# Lecture Unit 07

# Laser-based Joining and Cutting

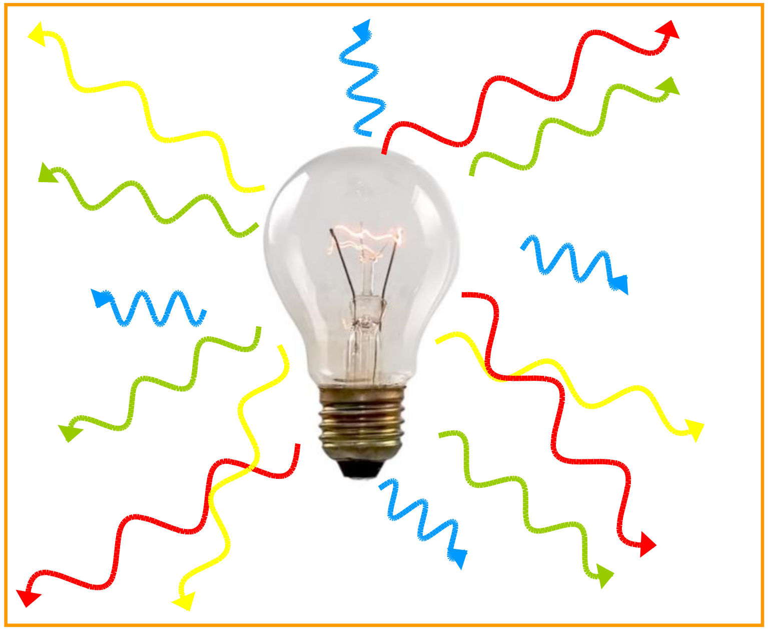
# Beam Processing Technologies within DIN 8580

| 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 | | | |

Laser beam can be found in all groups of DIN 8580

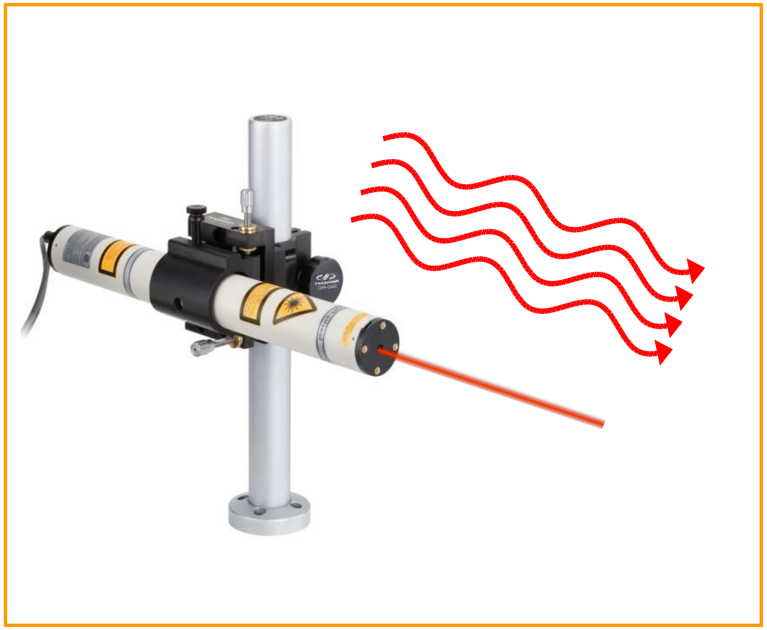
# Properties of Laser Light

## Laser radiation is light with special properties



Light in everyday life (e.g. sun, light bulb):

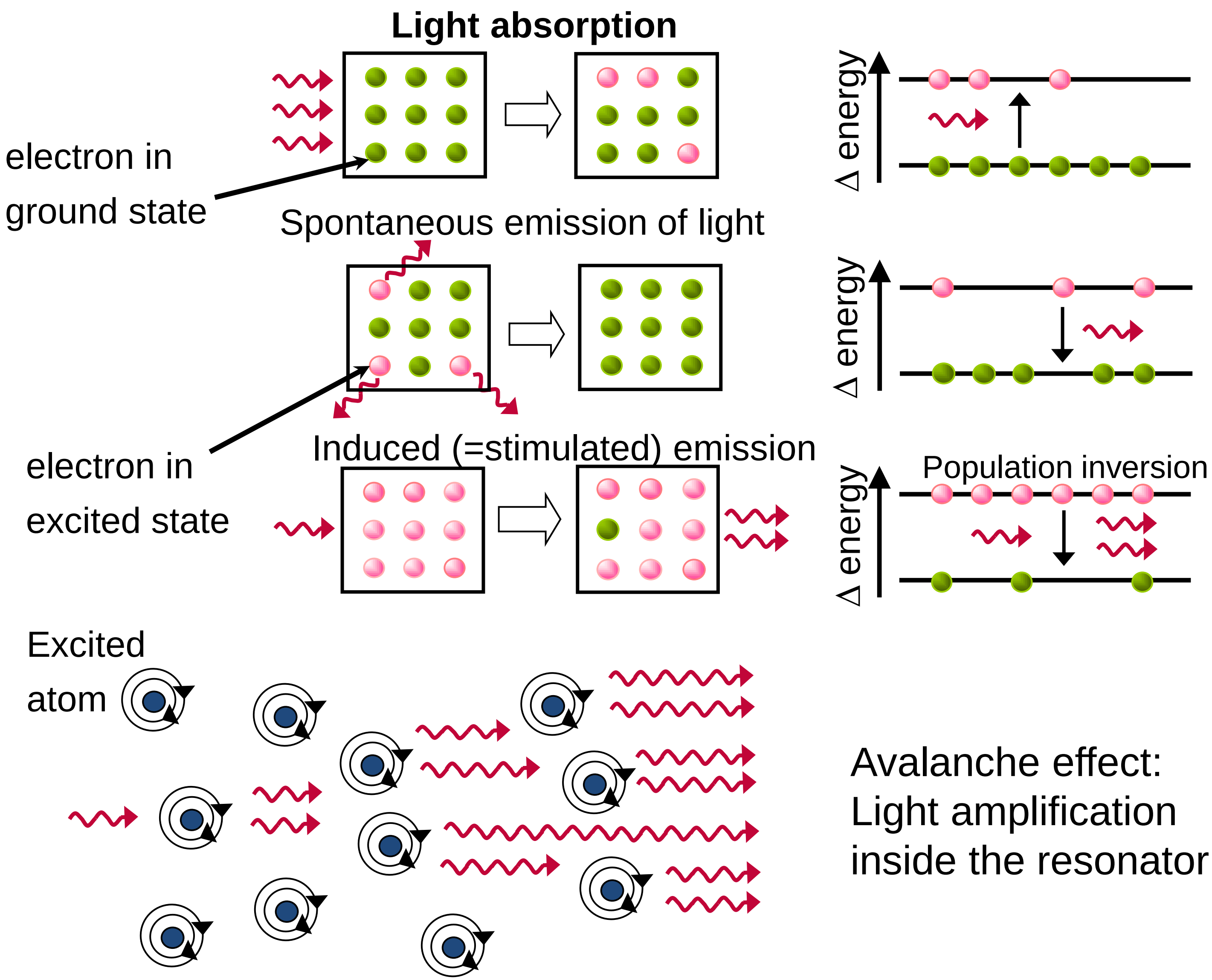
- superposition of numerous light waves
- different wavelengths and directions



Laser light:

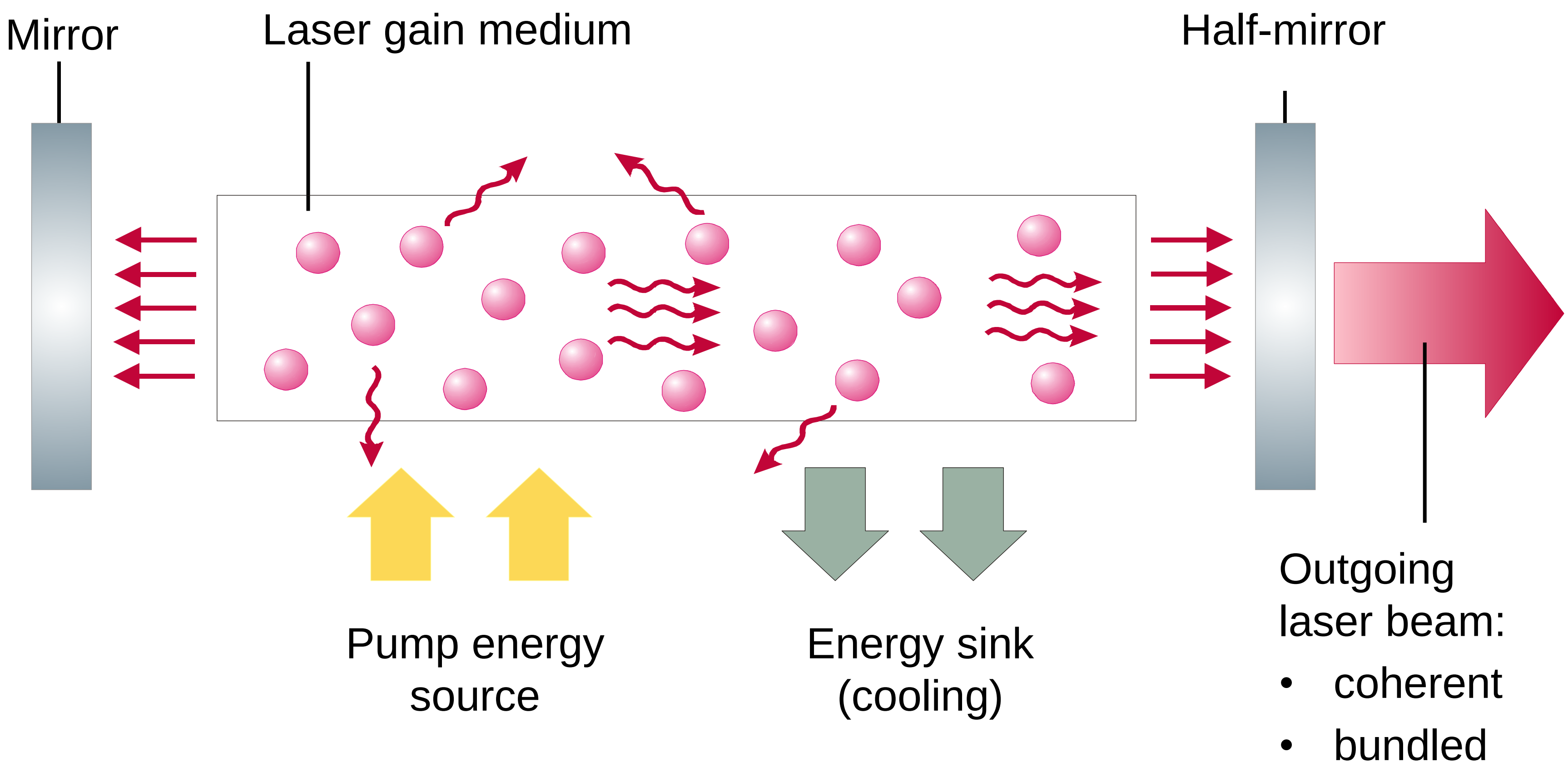
- unidirectional beam
- monochromatic
- temporal and spatial coherence

