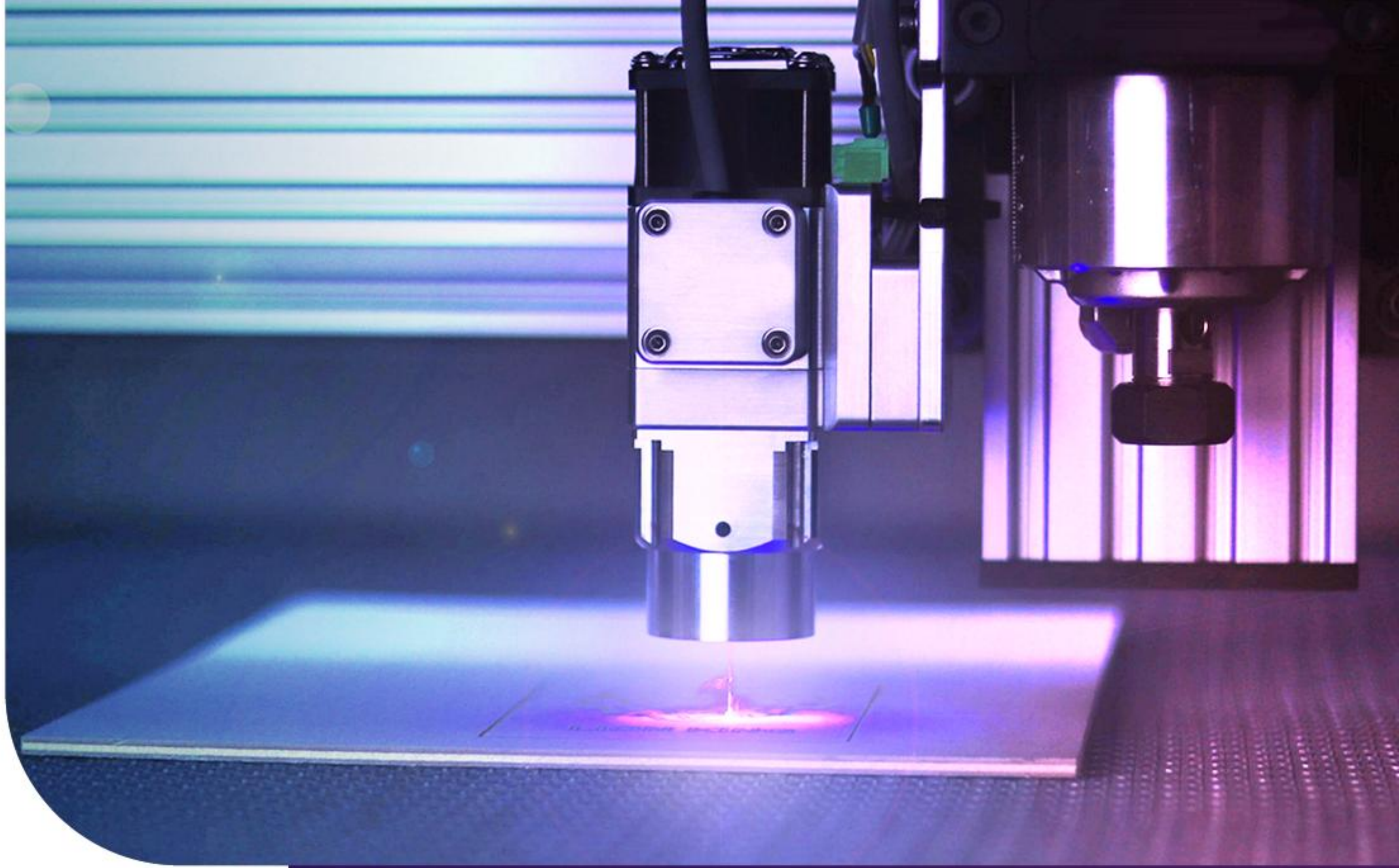
FLASH

Flexible Laser-Based Manufacturing

WP10, Task 10.4

The Laser-based Manufacturing Workshop



Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. **HORIZON-CL4-2023-TWIN-TRANSITION-01-02.**

Disclaimer

This material has been prepared solely for educational and non-commercial purposes. Some images, diagrams and references included within this presentation may originate from publicly available online sources and are used here under the understanding of fair educational use.

Content

FLASH
Flexible Laser-Based Manufacturing

1 – Introduction to lasers

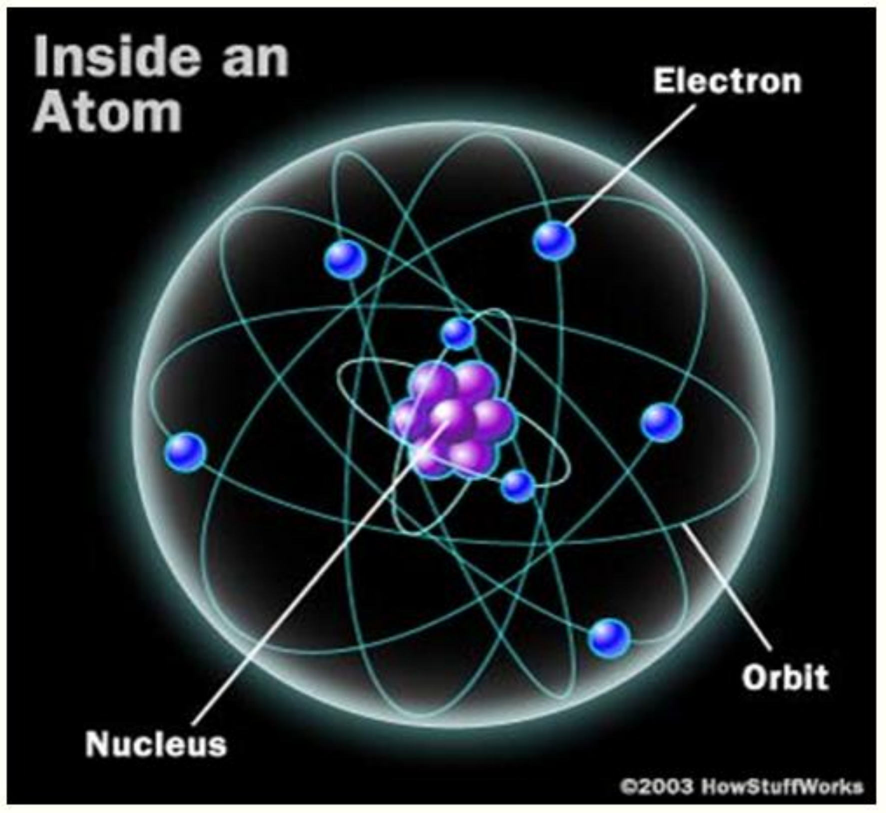
Flexible Laser-Based Manufacturing

Co-funded by the European Union

1.0 Overview

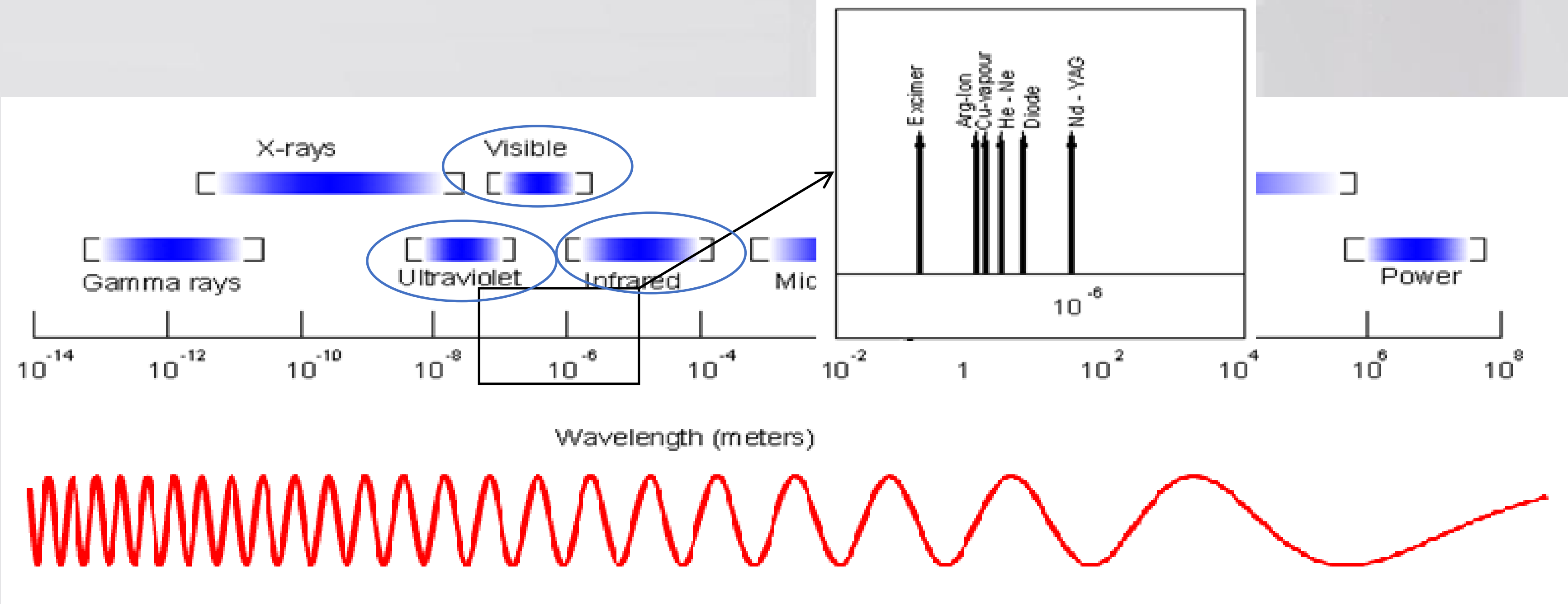
1. Introduction
2. Components of a typical laser machine
3. Principle and operation of common industrial lasers
4. Common terminologies in laser
5. Laser - material interaction
6. Major components of a laser system

