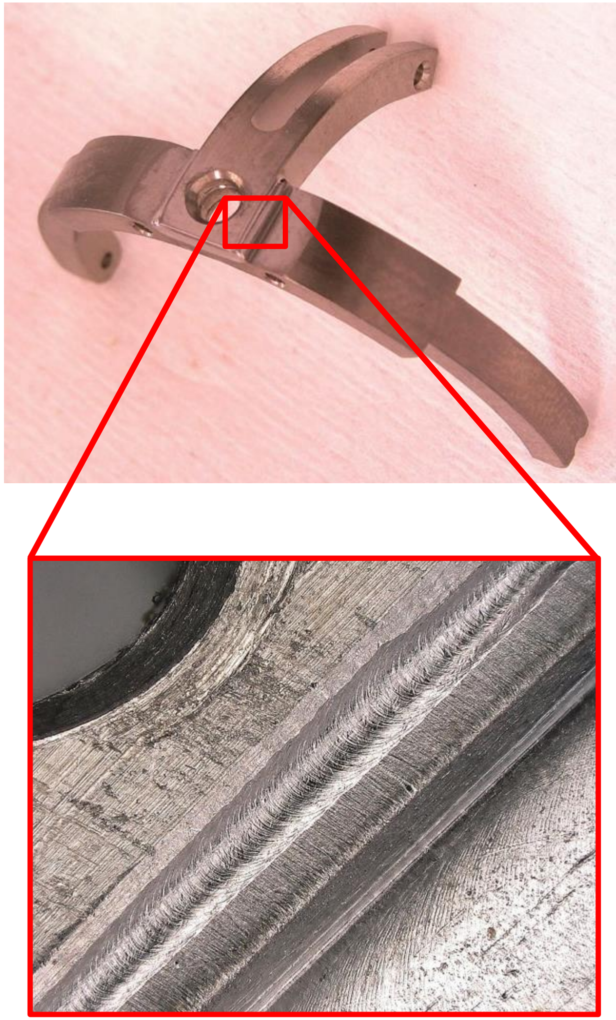
Cross section of the welding seam



Copper and stainless-steel welded joint

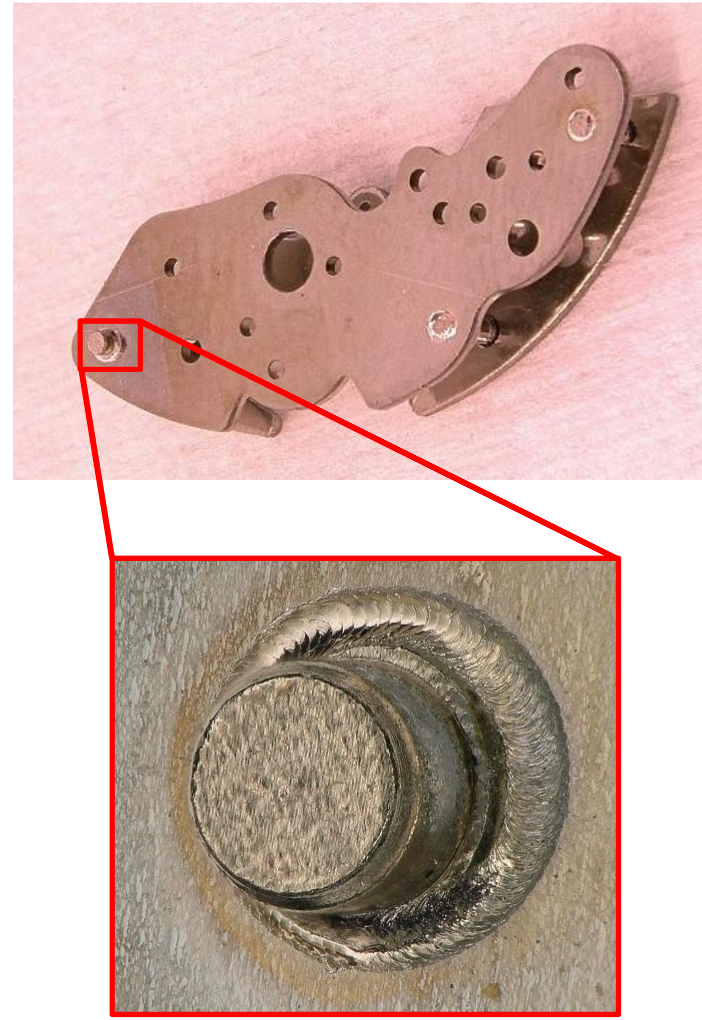
Applications of Electron Beam Welding (3)