# Generation of Laser Radiation



# Principle of Light Amplification

## Schematics of an optical resonator



# Live-Survey

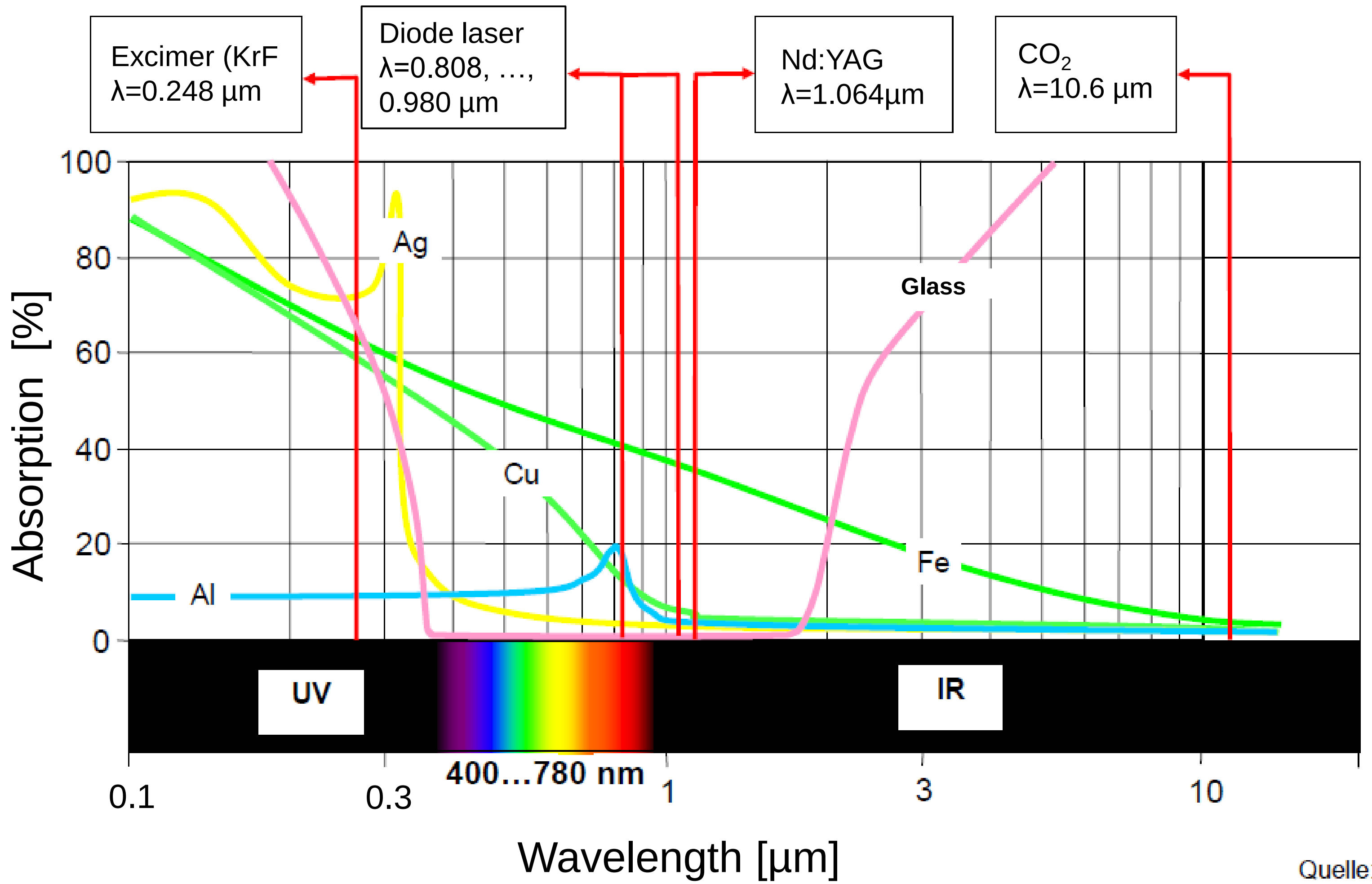
Which emission mechanism is crucial for the generation of laser radiation?

a) spontaneous emission

b) stimulated emission

Result

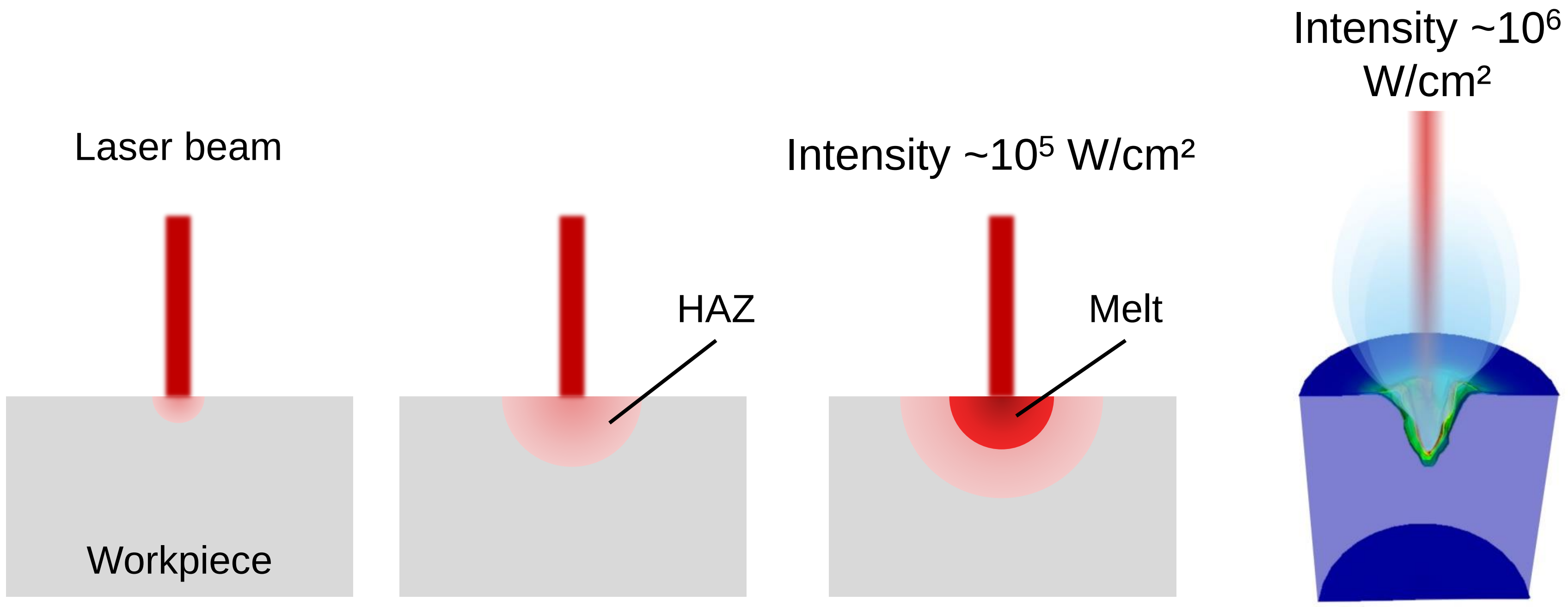
# Absorption Spectra of Different Materials




Quelle: Trumpf

# Laser Beam: Interaction with Matter

## Interaction of continuous laser radiation with matter




Incidence and absorption of laser beam

Heat conduction into material

Melting of the material

Evaporation and keyhole formation

Increase in intensity

# Live-Survey

Which beam-based tool can be deflected faster?