1.1 Laser Beam Introduction



Light Amplification by Stimulated Emission of Radiation

1.1 Laser - Introduction

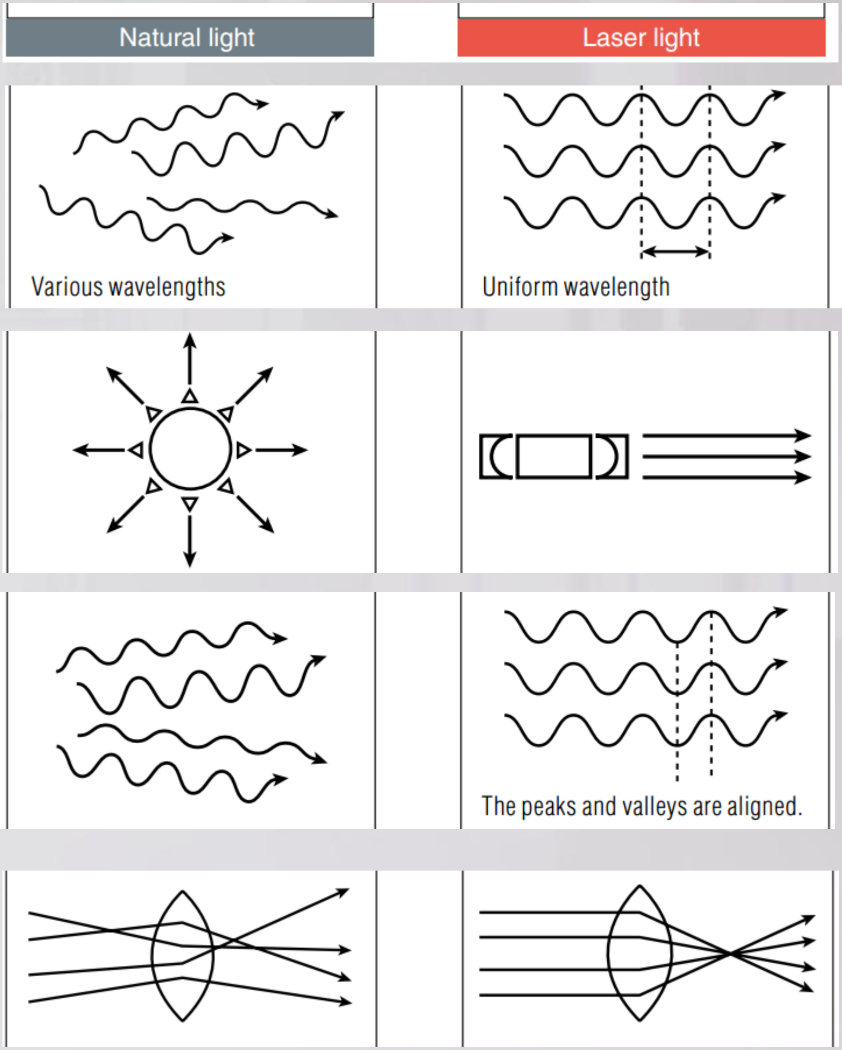


- Notion of light or optical radiation relates to electromagnetic waves ranging from 0.07μm to 100 μm. Ultraviolet to far infrared.

- Laser is a form of electromagnetic radiation in and around visible region of the spectrum.

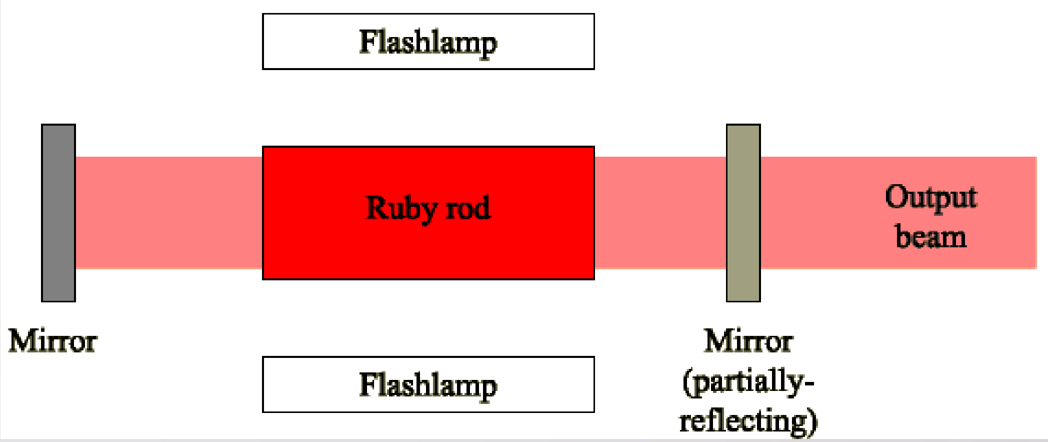
1.1 Properties of Laser Light

- ➢ Monochromaticity /Single wavelength
- ➢ Directionality
- ➢ Coherence
- ➢ High energy density



1.2 Main Components of Laser

- Stimulated emission is the basis of producing laser emissions.
- Gain medium or Laser medium
- Pump source
- Mirrors forming an optical resonator

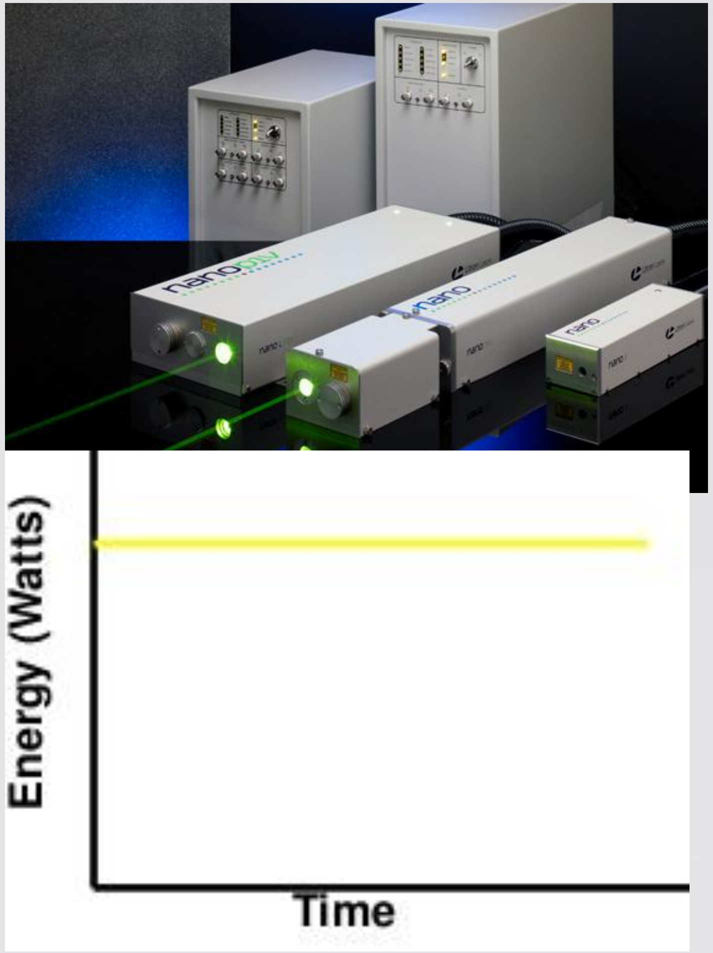


1.3 Common Industrial Laser Types

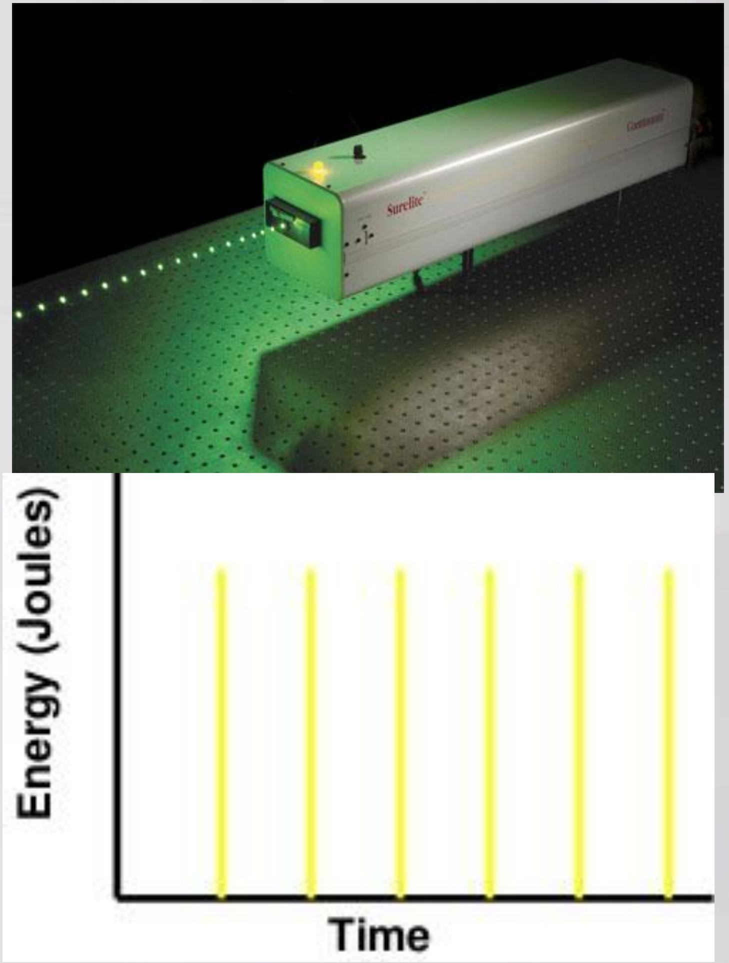
Laser Type	Wavelength	Applications
Semiconductor diode lasers		
Diode laser	Infrared to visible	Pump light source, Material processing
Solid-state lasers		
Fibre laser	1.07 - 1.08 µm	Material processing
Nd:YAG laser	1.064 µm; 532nm; 366nm	Material processing
Thin-disk laser (Yb:YAG)	1.03 µm	Material processing
Gas lasers		
CO_2 laser	10.6 µm	Materials processing
Excimer laser	193 nm, 248 nm, 308 nm	Micro-machining