Part of a SEM



Oxygen free welding seam
seam width approx. 288 µm

Part of wristwatch



Width of welding seam
< 150 µm

Advantages and Disadvantages of Electron Beam Welding

Advantages

- Very slim weld seams due to very high intensity compared to TIG or laser welding

  → Small heat-affected zone, minimum distortion
- Corrosion protection due to welding in vacuum
- High welding feed rates, up to 60 m/min (Laser welding: ~10 m/min)
- Welding of dissimilar materials
- Penetration depths of 0.03 mm to 300 mm possible
- Complex workpiece geometries with different wall thicknesses are weldable

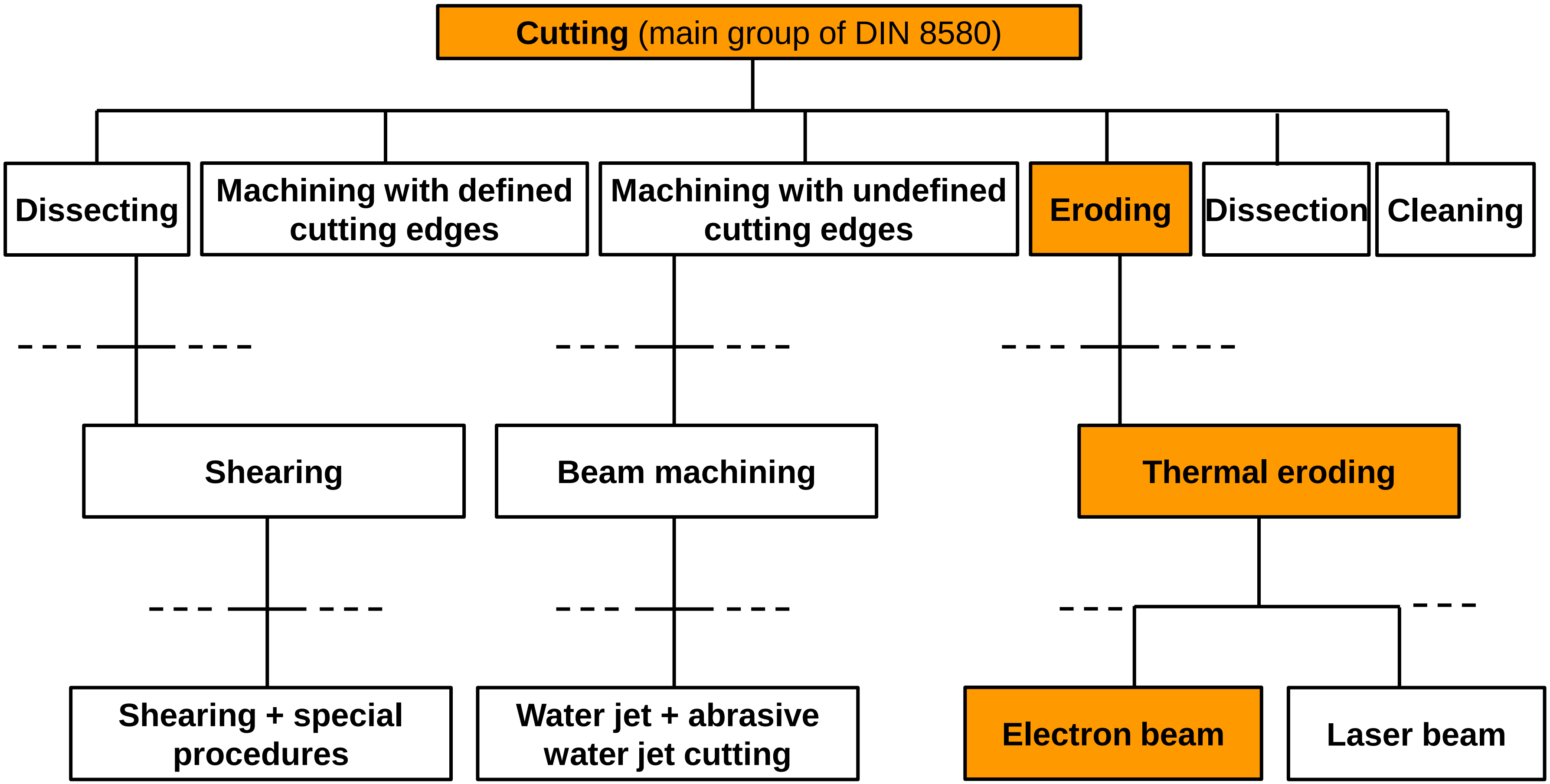
Disadvantages

- High investment and operating costs due to vacuum pump
- Only electrically conducting materials weldable
- Gap-free clamping and cleaning of the joint partners necessary
- Generation of X-rays -> shielding necessary
- Adaption of working chamber and manipulator depending on the welding jobs