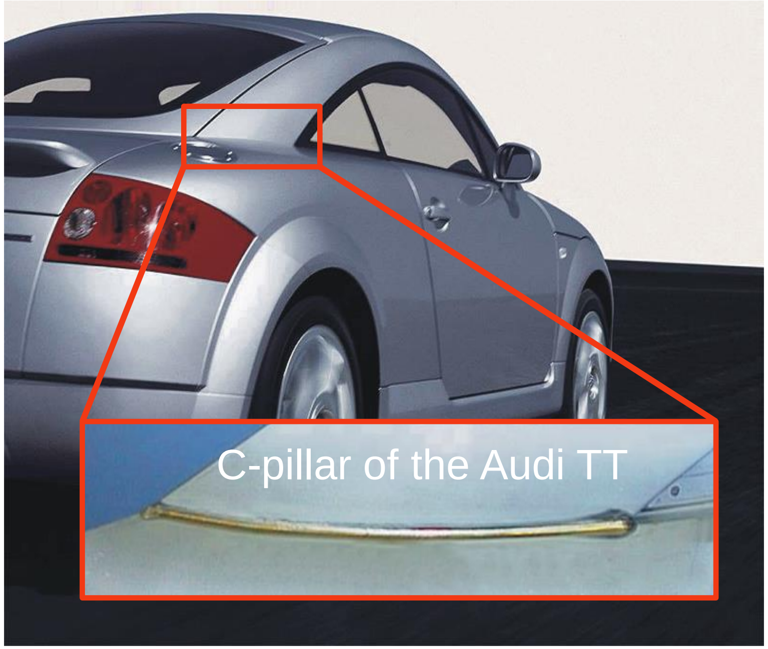
a) laser beam

b) electron beam

Result

# Applications of the Laser Beam

Brazing

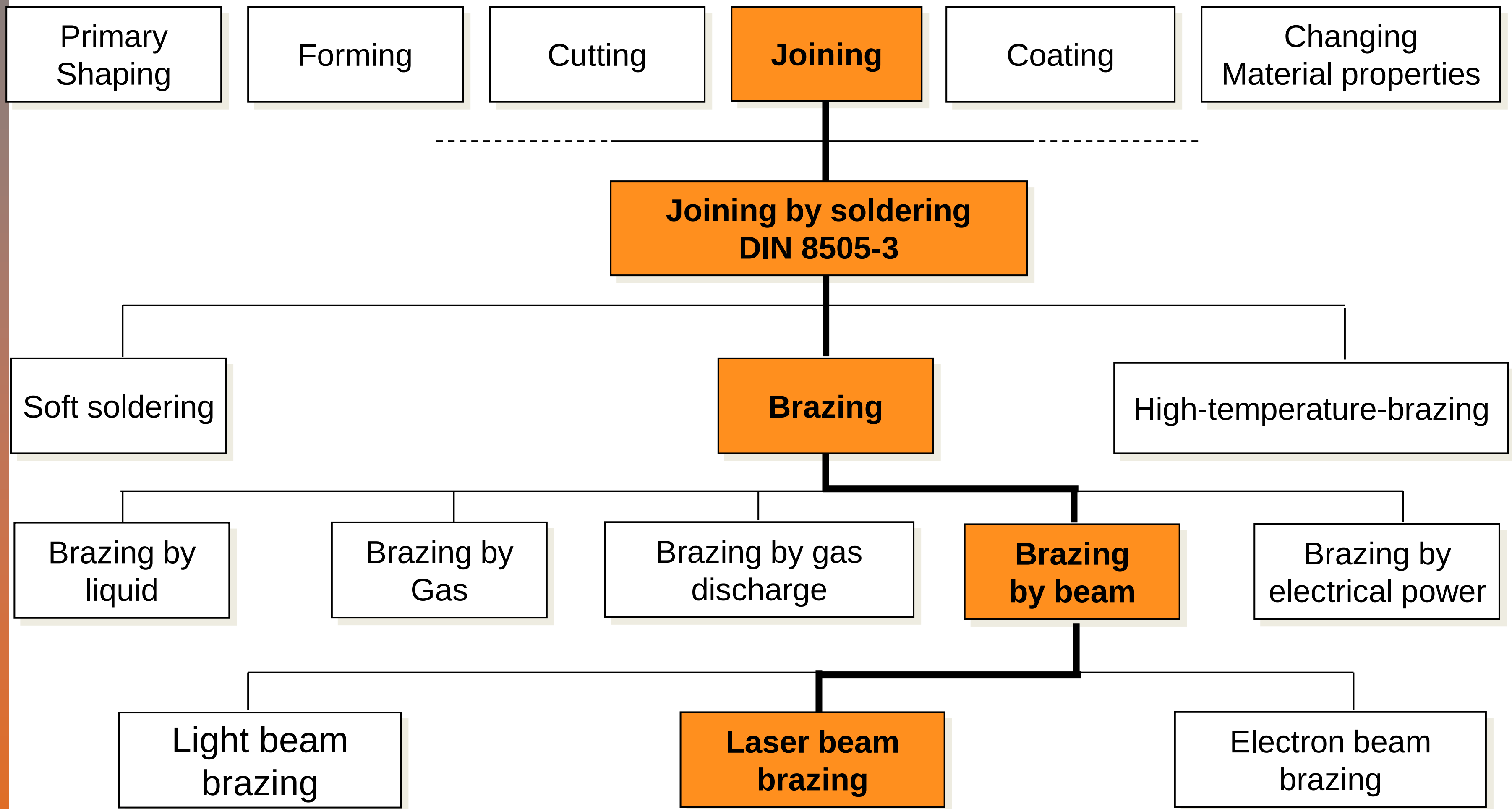



Cutting

Welding

# Laser Beam Brazing

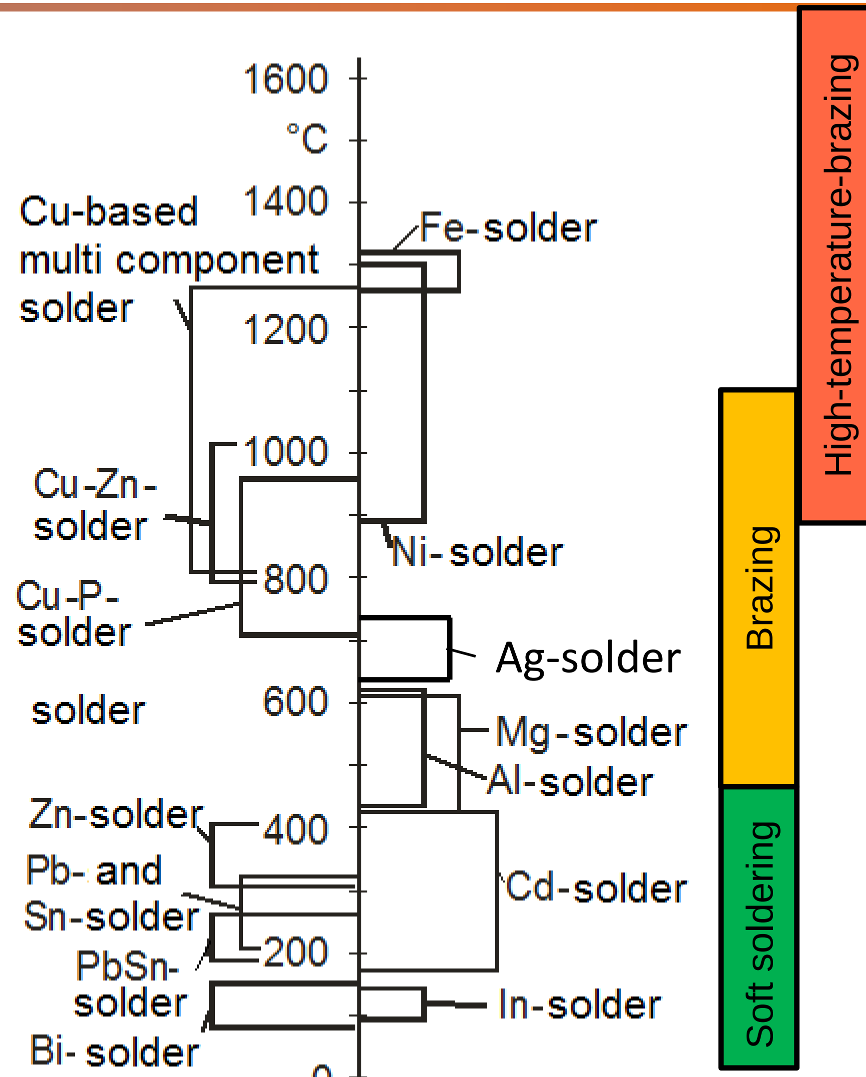
Classification of Laser Beam Brazing according to DIN 8580 and 8505-3



# Different Soldering Methods

## Soldering:

- Thermal process in which metal parts are joined together or coated by molten solder (filler metal)
- Soldering flux and/or shielding gases may be used

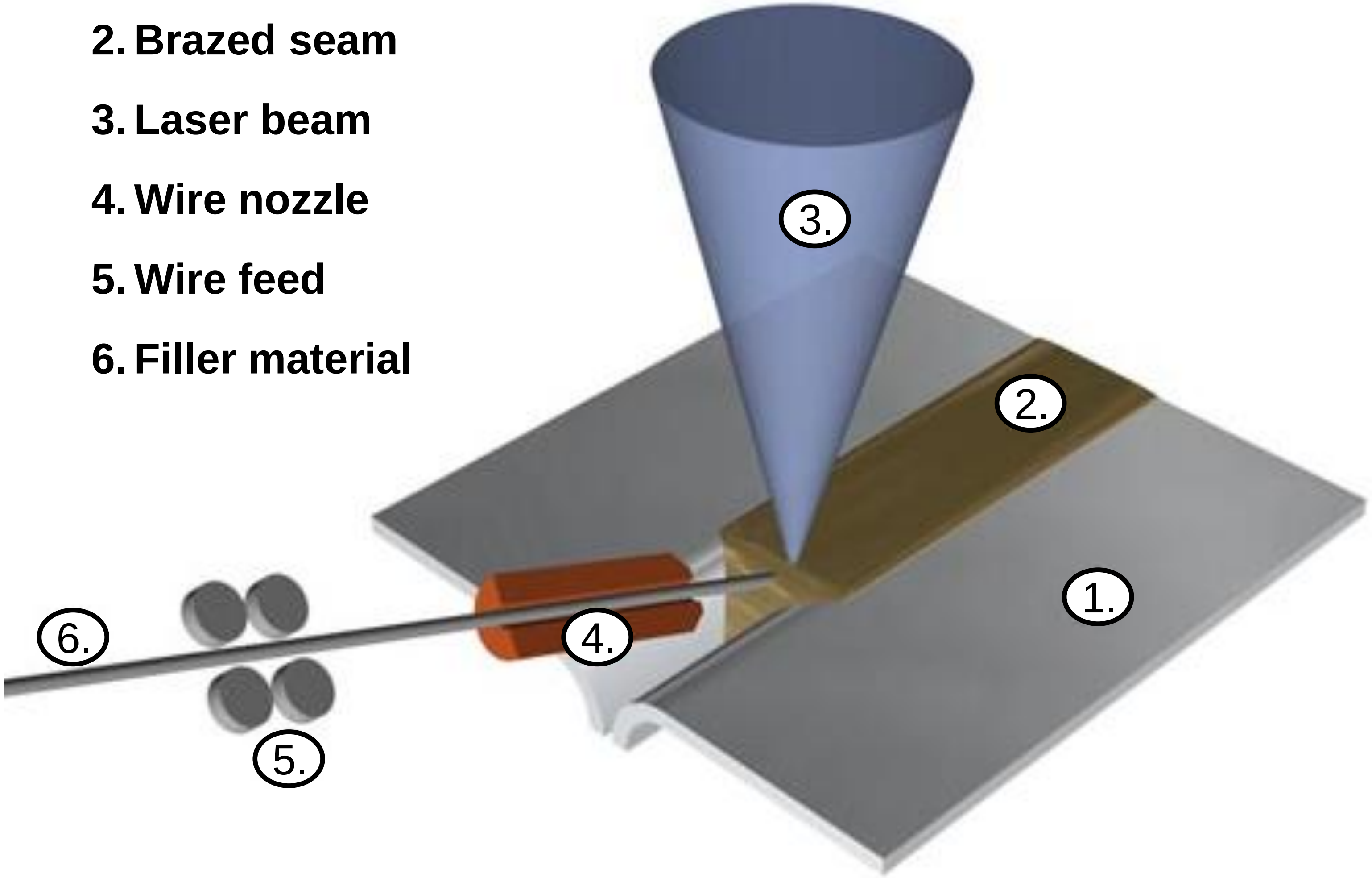





- Up to 450°C: Soft soldering
- From 450°C: Brazing
- From 900°C: High-temperature brazing

# Schematic Representation of Laser Beam Brazing

1. **Workpiece**
2. **Brazed seam**
3. **Laser beam**
4. **Wire nozzle**
5. **Wire feed**
6. **Filler material**