1.4 Laser Pulsing

Continuous wave



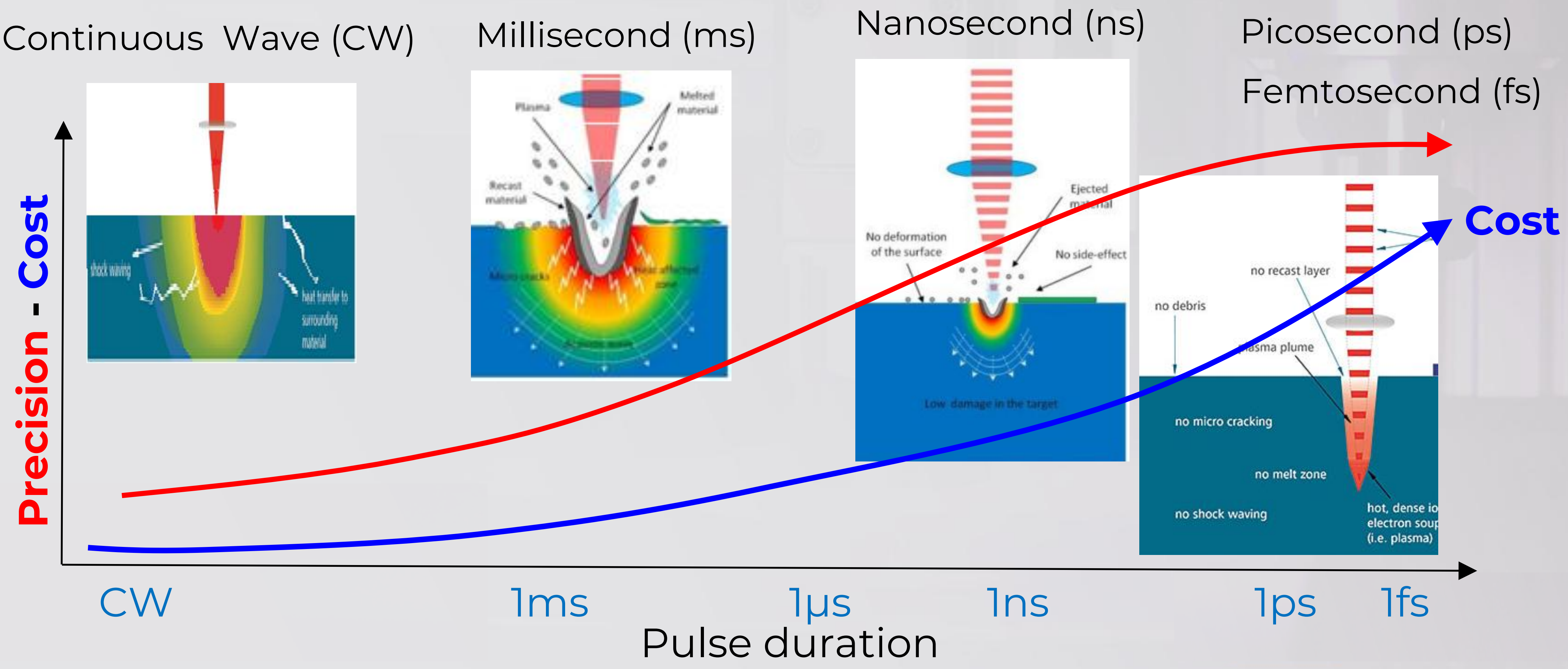
Pulsed



Source: https://litron.co.uk/product-range/lasers-for-piv/

Source: https://www.photonicsolutions.co.uk/product-detail.php?prod=6080

1.4 Laser Pulsing



1.4 Common Laser Terminologies - Power & Power density - CW

Power = W (J/s)

Power density = Power/beam spot area = W/cm^2

$$F = \frac{P}{A}$$

F: Power density (W/cm^2)
P: Laser power
A: Beam cross sectional area

$$P = \frac{E}{\Delta t}$$

P: Laser power
E: Energy (J)
Δt = Pulse duration (*s*)

1.4 Common Laser Terminologies - Peak & Average Power – Pulsed lasers

Peak Power:

Rate of energy flow in every pulse

$$P_{peak} = \frac{E}{\Delta t}$$

E = Pulse Energy (J)
Δt = Pulse duration (s)

Average Power:

Rate of energy flow averaged over one full period

$$P_{Avg} = \frac{E}{T} = Ef$$

$$Frequency = f = \frac{1}{T}$$

Fluence:

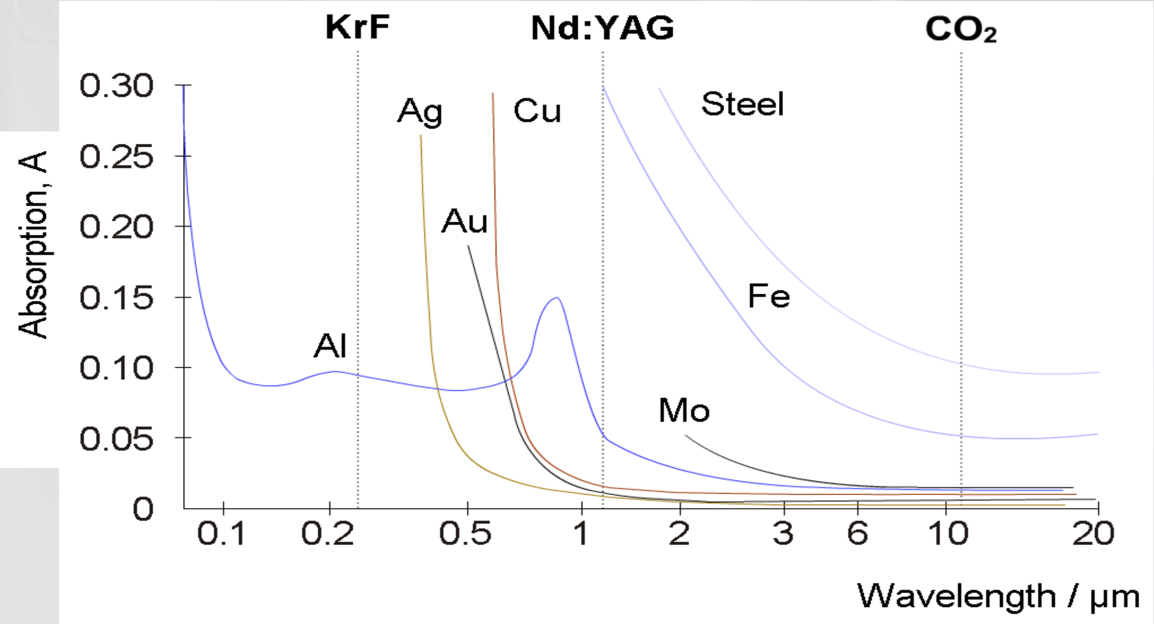
Ratio of pulse energy to spot area

$$F = \frac{Pulse\ energy\ (J)}{area(cm^2)}$$

1.5 Laser – Material Interaction

Absorption of a laser beam by material mainly occurs in three ways:

1. Fresnel absorption - Thermal based process
2. Ablation - Non-thermal based process
3. Inverse Bremsstrahlung absorption (not for opaque material)



1.6 Major Components of a Laser System

1. Laser (Fibre; Excimer; Nd:YAG; Diode.....)
2. Beam delivery system
3. Beam focusing system
4. Assist gas
5. Beam manipulation system

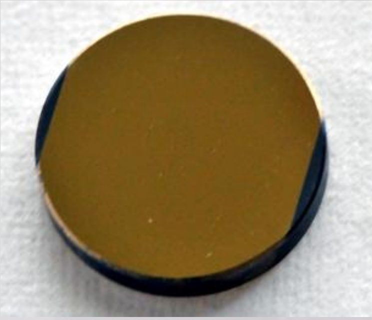
1.6 Major Components of a Laser System
Beam delivery system

Depending upon the wavelength and laser power/energy

A. Mirror (can be used for all lasers)

B. Fibre optics (restricted to some wavelength and beam intensity)

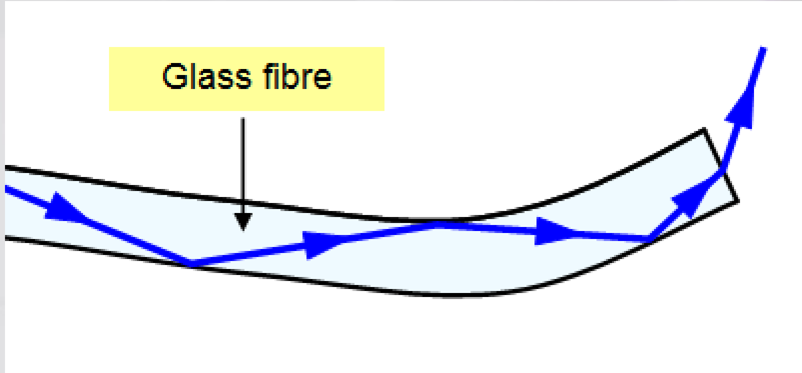
1.6 Major Components of a Laser System Mirrors



Copper with gold coating

Fused silica with dielectric coating

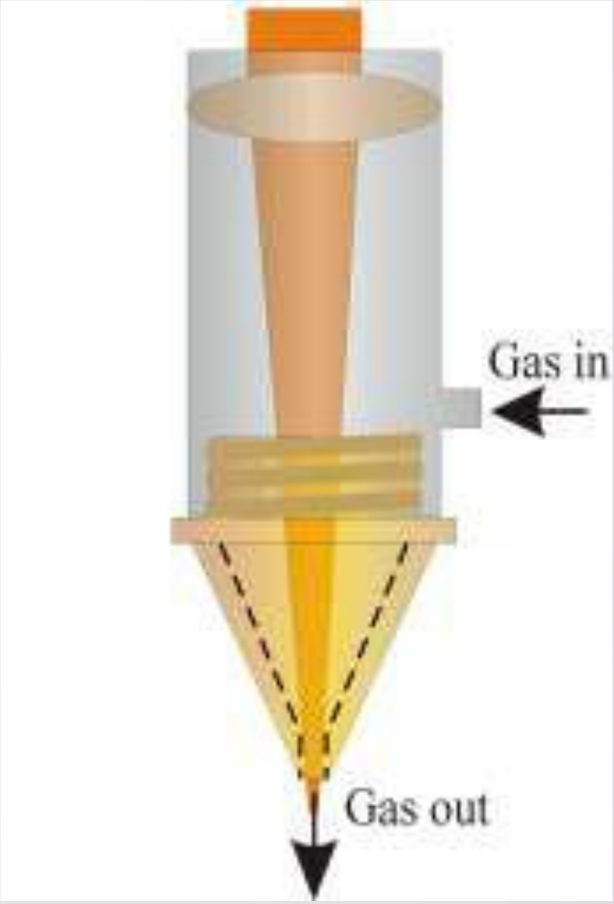
1.6 Major Components of a Laser System
Fibre Optics



1.6 Major Components of a Laser System
Nozzle and Nozzle Assembly

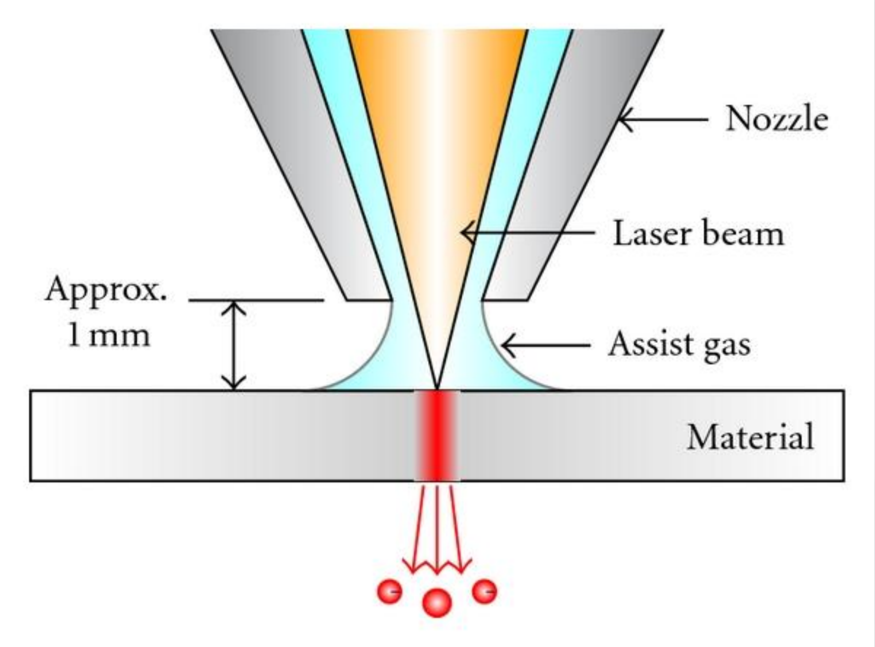
Below the lens, around the focused laser beam, a nozzle is generally used to

- **Direct gas to the interaction area**
- **Prevent damaging the optics**



1.6 Major Components of a Laser System
Assist Gas

- To remove the melt or oxides produced due to laser interaction.
- To protect melt pool and hot workpiece from atmospheric contamination and **oxidation**.
- As reactive gas to produce more energy.
- To cool the substrate and **blow away the plasma**.
- To protect the **laser optics from metal vapour**.