Electron beam welding seam

Electron Beam Drilling

Classification of Electron Beam Drilling according to DIN 8580 and 2310



Electron Beam Drilling

Basics

- Electron beam generation
- Focusing of the beam to intensities > 10^8 W/cm² by electromagnetic lenses
- Absorption of electron beam by workpiece
- I > 10^8 W/cm²: generation of a vapor capillary surrounded by a film of molten material in almost any material
- Characteristic: Usage of an evaporating material (backing material) for driving out the molten material

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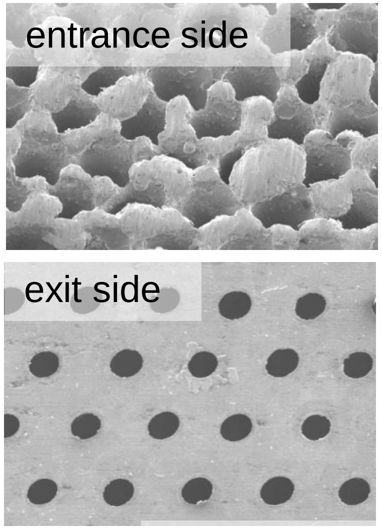
Principles of Electron Beam Drilling

- Absorption of the pulsed electron beam at workpiece surface
- Melting and evaporation of the material -> melt ejection partially realized by evaporation
- Penetration of the vapor capillary into the workpiece
- Evaporation of backing material when irradiated by the electron beam
- Melt ejection from the capillary by the explosion-like expansion of the gas generated by the backing material

→ Narrow heat-affected zone (HAZ) along the drill hole

→ Precise and burr-free edges at the exit side



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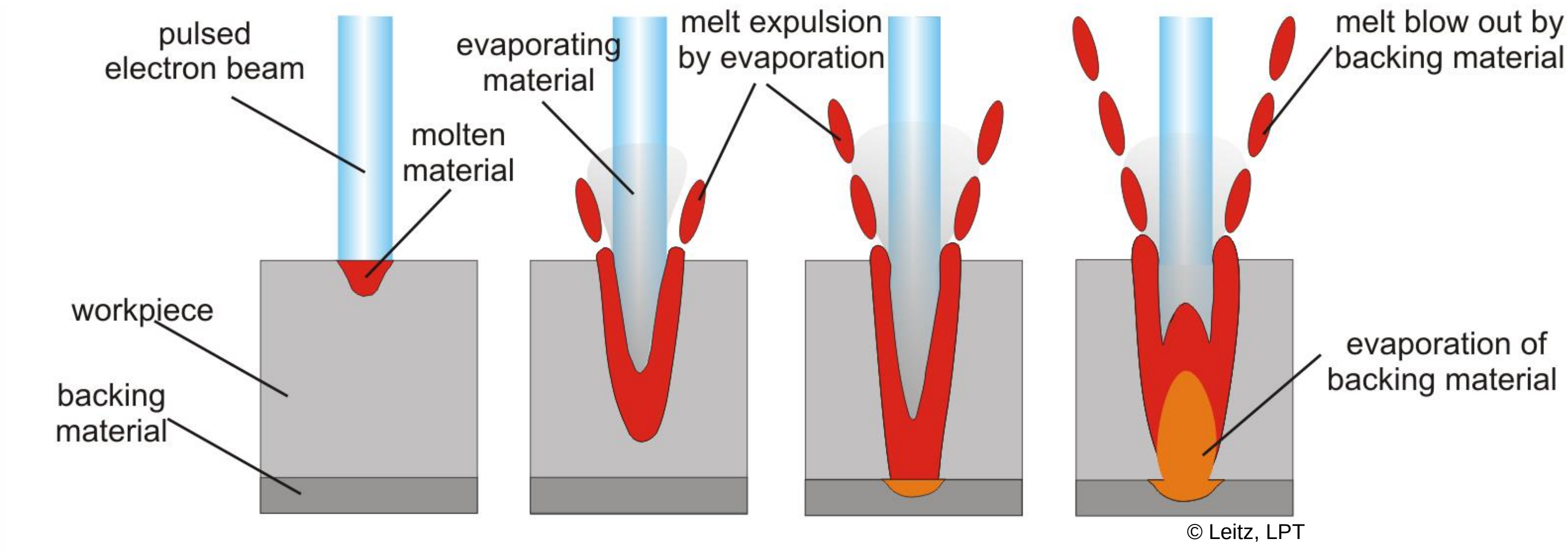