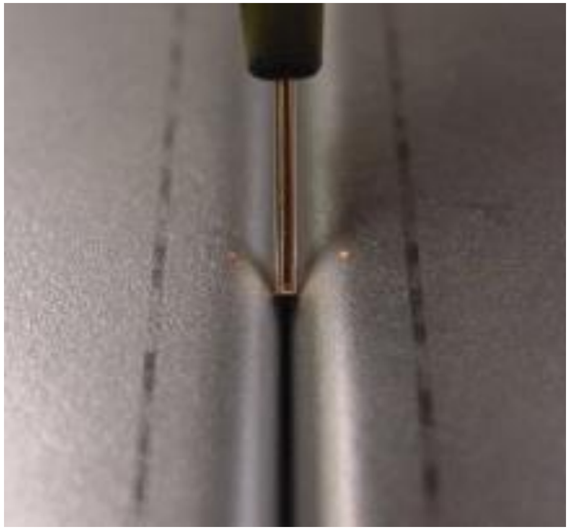



© Migweld

# Process Sequences and Characteristics of Laser Beam Brazing

**Process sequences:**

1. Heating-up of the joining partners, the filler material and the flux (better melting, protection against oxidation, cleaning)
2. Activation of the flux/protective gas: Removal of surface oxides
3. Melting of the filler metal
4. Wetting of the joining partners
5. Diffusion processes: Forming of mixed crystals or intermediate compounds



**Characteristics of brazing:**

1. Joint partners only warmed, only filler material is molten ($T_M$ > 450 °C)
2. Mechanical strength of joint comparable to that of the filler material
3. Properties of joint depend on amount of wire and temperature distribution

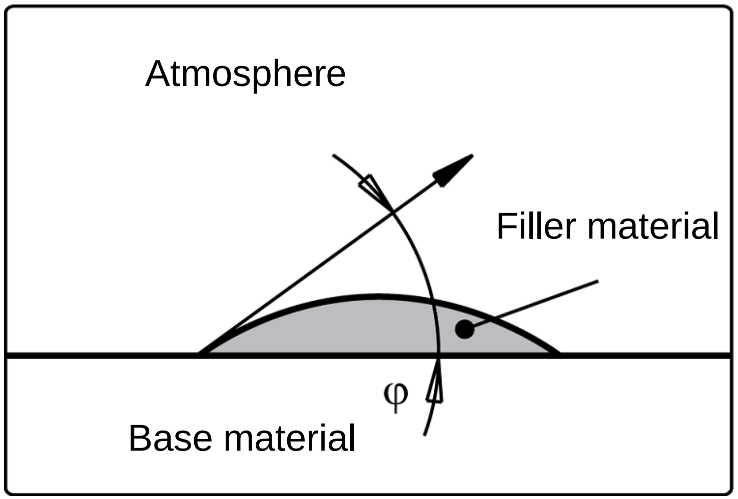
What does decisively influence the wetting during laser-based brazing?

a) surface temperature of the joining partners
b) flux
c) both

Result

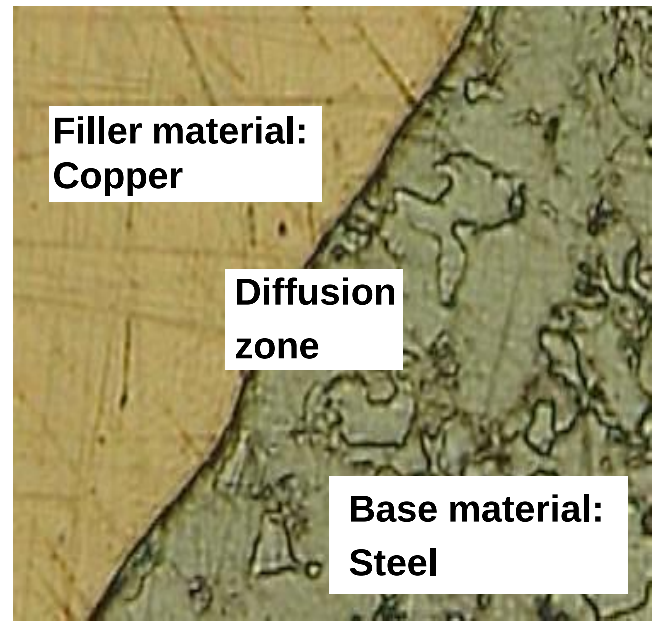
# Wetting and Diffusion

## Wetting




- Contact angle φ is determined by the surface tension
- Solderability depends on the contact angle

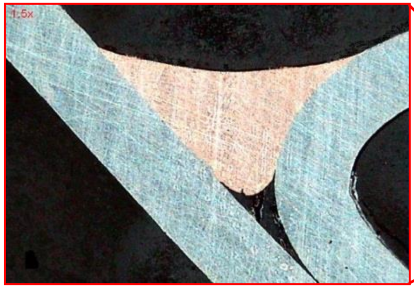
## Diffusion




Diffusion zone 1-10 µm, depends on:

- Temperature
- Brazing time
- Alloys

# Application of Laser Beam Brazing



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Laser beam brazed joints

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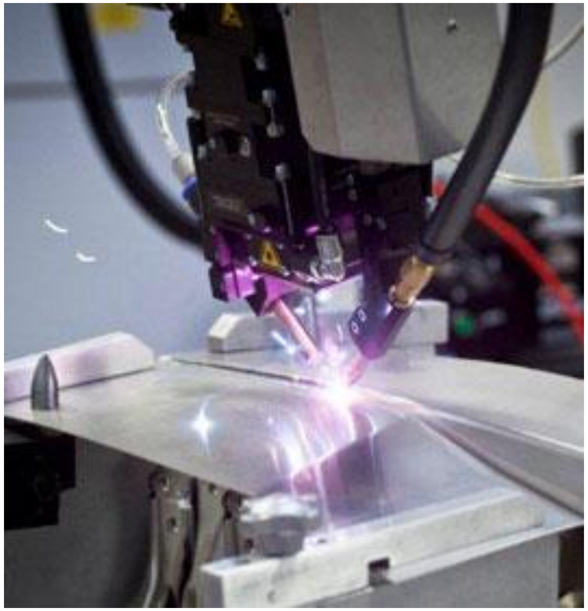

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# Advantages and Disadvantages of Laser Beam Brazing

Advantages

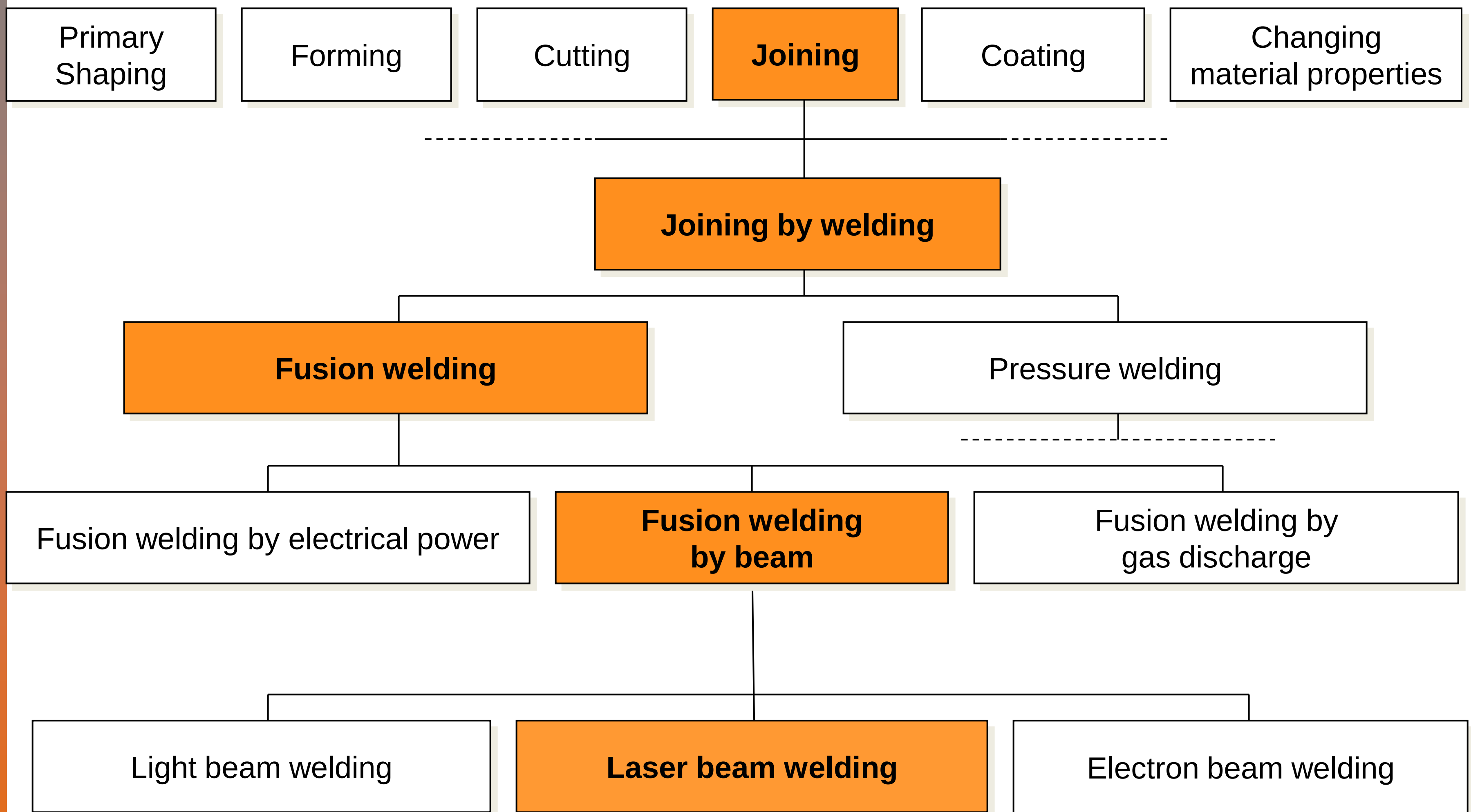
- Solid joint with lower heat input into the base material than brazing in a furnace
- Good gap bridging due to added material
- Dense, firmly bonded connection
- Little need for post-processing
- Direct coating possible (better surface than weld seams)
- Joints are detachable by melting the braze
- Joining of diverse material possible

Disadvantages

- Surface preparation necessary -> removal of surface oxides
- Strength of the joint is lower than that of the base material
- Risk of corrosion due to differences in potential of the braze and base material
- Feed rates < 4 m/min (welding 8-10 m/min)

# Laser Beam Welding of Metals

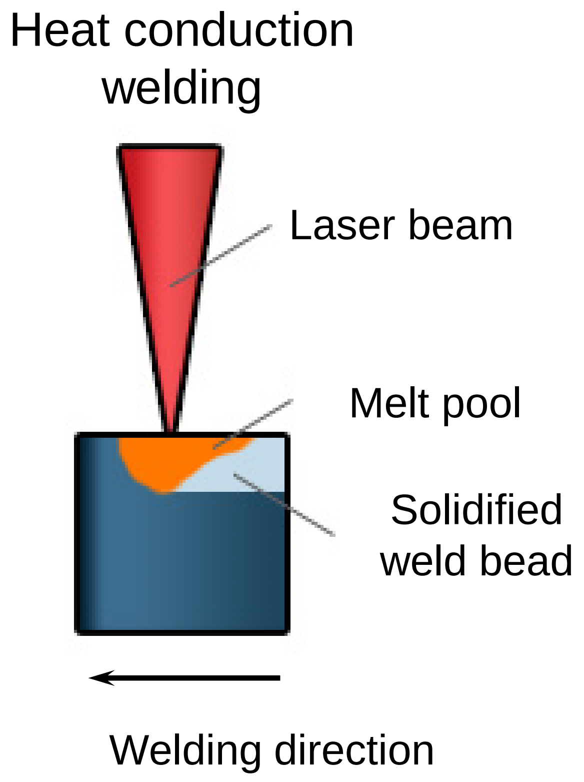
Classification of Laser Beam Welding according to DIN 8580 and 1910