Source: Ozaki, Hitoshi, et al. "Cutting properties of austenitic stainless steel by using laser cutting process without assist gas" *Advances in Optical Technologies* 2012 (2012).

1.6 Major Components of a Laser System
Beam manipulation systems

To achieve relative movement between the laser beam and the work piece

- CNC based
- Robot
- Galvo scanner

1.6 Major Components of a Laser System
Beam manipulation systems – CNC System

- The workpiece is moved by clamping it to a CNC table e.g. milling machine bed.
- For small and medium sized components.
- For machining complex surfaces e.g. turbine blades, a minimum 5-axis system is used.

Simple X-Y axis traverse

Source: https://www.aerotech.co.uk/

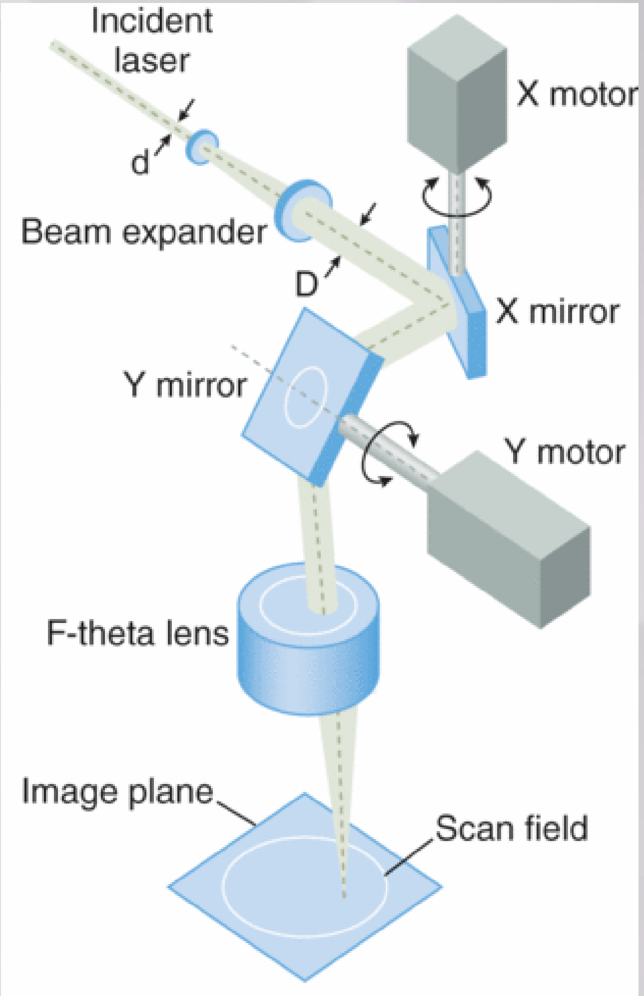
1.6 Major Components of a Laser System
Beam manipulation systems - Robot

- Mostly with fibre coupled lasers like Nd:YAG, Fibre, Diode.

https://www.youtube.com/watch?v=7k20Zp5aPjY

1.6 Major Components of a Laser System
Beam manipulation systems - Galvo Scanner

- Fast (10s of m/s) and accurate scanning.
- Application: **Laser marking**, laser cutting, rapid prototyping
- Size is limited by keeping within the "depth of focus" i.e. not de-focusing enough to change the processing characteristics



Source: https://www.laserfocusworld.com/optics/article/16554962/optical-materials-silicon-carbide-mirrors-benefit-highspeed-laser-scanning

FLASH

Flexible Laser-Based Manufacturing

2 – Laser cutting

Flexible Laser-Based Manufacturing

Co-funded by the European Union

2. Overview - Cutting

1. Laser cutting methods
2. Features of laser cutting
3. Main process variables
4. Typical applications

2.1 Laser Cutting Methods

Process description:

1. Heating
2. Melting / Exothermic reaction
3. Vaporisation/ Ejection

Types of laser cutting:

- Vaporisation
- Fusion (melt and blow)
- Reactive Fusion (melt, burn and blow)
- Cold Cutting (ultra-short pulse laser)

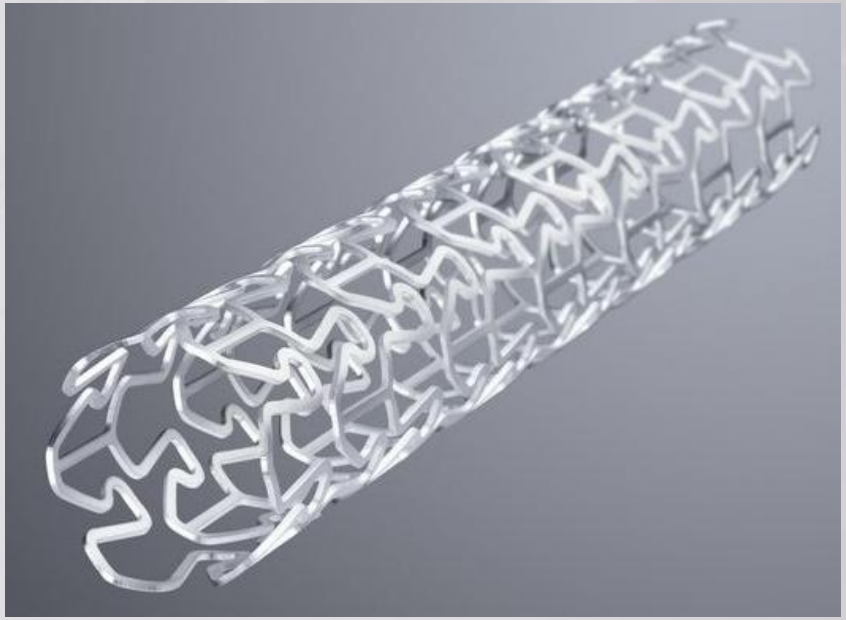
2.1 Laser Cutting Methods
Vaporisation Cutting

- The **focused beam first heats up the surface to boiling point** and thus generates a keyhole.
- Keyhole causes a sudden increase in the absorptivity due to black body multiple reflections and consequently deepens quickly.
- As deepening progresses, vapour is generated which escapes, blowing ejecta out of the hole/kerf.
- Better for cutting non-conductive materials which do not melt – wood, concrete, carbon.
- Cutting metals < 1.5 mm thick

Source: https://www.trumpf.com/en_GB/applications/laser-cutting/sublimation-cutting/

2.1 Laser Cutting Methods
Vaporisation Cutting

- Rarely used in sheet metal fabrication.
- Used in applications involving delicate cutting work, such as producing stents.



www.trumpf.com

2.1 Laser Cutting Methods
Fusion Cutting - Melt and Blow

- Once a material has been melted and a hole is made, then with a sufficiently strong gas jet it is possible to blow the molten material out of the cut – *melt and blow*.
- The need to raise the temperature of the material to boiling or beyond to effect ejection is avoided; therefore, fusion cutting requires only half the energy for vaporization cutting.
- Because boiling does not occur, the HAZ in fusion cutting is very small and the cuts themselves are clean.
- More efficient than vaporisation method but less efficient than the reactive fusion cutting.

2.1 Laser Cutting Methods
Reactive Fusion Cutting- Melt, burn and blow

- If a gas is used that react exothermically with the material being cut then a heat source additional to the laser beam is present.

- The reactive (burning) gas (oxygen) reacts exothermically with the workpiece (iron → iron oxide) adding a second heat source (laser = 60% of heat & oxygen 40% of heat) to speed up the process.

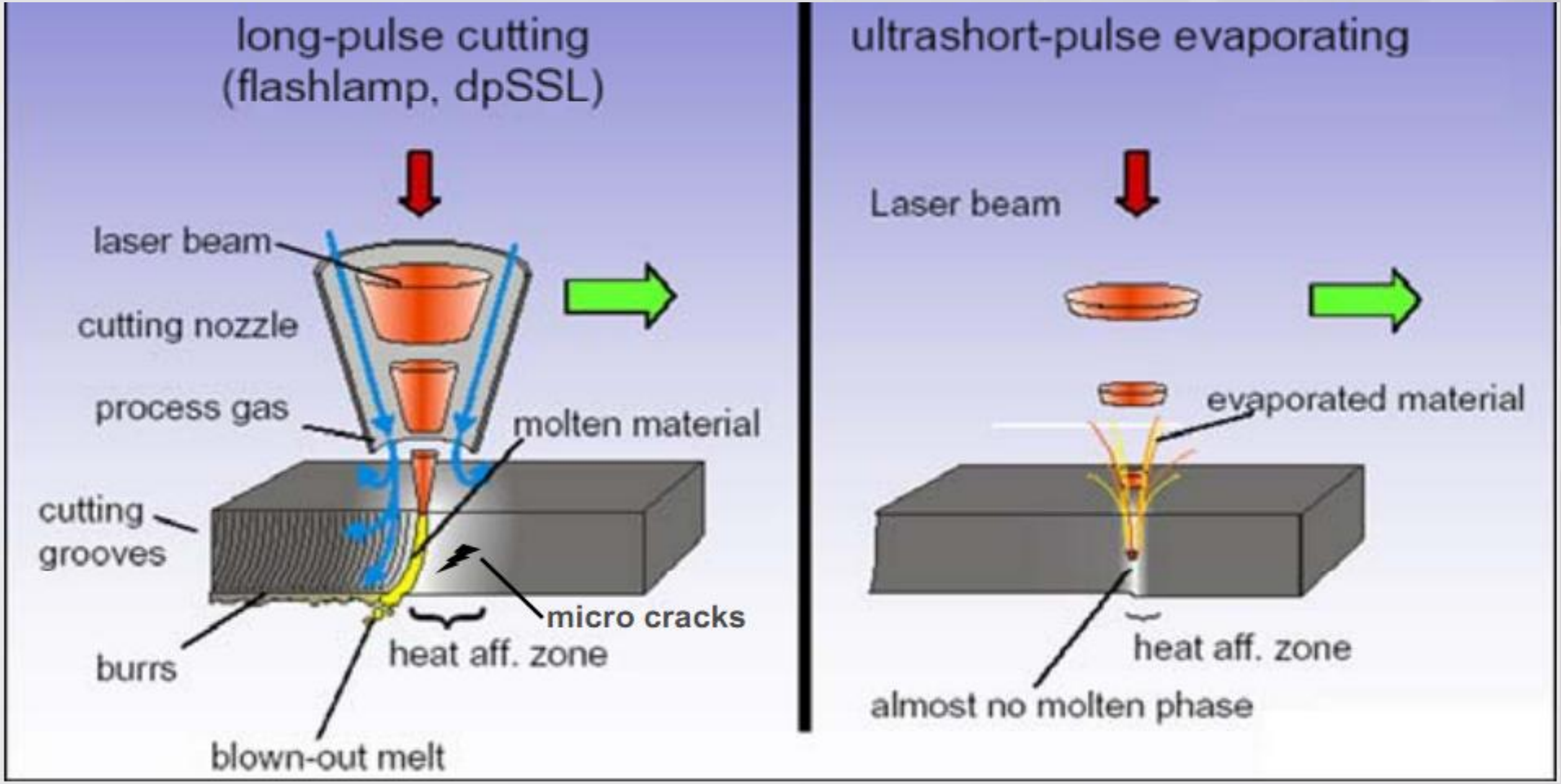
- If this reactive gas is supplied as a sufficiently strong gas jet then it will not only drag the melt out of the kerf, but will also react with melt – *melt, burn and blow.*