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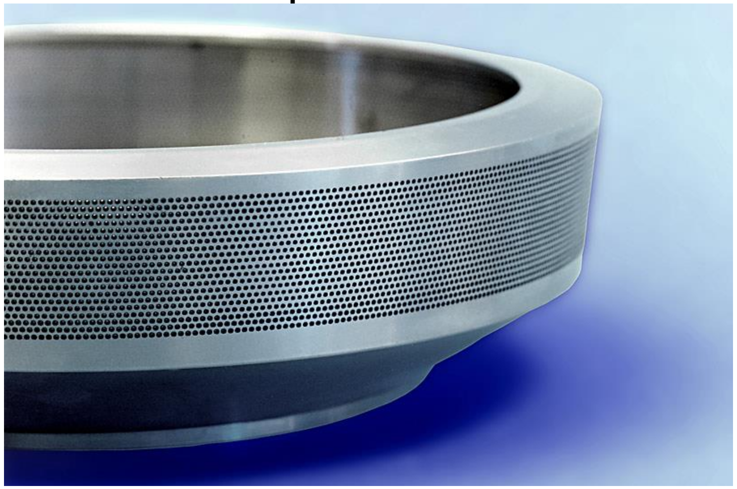
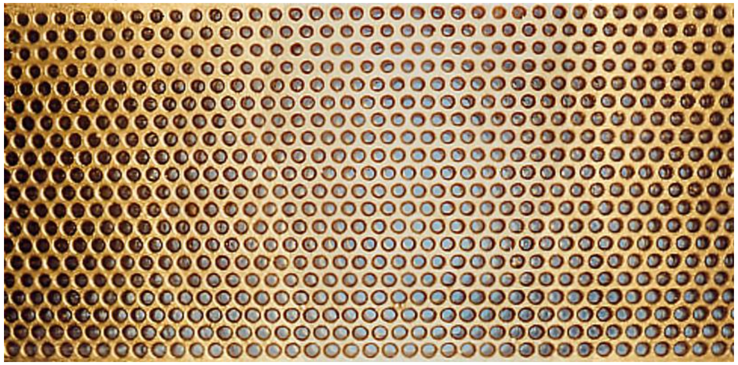
Applications of Electron Beam Drilling

Spinning head for production of optical fibers

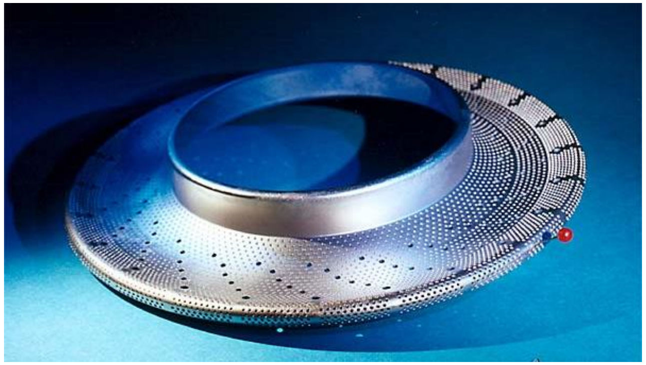


Combustion chamber

Detail of bore holes generated by electron beam drilling



Part of gas turbine



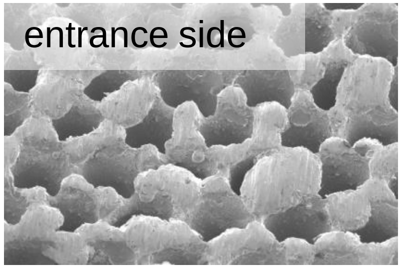
Advantages and Disadvantages of Electron Beam Drilling

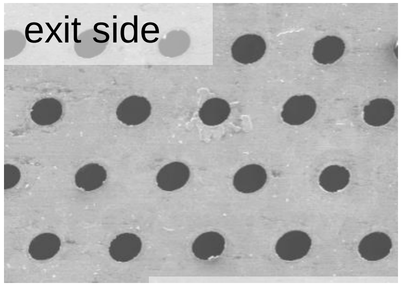
Advantages

- Drill hole diameter and taper ratio can be varied continuously in contrast to mechanical drilling
- Fast processing speed as a consequence of high intensities and feed rates

  -> more rapid deflection of the electron beam possible compared to the laser beam
- Very small heat affected zone along entire bore hole
- Precise and burr-free edges on the back side
- Electron beam as a wear-less tool
- Variation of processing parameters without changing the tool
- Drilling without special preparations, drill holes under a very low angle of incidence with respect to the workpiece surface can be achieved;

  -> with mechanical drilling the drill will break when drilling under a low angle





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Disadvantages

- High investment costs due to vacuum chamber and pumps
- Shielding necessary due to the generation of X-rays
- Drill hole diameter limited to rather small geometries