# Heat Conduction Welding

## Characteristics:

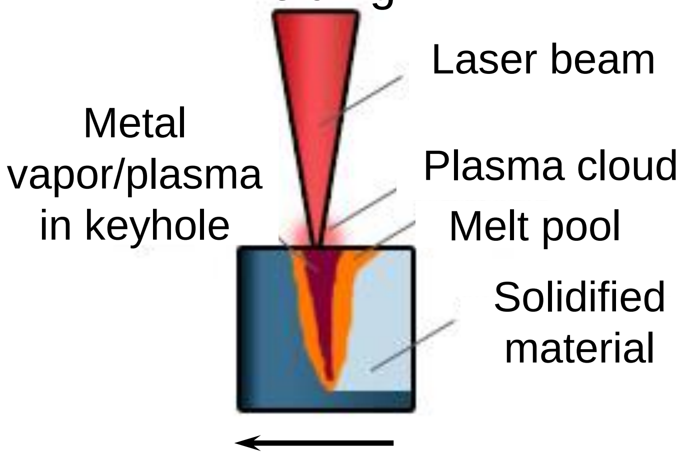
- Intensity > $10^5$ W/cm$^2$ -> no evaporation
- High energy input per unit length (power / feed rate)
- Semi-circular transverse section of the seam with a seam width of ~2x seam depth
- Uniform weld bead and weld root
- Weld depth depends significantly on thermal conductivity of the material
- Fields of application:
  - Covers and housing
  - Jewellery
  - Medical components
  - Electronics

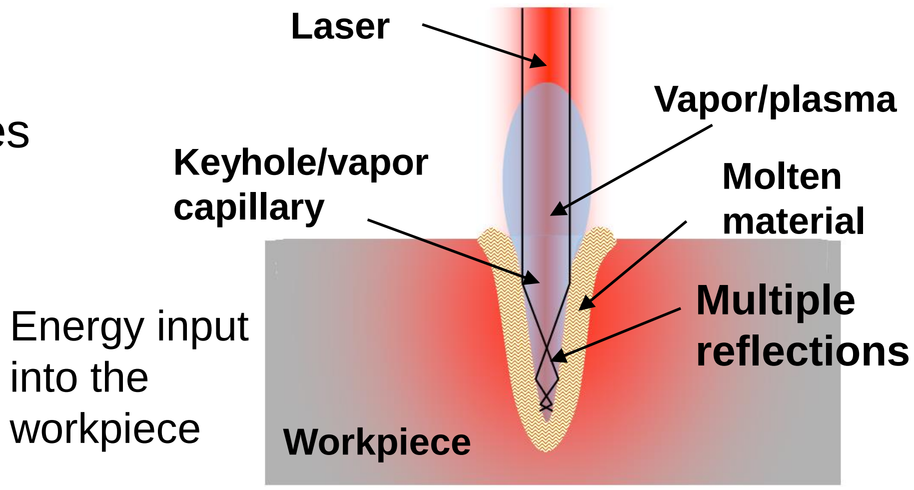


# Laser Deep Penetration Welding

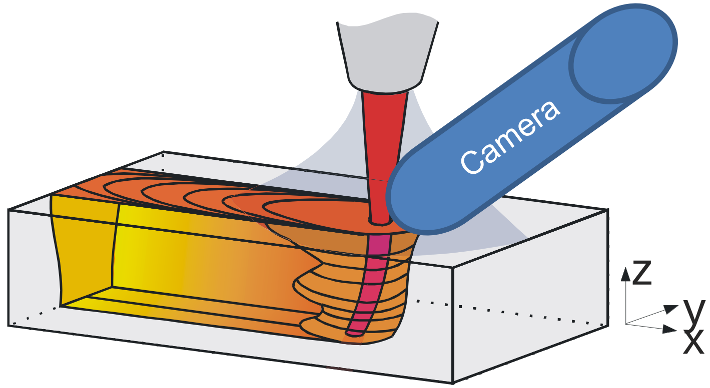
## Characteristics:

- Laser intensity > $10^6$ W/cm$^2$ -> evaporation of metallic material
- High feed rates (10 m/min)
- Low thermal influence on surrounding material
- High energy coupling efficiency due to multiple reflections inside keyhole
- Large ratio of weld depth to width
- Uniform weld bead and weld root
- Fields of application:
  - Welding of thick-walled pieces
  - Gear components

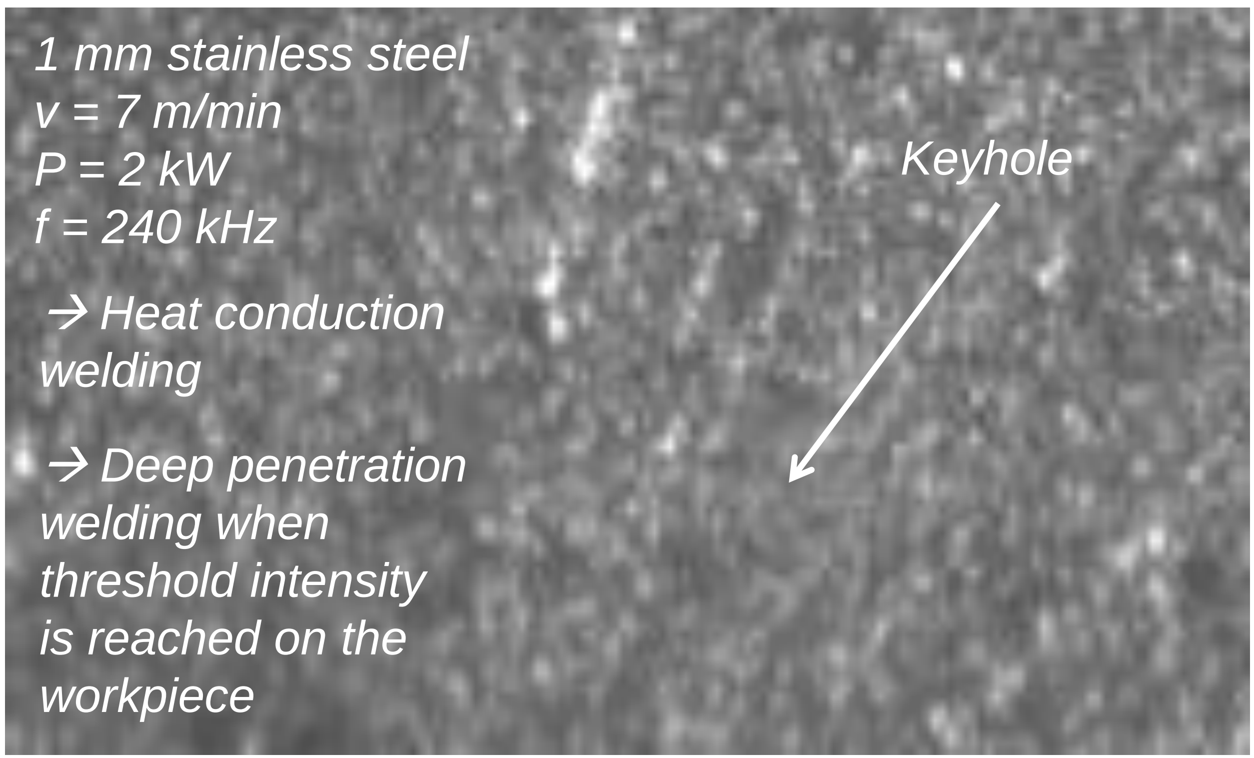


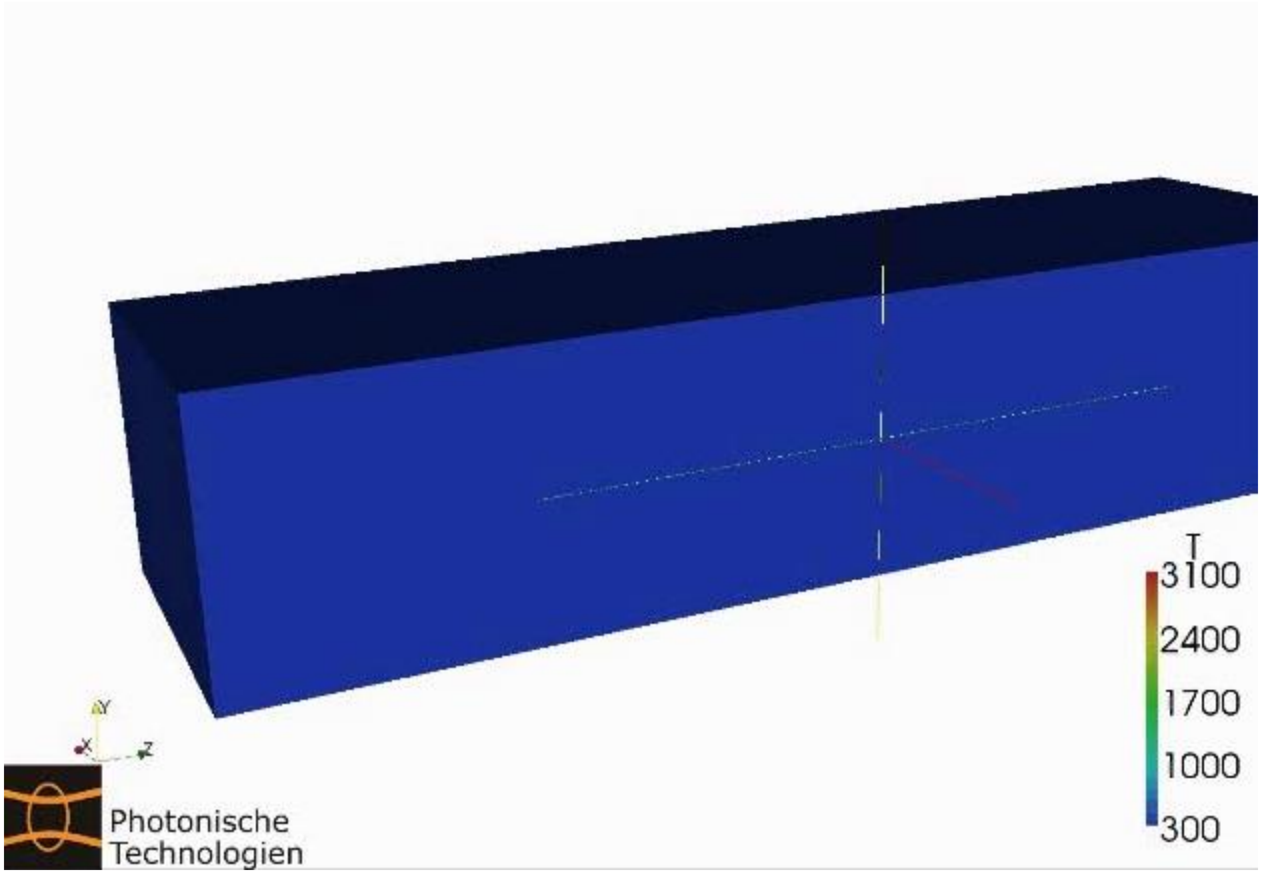
# Heat Conduction Welding ⟷ Deep Penetration Welding