- The added energy allows a faster cut.

$$Fe + \frac{1}{2}O_2 \rightarrow FeO + \Delta H$$

$$\Delta H = 275.58 \text{ kJ/mol}$$

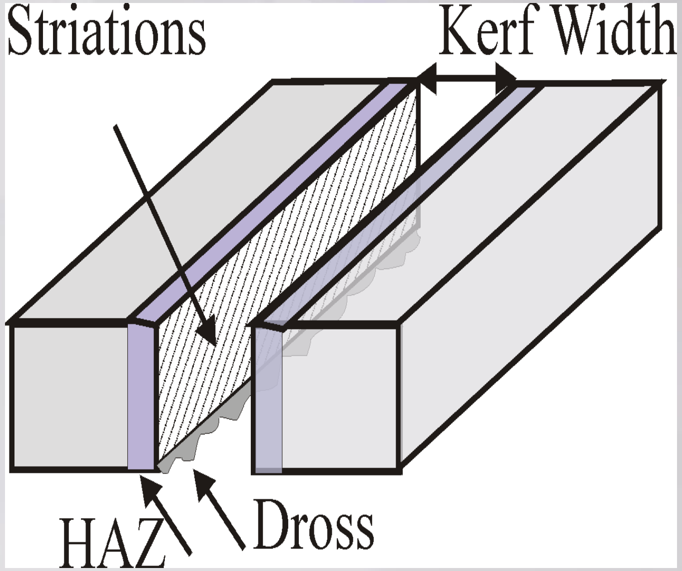
2.1 Laser Cutting Methods
Cold Cutting – using ultra-short pulse laser



Source: Swisstec

2.2. Features of the laser cut samples

- The cut width is called the kerf width.
- Un-removed molten material is called dross.
- The characteristic marks on the cut edge are called striations.
- The heated but un-melted material is called the heat affected zone (HAZ).



2.3 Main process variables - Laser Cutting

Laser cutting is a multi-parameter process:

- **Laser characteristics** (power, mode, pulse or CW, size, wavelength, polarization, optical configurations)
- **Gas properties** (pressure, nozzle position, alignment, composition)
- **Transporter properties** (speed, focal position)
- **Material properties** (optical, thermal)

2.3 Main process variables - Laser Cutting

Typical Laser Types:

- CO_2 laser
- Nd:YAG lasers
- Fiber laser
- Ultra-short pulse lasers

Typical Gas Jet Compositions:

- O_2 Mostly for reactive fusion cutting.
- Argon For aerospace application, reactive gas and nitrogen is avoided.
- Nitrogen High-speed cutting of thin sheets and to avoid oxidation scales on steel.
- Compressed air Low cost, but increase oxidation and dross.

2.4. Typical Applications

- Automotive construction
- Aircraft construction
- Metalworking
- Sheet metal working
- Shipbuilding
- Textile industry
- Medical technology


https://www.trumpf.com

3 – Laser drilling

Flexible Laser-Based Manufacturing

FLASH
Flexible Laser-Based Manufacturing

Co-funded by
the European Union

3. Overview - Drilling

1. Introduction
2. Types of laser drilling
3. Physical process in drilling of metals
4. Process parameters in laser drilling
5. Typical applications

3.1. Laser Drilling - Introduction

Laser drilling is used to create small holes in a material by either:

1. Melting and removing the molten materials with a gas jet;

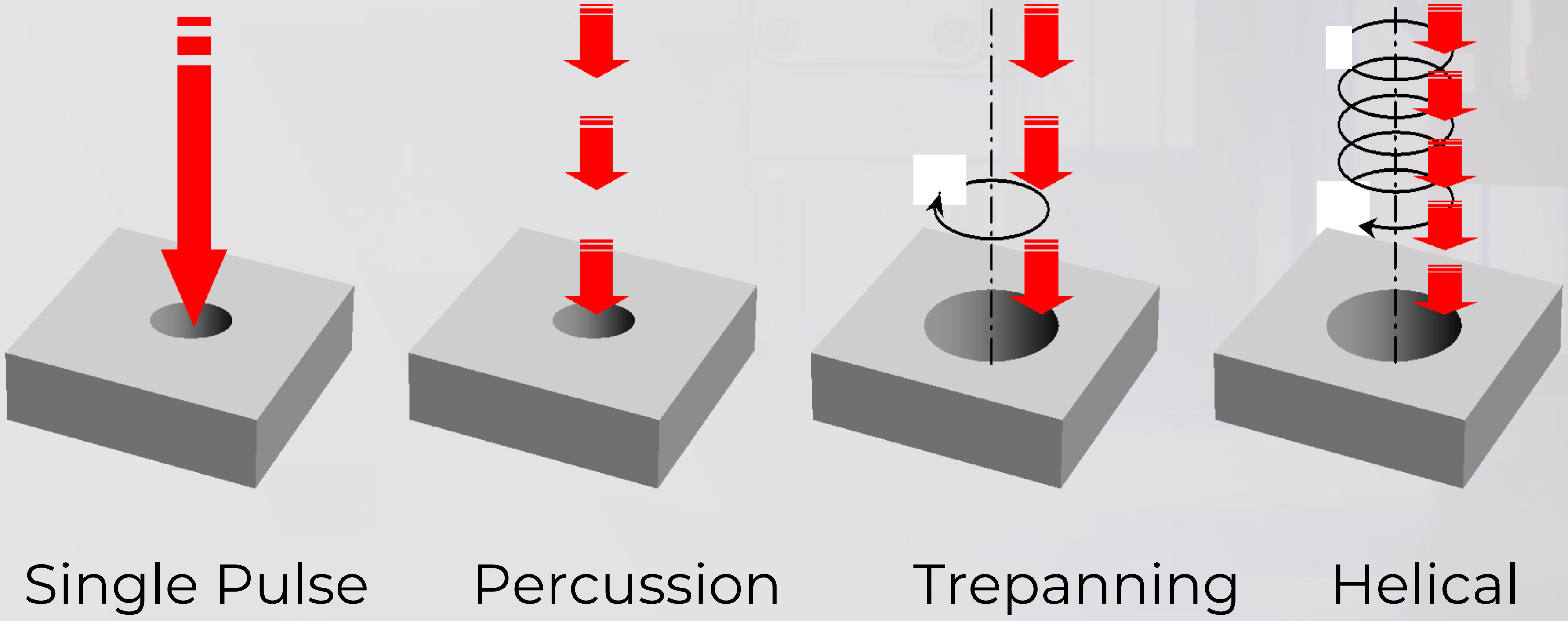
2. Removal by exothermic reaction;

3. Vaporization;

4. Ablation.

3.2 Types of Laser Drilling

The laser pulse to effect drilling can be delivered to substrate surface in four ways:

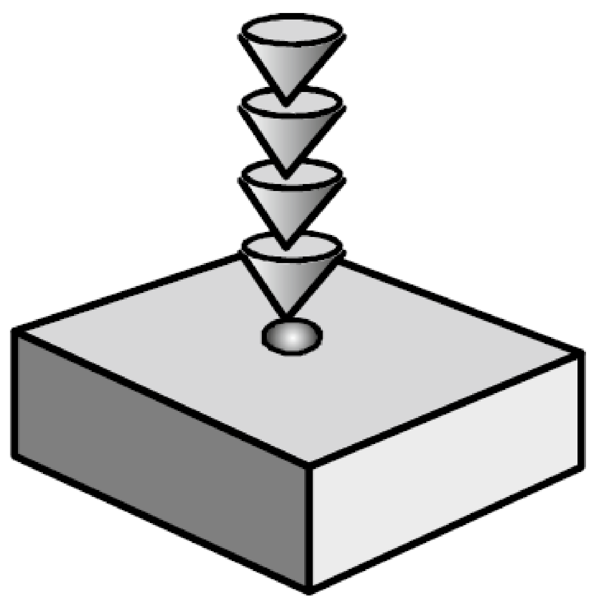


3.2 Types of Laser Drilling
Single pulse

- Diameters <500 μm in foils and thin metal sheets.
- **Fast drilling.**
- Poor reproducibility.
- **On-the-fly drilling – constant movement.**
- Drilling thin foils, food packaging.
- Drilling holes in aircraft wings.

3.2 Types of Laser Drilling
Percussion

- Series of pulses with specified energies and durations are directed onto the same spot on the substrate surface.
- Diameters between 200µm and 1m in materials of up to 10 mm thickness.
- Drilling holes in turbine blades.
- High aspect ratio.
- Reduction in process time.
- Also used with on-the-fly drilling.



Source: https://www.youtube.com/watch?v=83OQTZZ4ML8

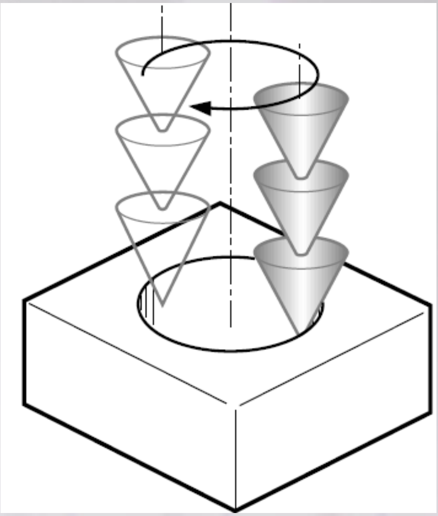
3.2 Types of Laser Drilling
Trepanning

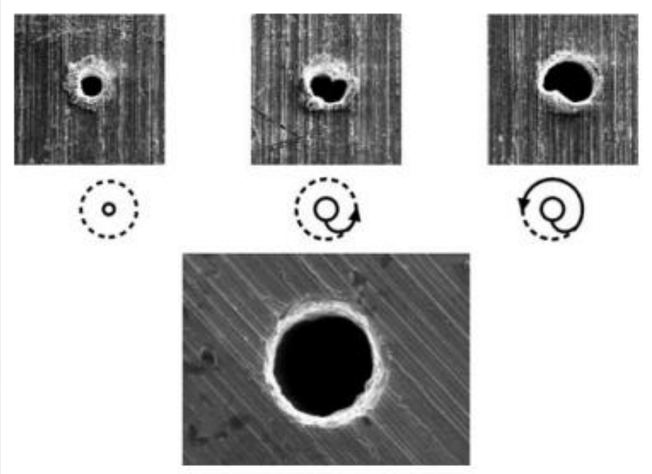
- Cutting out the hole by performing a relative motion (circular or noncircular) between the laser beam and the workpiece.