Front view of the keyhole with slight inclination to the weld path



# Simulation of Melt Pool Dynamics during Laser Deep Penetration Welding



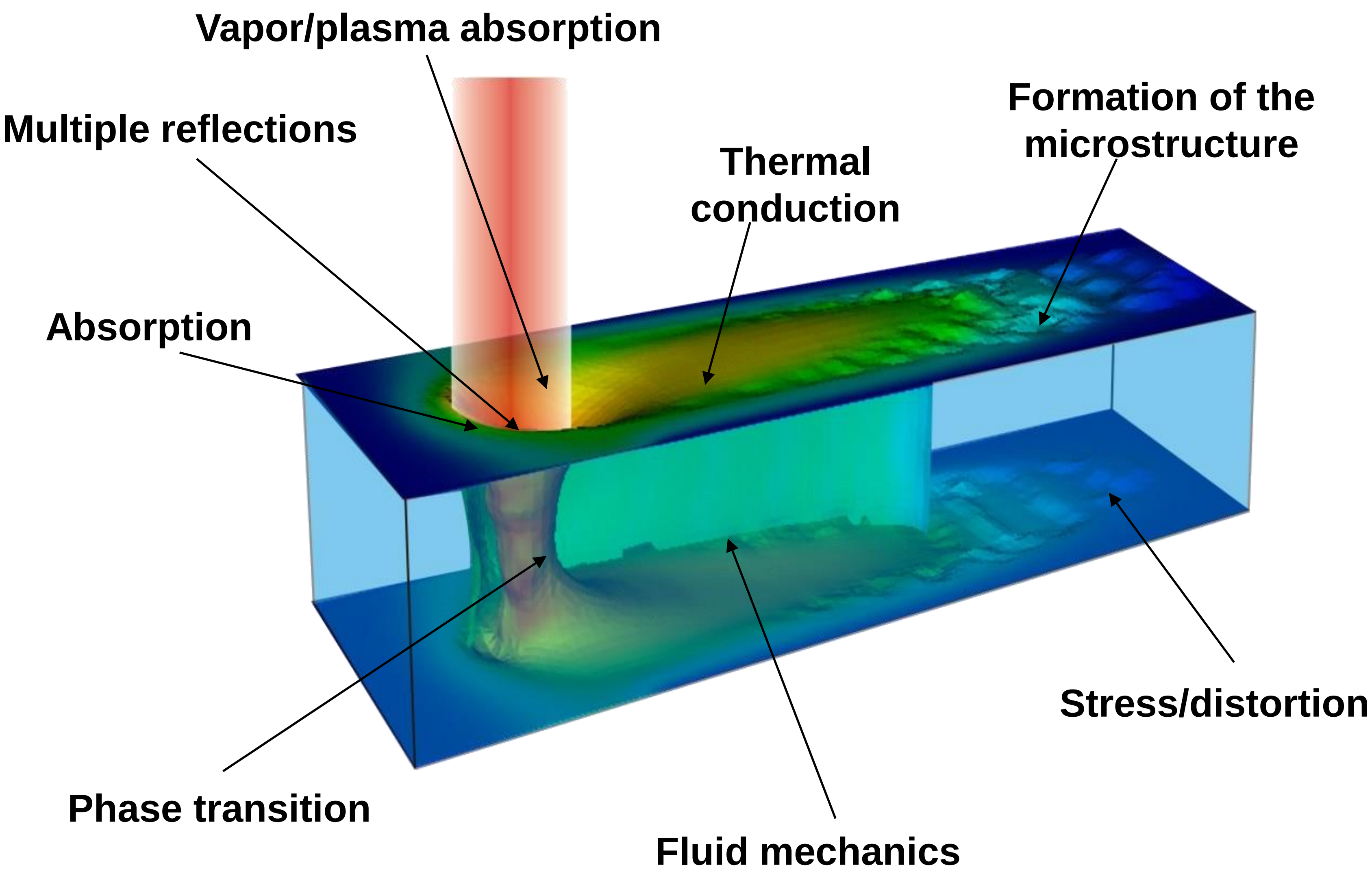

Steel, s = 1 mm

$r_f$ = 200 µm

I = 1.5e6 W/cm²

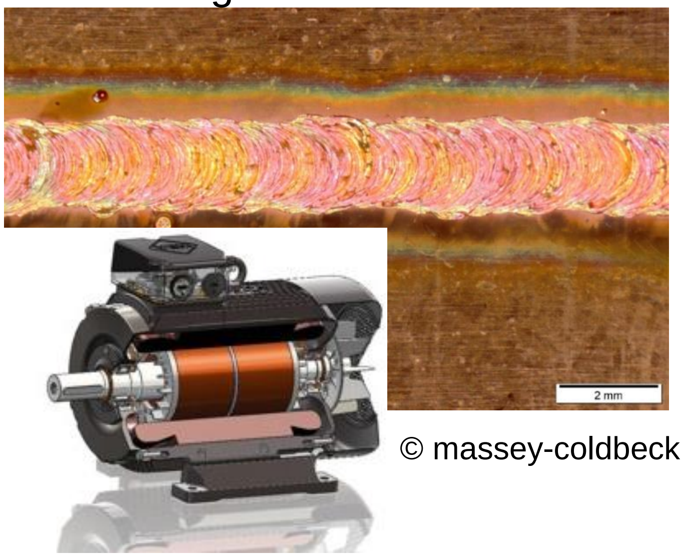
v = 6 m/min

# Physical Effects



# Applications of Laser Beam Welding (1)

Contacting inside electric motors

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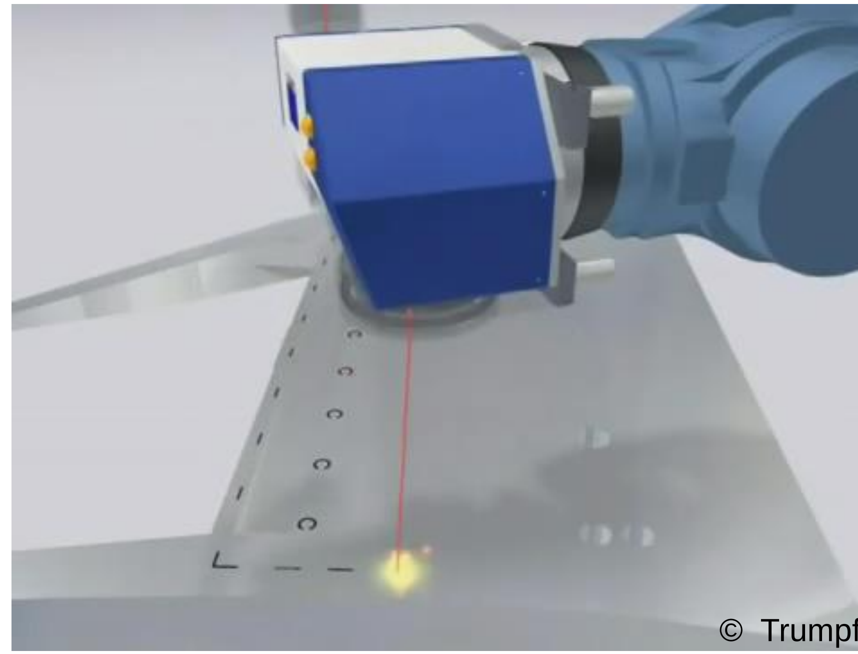
Welding of car doors



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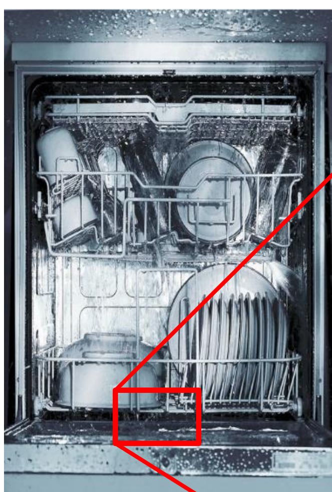

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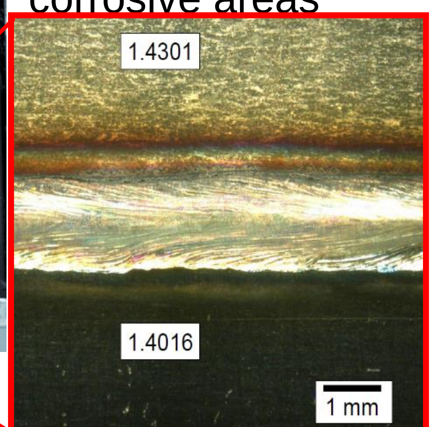
Welding of different stainless steels in corrosive areas




Circumferential joint weld on an endoscope

# Advantages and Disadvantages of Laser Beam Welding

Advantages

- Higher intensity compared to TIG welding
- Higher feed rate (8-10 m/min) than brazing (4 m/min)
- Welding under specified atmospheric conditions
- Less thermal distortion compared to TIG welding
- Welding of areas which are difficult to access
- Weldability of different materials

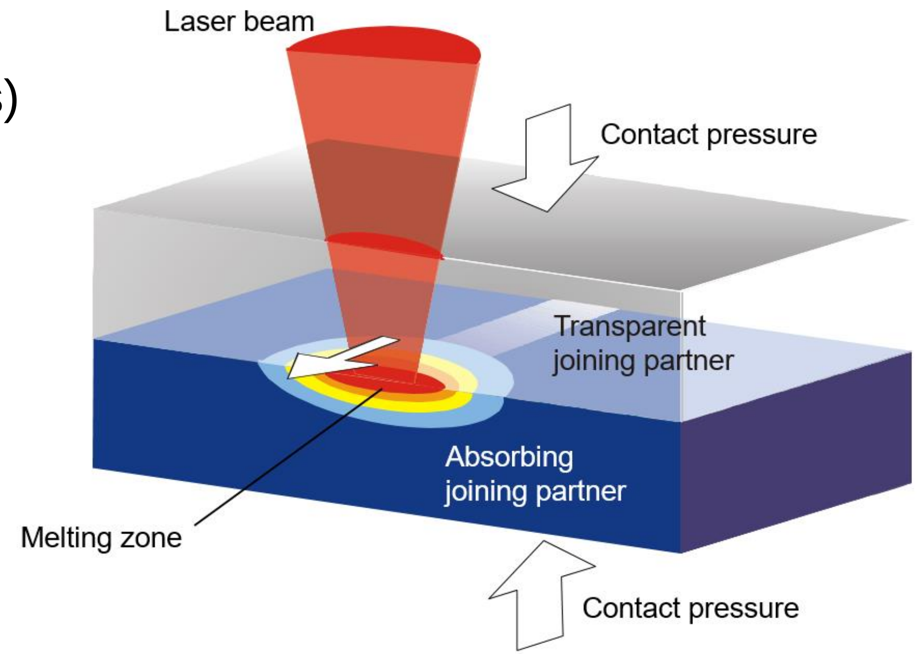
Disadvantages

- Bad gap-bringing due to frequently no additional material
- Lower efficiency level than electron beam welding
- Protection from laser radiation needed
- Spatter formation requires safety housing for optical components

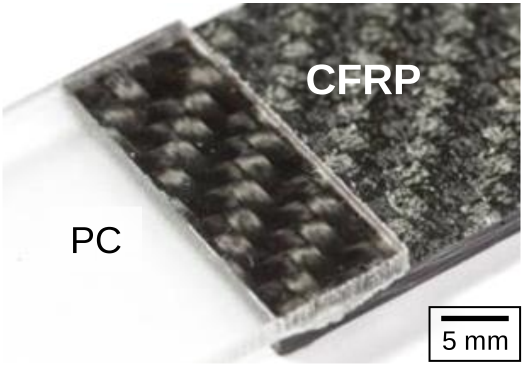
# Laser Beam Welding of Plastics

**Material requirements:**

- Thermoplastics (meltable polymers)
- Overlapping melting temperature range of joining partners
- Compatibility of molten materials (miscibility, weldability)
- Transmission of the laser radiation through upper joining partner
- Absorption of the laser radiation by lower joining partner

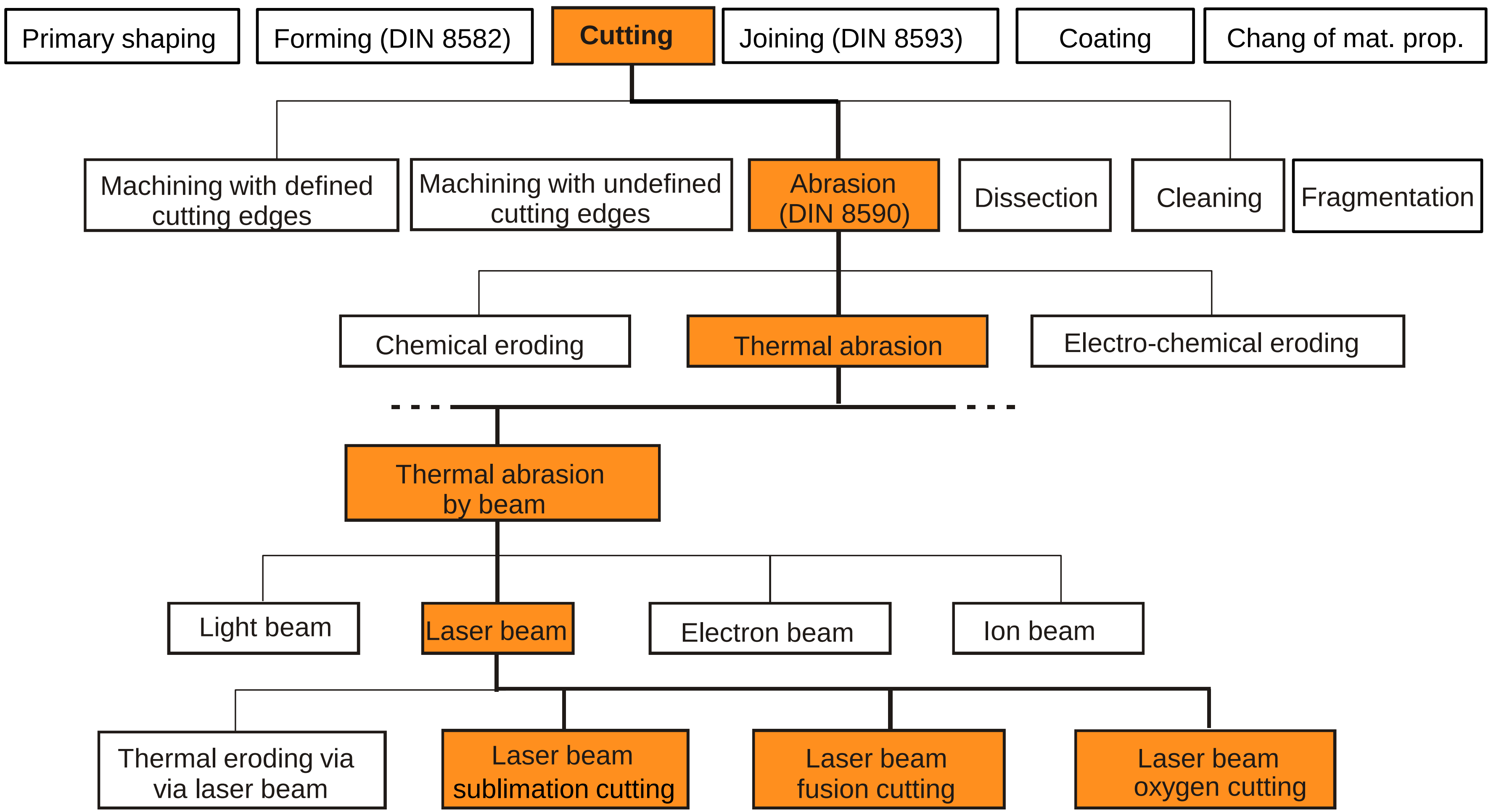



**Fusion of CFRP with Polycarbonate**



# Laser Beam Cutting

## Classification of Laser Beam Cutting according to DIN 8580 and 2310



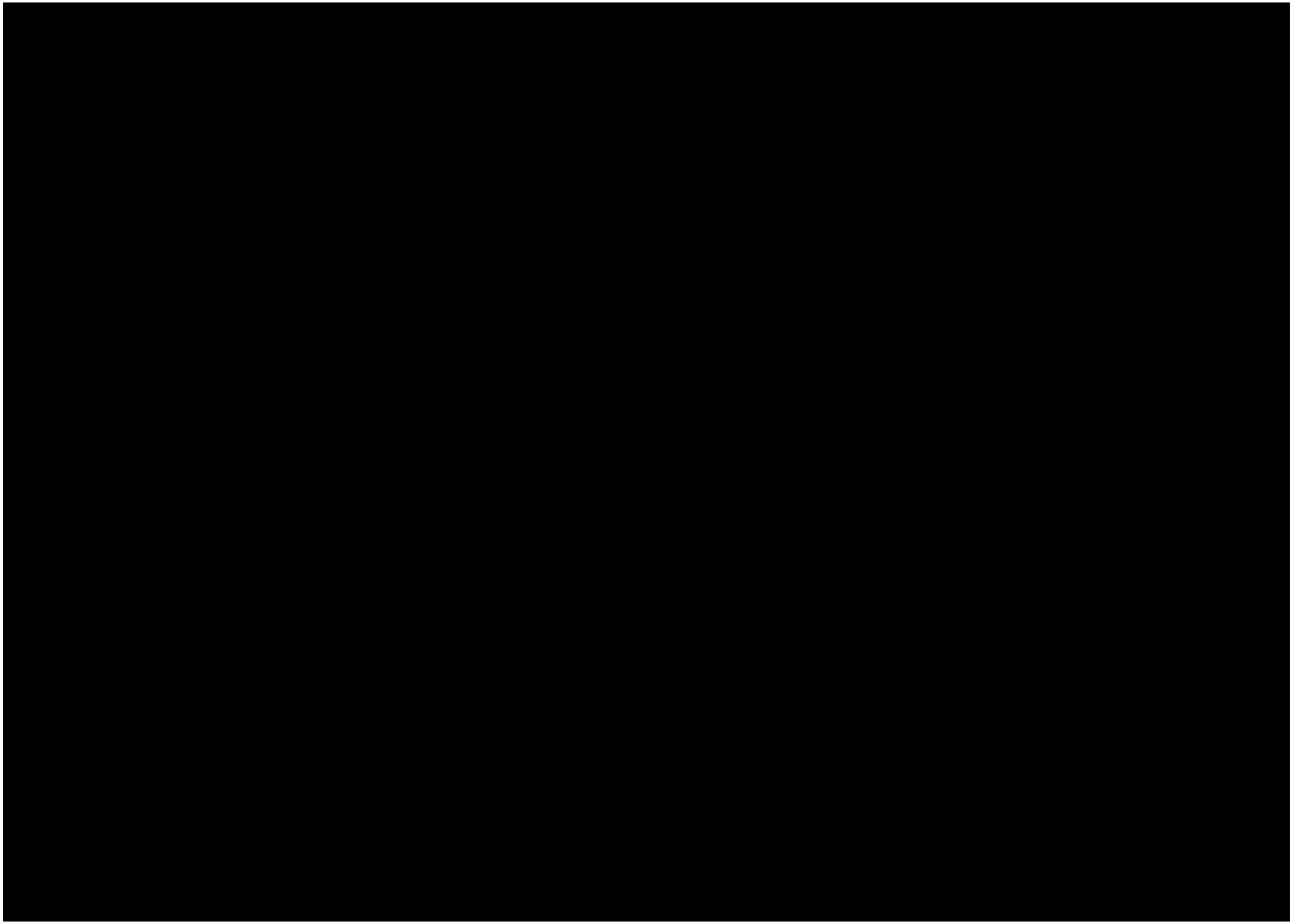
# Laser Beam Cutting: Motivation

## Laser beam cutting of hot-formed steels


**Hardness of the material is challenging for mechanical cutting:**
- Extremely high tool wear
- High processing forces required
- Risk of micro-cracks at cutting edges

**Advantages of laser beam cutting:**
- No wear of tool and stable process
- No deformation effects, small HAZ
- Cutting of different geometries by adjusting NC-Code