- Beam focused to smaller diameters.

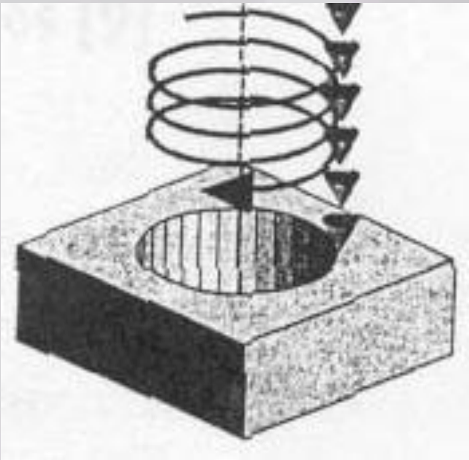
- **Improved hole quality and repeatability.**

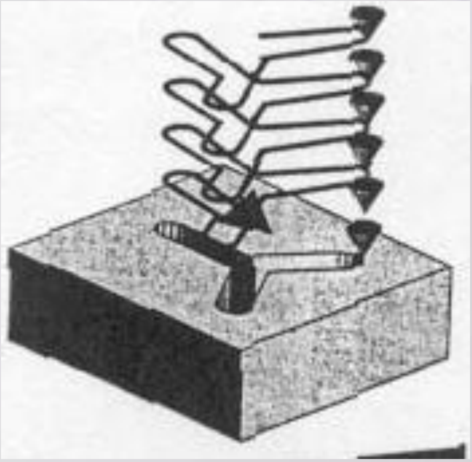
- Time consuming and is often limited to depths less than 12 mm.





3.2 Types of Laser Drilling
Helical Drilling





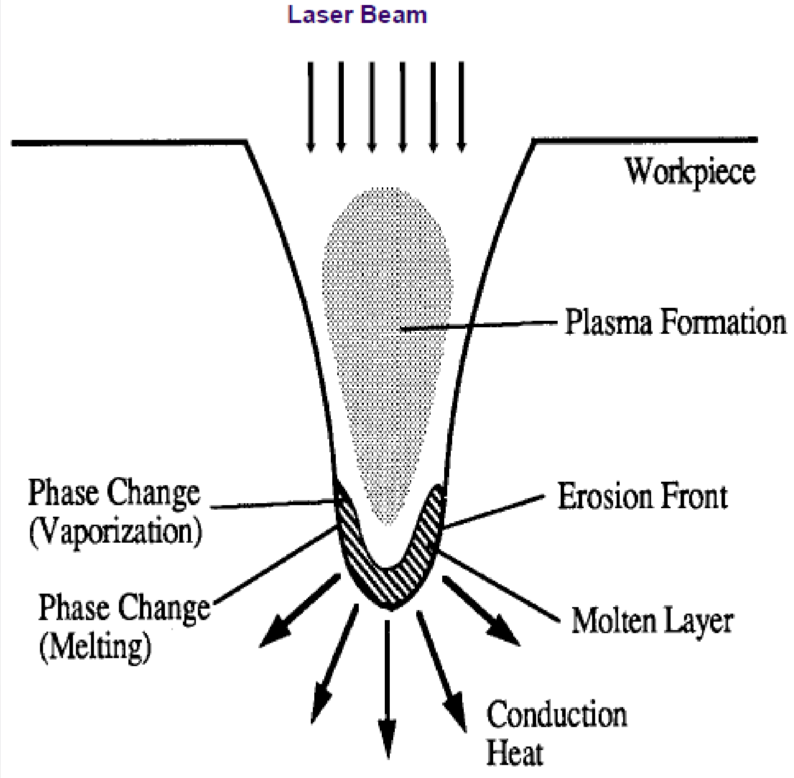
- Breaking up of the process into a multitude of ablation steps in order to enhance the accuracy.
- In contrast to trepanning, the helical drilling reaches the breakthrough only after many turns of spiral describing the path of the ablation front.
- More deviation from circular geometry can be reduced than trepanning.
- Recast layers can be greatly reduced or completely avoided.

https://www.youtube.com/watch?v=CS60VzA

3.3 Physical process in drilling of metals

Drilling stages

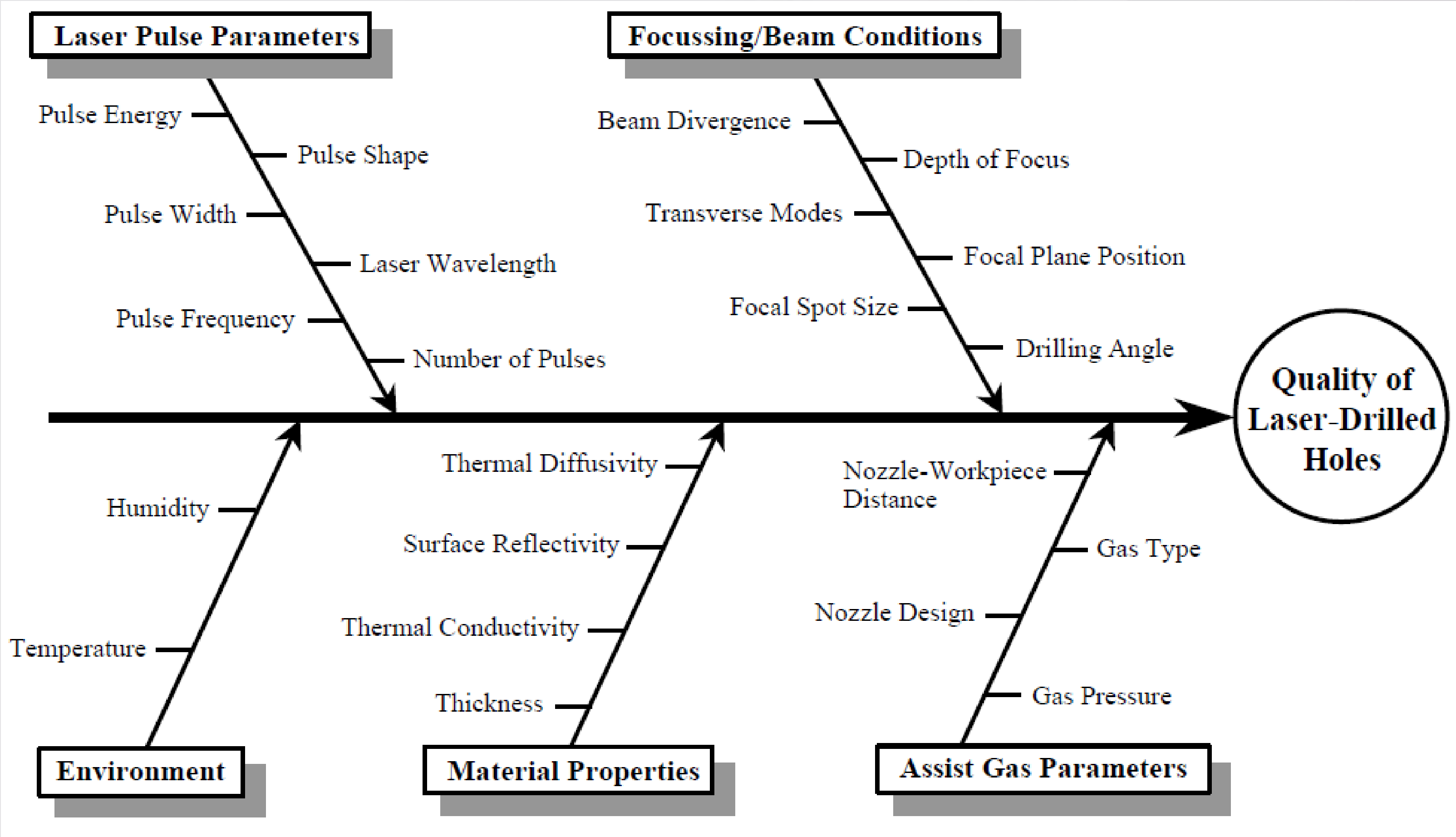
1. Surface heating without phase change.
2. Surface melting.
3. Vaporization.
4. Melt ejection.



Other phenomena

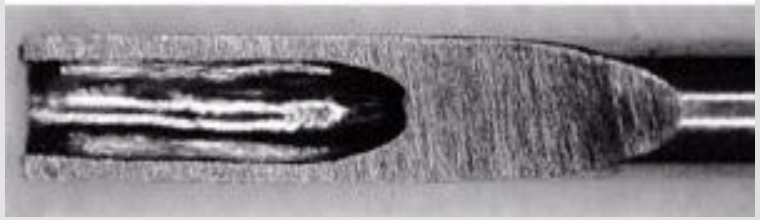
1. Multiple reflections.
2. Plasma formation.