# Laser Beam Cutting



Source: directindustry.de

# Laser Beam Cutting: Process Variants

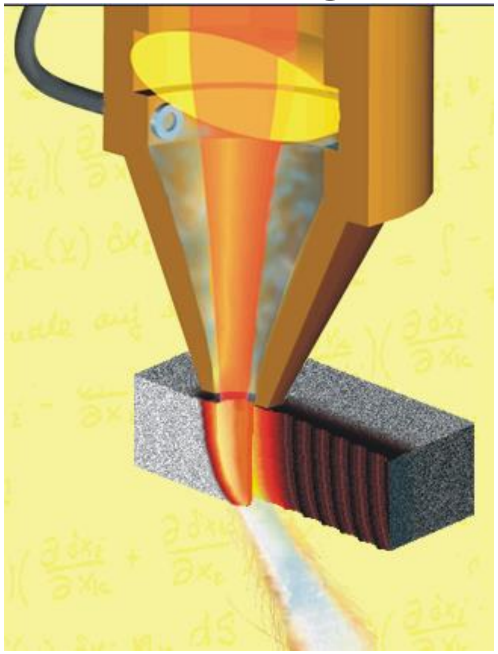
## Sublimation cutting

- Evaporation of material (sublimation)
- Inert gas protection (e.g. Argon)
- Low plate thickness
- Very low feed rates

## Fusion cutting

- Melting of material
- Dissipation of metal vapour by inert gas under high pressure
- Driving out of melt by inert gas flow
- Medium plate thickness
- Medium feed rates

## Flame (oxygen) cutting



- Melting and burning of material
- Active gas, e.g. oxygen
- Cutting of thick plates (steel: up to 80 mm)
- High feed rates

# Live-Survey

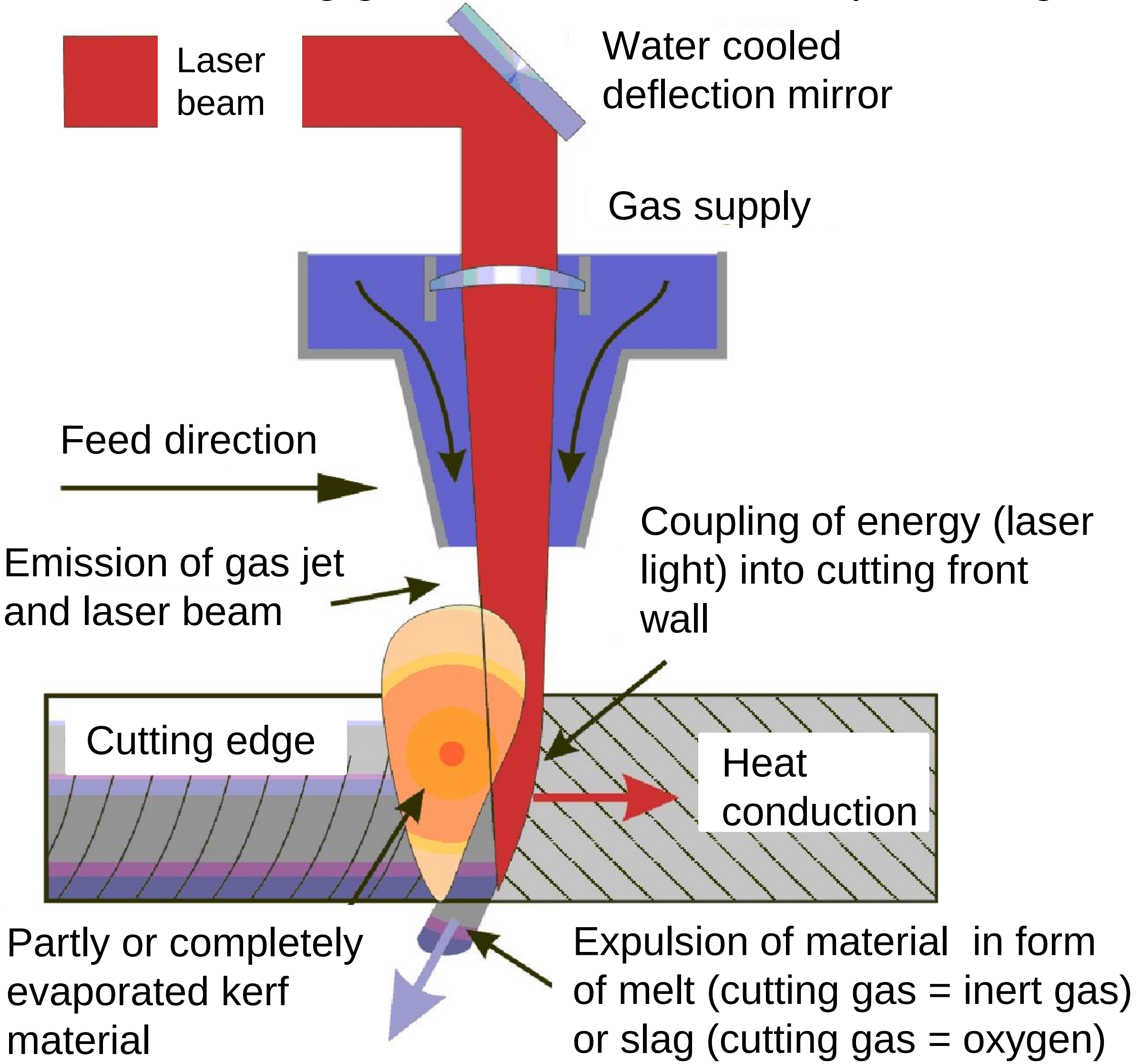
Which of the processes has the higher energy efficiency, considering an equivalent gap size?

a) sublimation cutting
b) fusion cutting
c) both are similar

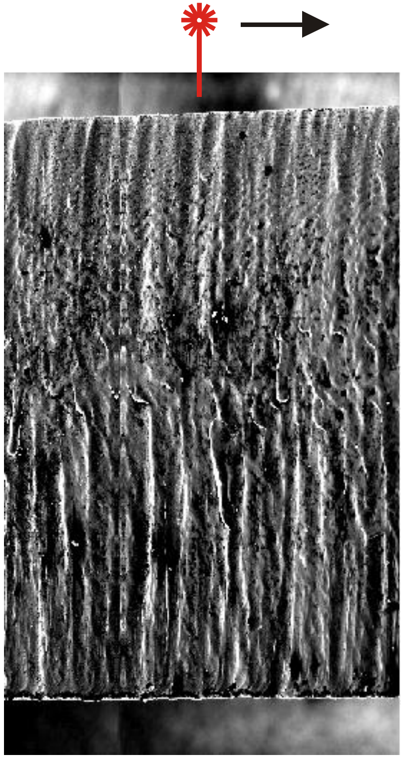
Result

# Laser Beam Fusion Cutting and Flame Cutting: Execution

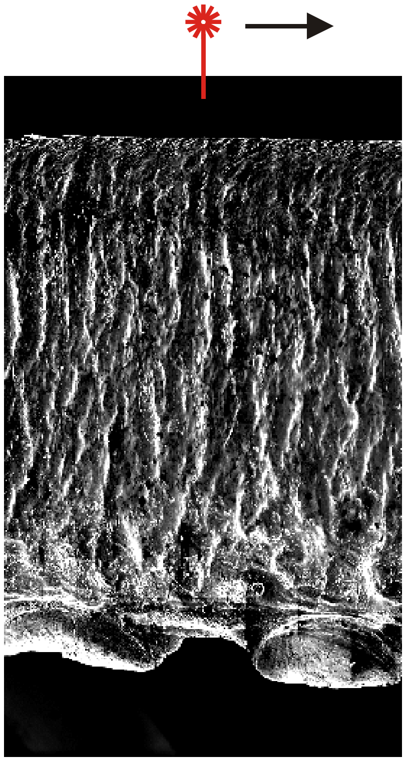
- Fusion and flame cutting are comparable processes: in flame cutting $O_2$ is used as cutting gas for additional heat input through exothermal reaction




# Laser Beam Fusion and Flame Cutting: Comparison



- **Fusion cut**
- Stainless steel
- Oxide free cutting edge (shielding gas $N_2$)



- **Flame (oxygen) cut**
- Stainless steel
- Strong accumulation of oxide

Process parameters: P=750 W, v=2.5 m/min, v=1.4 m/min, s=2 mm

# Laser Beam Cutting: Applications

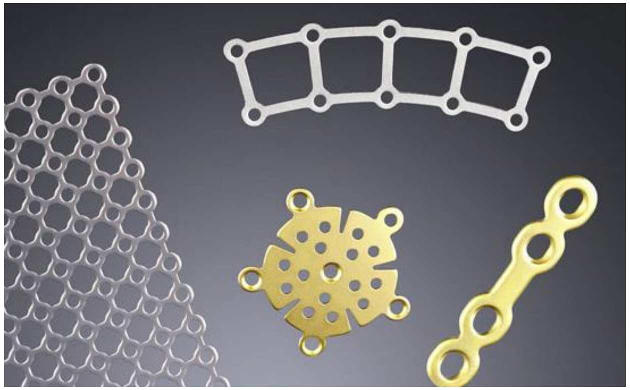
- Flame cutting of mild steel up to 80 mm
- Fusion cutting of stainless steel up to 15 mm
- Sublimation Cutting: Cutting of fine outlines

Mild steel (thickness 40 mm)

Wheel of a printer


Laser beam cutting of jewellery

Laser cut implant systems



# General Advantages of Laser Beam Cutting

- **Non-contact tool →** no mechanical stress on the workpiece, no tool wear

  Mechanical cutting: High mechanical stress due to chipped manufacturing, wear of the cutting tool
- **High precision →** laser can produce highly precise cuts and fine contours

  Mechanical cutting: Precision limited by dimension of the cutting tool
- **Small HAZ→** little thermal stress on the workpiece

  Mechanical cutting: High thermal stress on the workpiece, cooling and/or lubricant necessary
- **Flexibility →** variety of tasks can be performed with the same tool, different processes can be carried out on one machine

  Mechanical cutting: new task requires a new cutting tool, which is often time-consuming and not suitable for a small lot size

Quelle: Fuchs/blz

# Advantages and Disadvantages of different Laser Beam Cutting Techniques

| | Sublimation cutting: | Fusion cutting: | Flame (oxygen) cutting: |
|---|---|---|---|
| **Advantages** | • Reduced amount of melt material → high quality of kerf edges<br>• Small HAZ<br>• Oxide-free cut edges<br>• Suitable for non-metals (e.g. wood, textile, etc.) and thin sheet metal | • Lower energy required for melting of the material than for evaporation → higher cutting speeds at same intensity<br>• No oxidation of cutting edges<br>• Suitable for glass, plastics and metals | • Additional energy due to the exothermic reaction between oxygen and the base material -> high cutting speeds<br>• Suitable for cutting of thick material (up to 80 mm steel) |
| **Disadvantages** | • High laser intensities required (> $10^6$ W/cm$^2$)<br>• Relatively slow cutting speeds<br>• Limited material thickness | • Precise adjustment of process parameters necessary<br>• Larger HAZ than Sub. Cutting<br>• Formation of grooves at the cross section of the cut<br>• High consumption of inert gas | • Oxidation of cutting edges<br>• Risk of material erosion (can be avoided with proper process control)<br>• High consumption of cutting gas |