3.4 Process Parameters for Laser Drilling

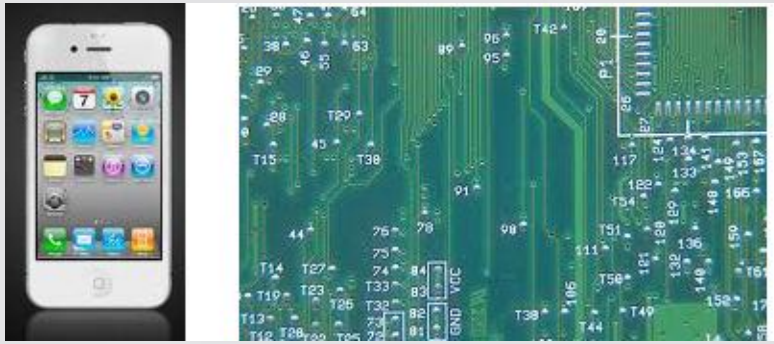


3.5. Typical Applications

- Microelectronics
- Medical devices
- Aerospace
- Automotive
- Jewellery



Surgical Needle



PCB Drilling

Laser Drilling of Combustors

FLASH
Flexible Laser-Based Manufacturing

4 – Laser surface engineering

Flexible Laser-Based Manufacturing

Co-funded by
the European Union

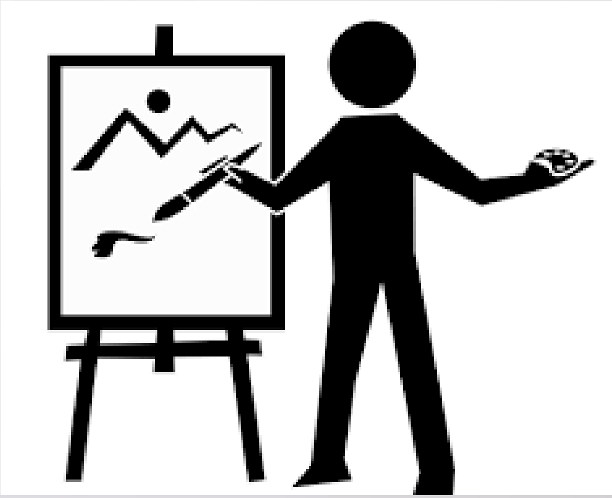
4.0 Overview

1. Introduction to laser texturing
2. Laser texturing technique
3. Theory of photon energy transfer
4. Laser source and capabilities
5. Laser texturing applications

4.1 Introduction
How does Laser Texturing Works?

Laser texturing in simple terms is effectively drawing with light

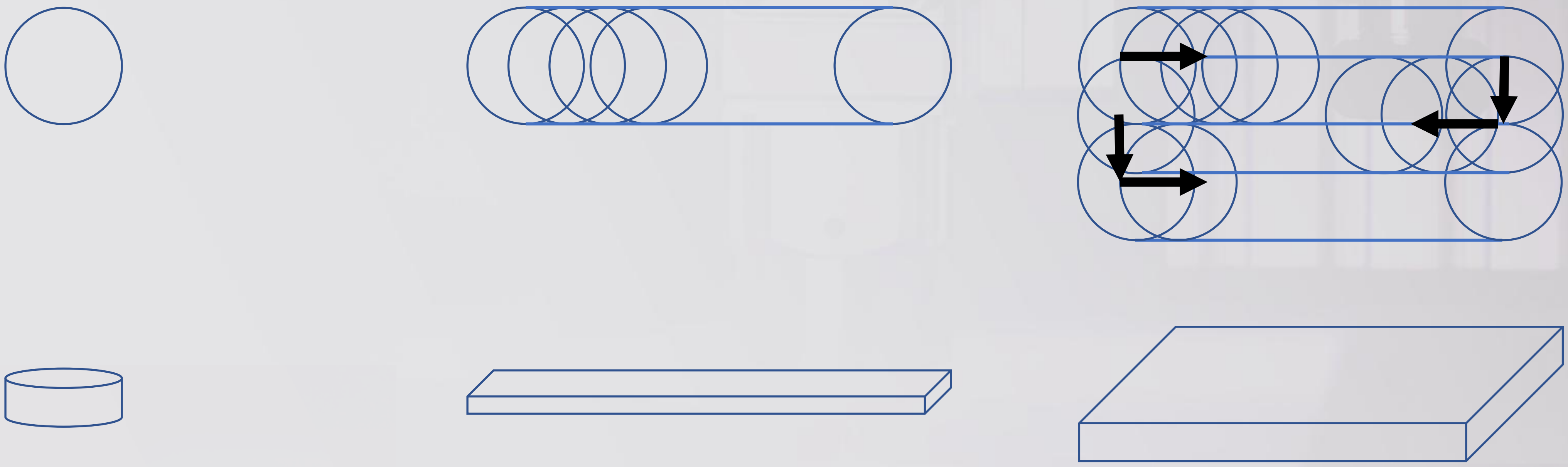
- Tool = laser beam
- Tool size = laser beam spot size (typically in tens of microns diameter as it is circular)



Source: choochart

4.1 Introduction
How does Laser Texturing Works?

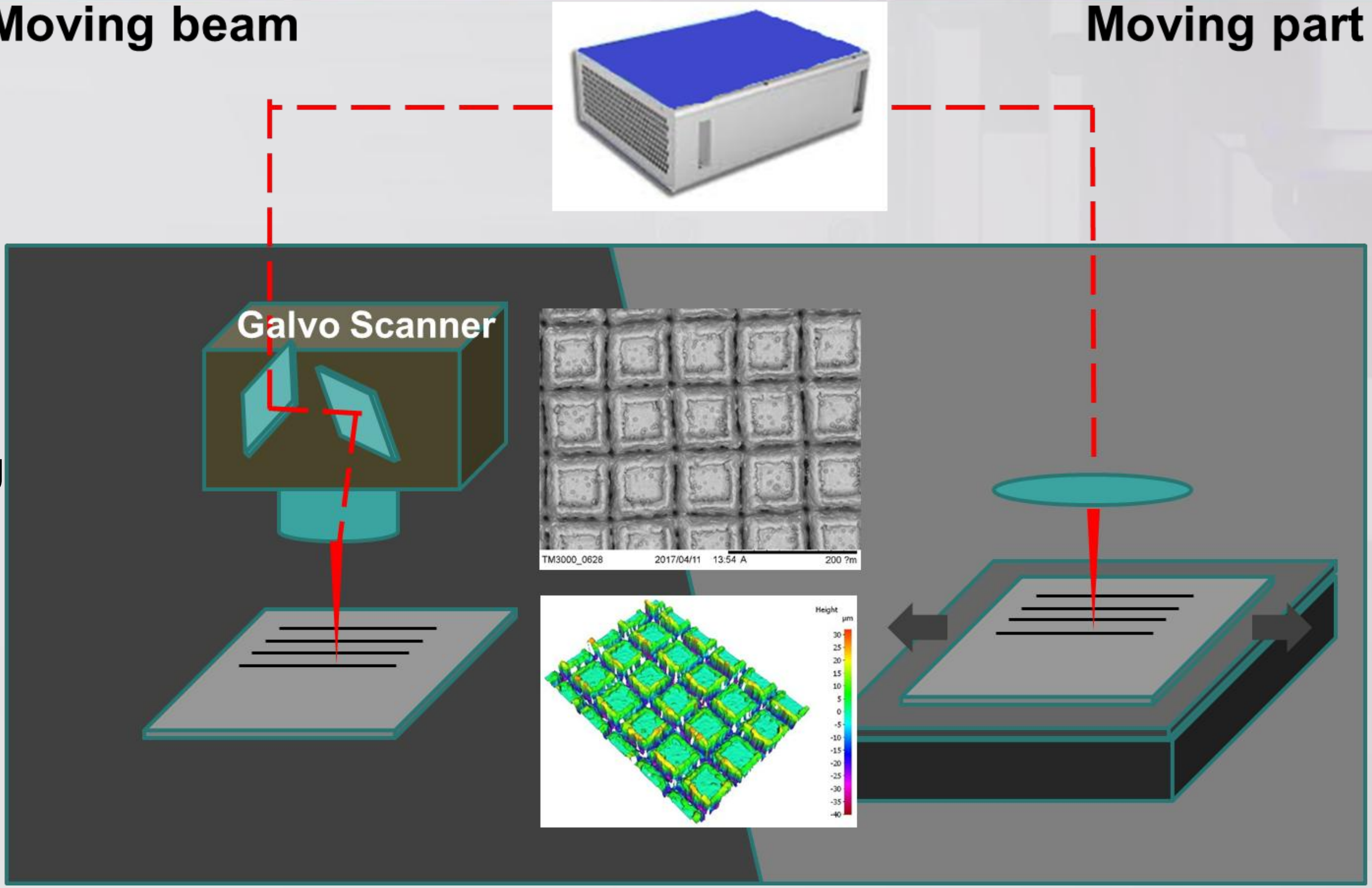
Spot	Line	Area



4.2 Laser Texturing Techniques

Moving beam **Moving part**

Small scanning area
100 × 100 mm



Slow processing speed

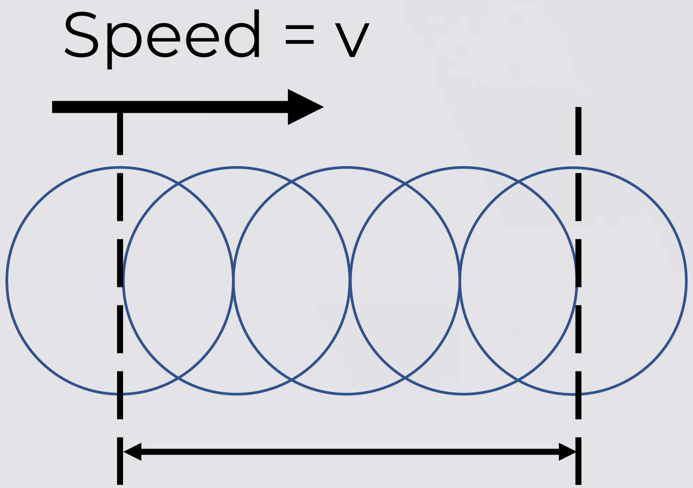
4.2 Laser Texturing Techniques
Fundamentals of pulsed laser ablation

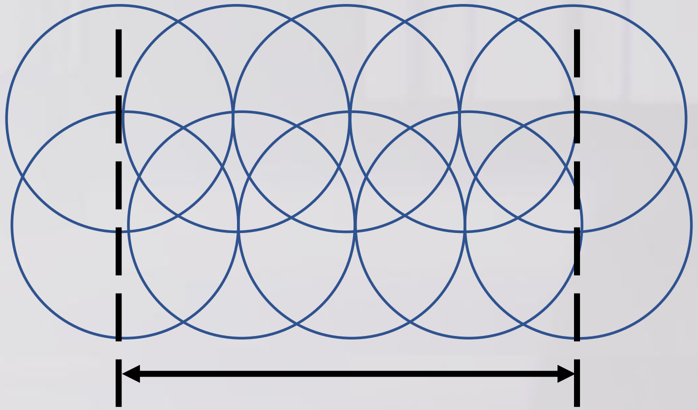
Key laser parameters/ matrix:

- Laser fluence (energy density)
- Number of Pulses (NOP)

$$Laser\ fluence = \frac{Pulse\ energy}{Beam\ spot\ size}$$

$$NOP = \frac{Beam\ spot\ size \times Frequency}{Speed}$$

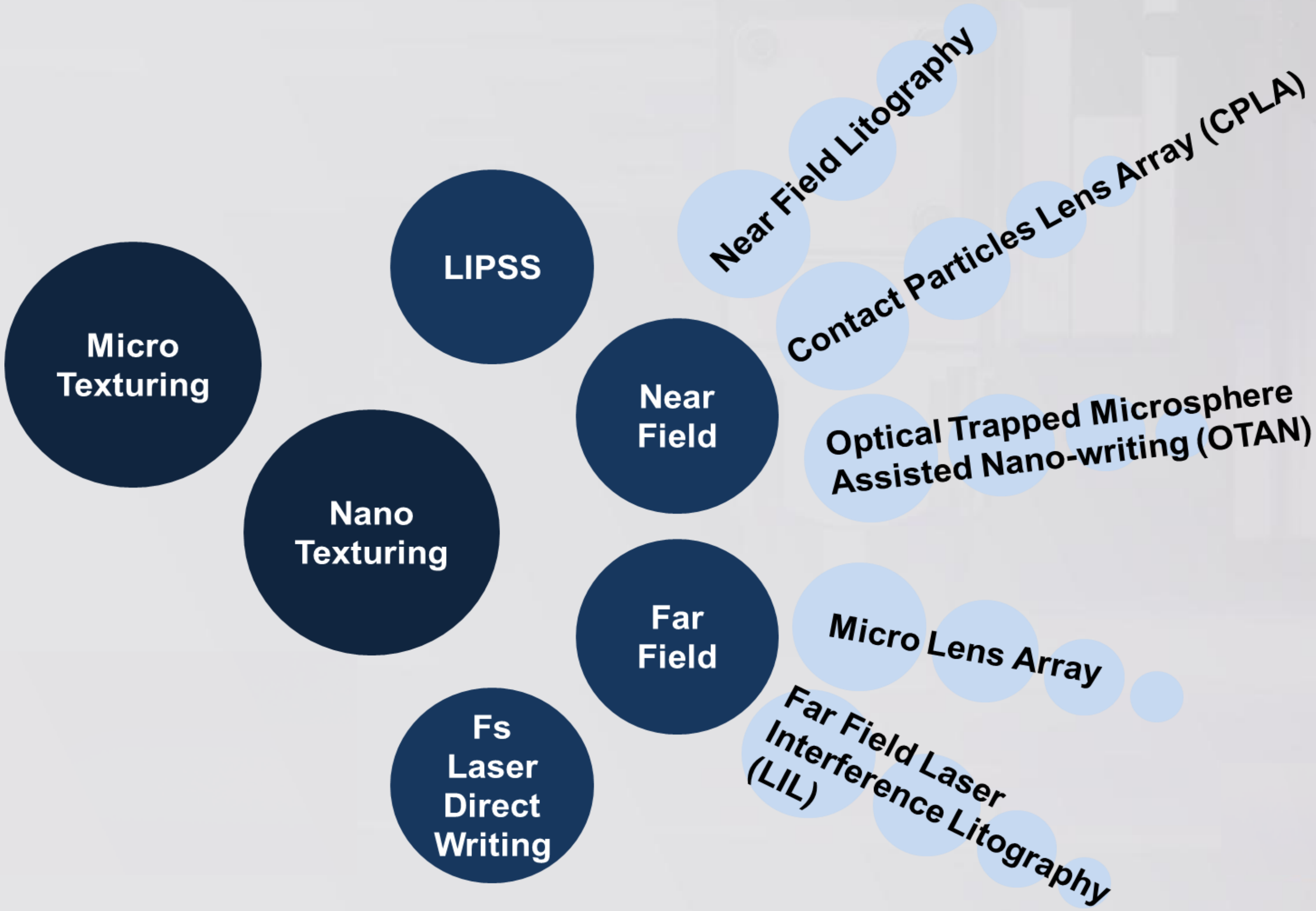




4.2 Laser Texturing Techniques
Texturing methodology

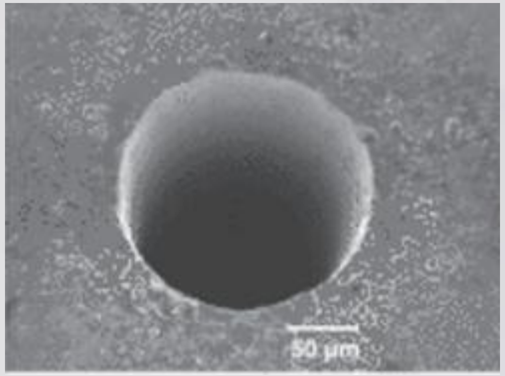
What are the differences between the two scanning tool path strategy?
Which one is faster? Why?
Which one will have less thermal damage? Why?

4.2 Laser Texturing Techniques

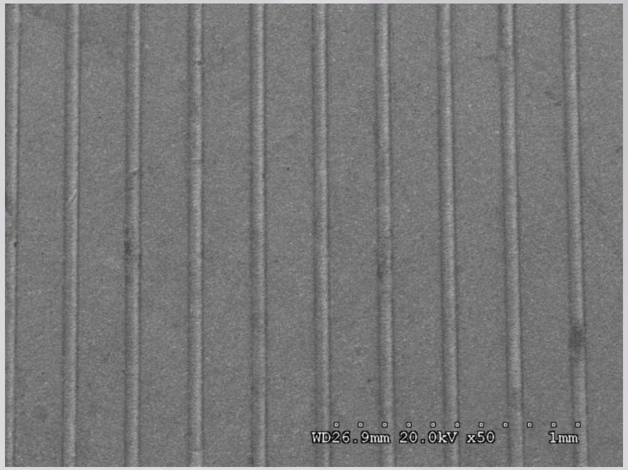


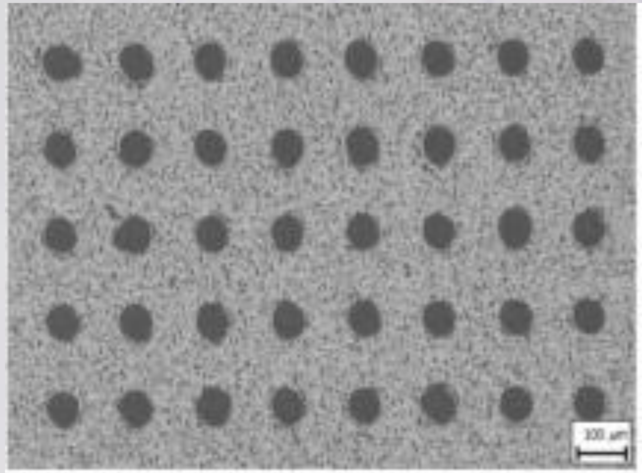
4.2 Laser Texturing Techniques
Micro texturing

- Produce texture of micro level
- Texturing size is limited by beam spot size
- Usually texture using laser fluence close to ablation threshold for high quality texture finish



Laser Focus World

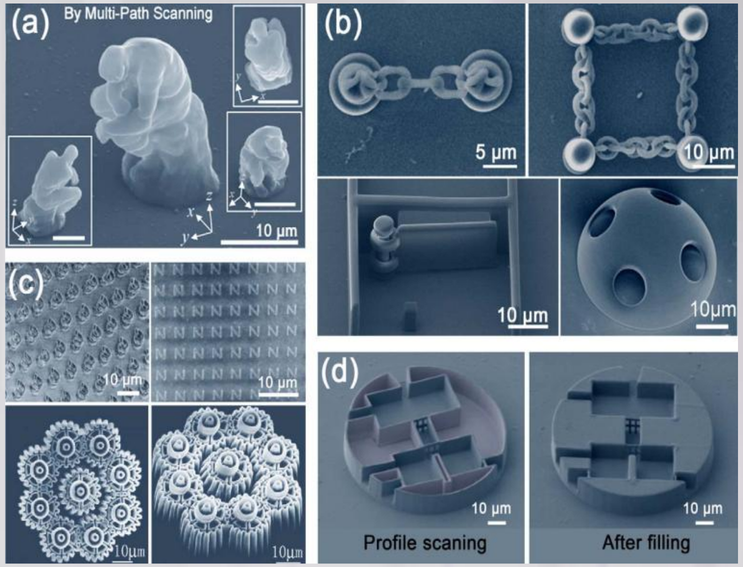


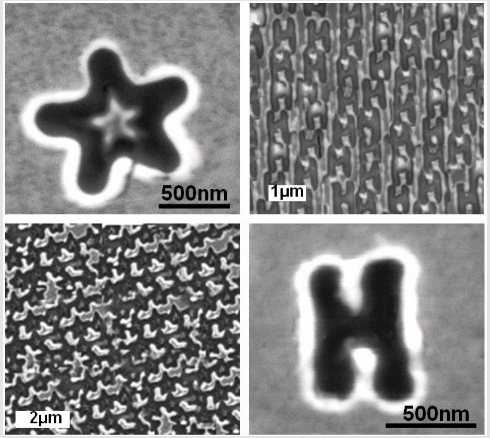


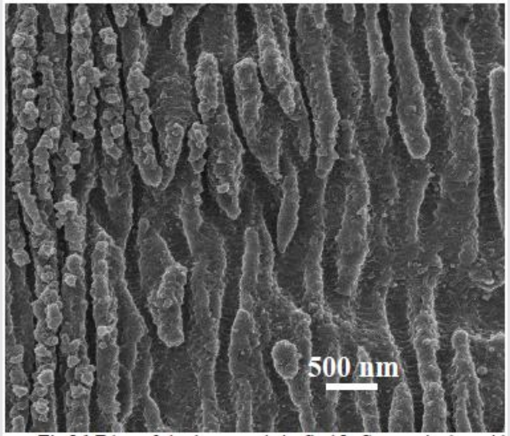
Joshi, Bhupendra & Tripathi, Khagendra & Gyawali, Gobinda & Lee, Soo. (2016). The effect of laser surface texturing on the tribological performance of different Sialon ceramic phases. Progress in Natural Science: Materials International. 26.

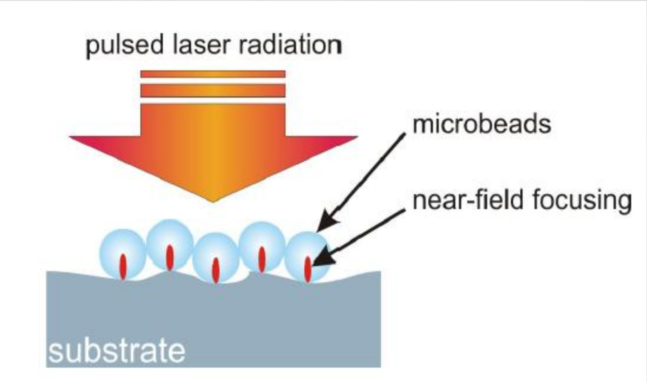
4.2 Laser Texturing Techniques
Nano texturing

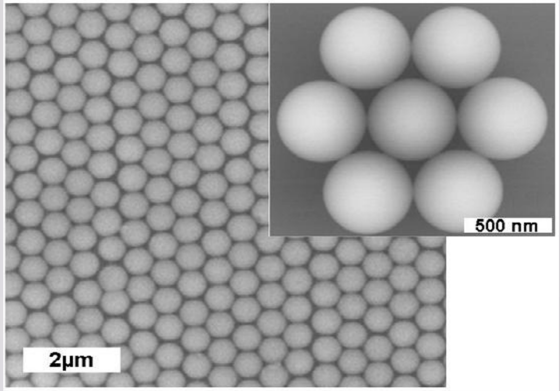
- Produce texture of sub-micro level
- Texture size is not limited to the beam spot size
- Limited type of materials are able to be textured:







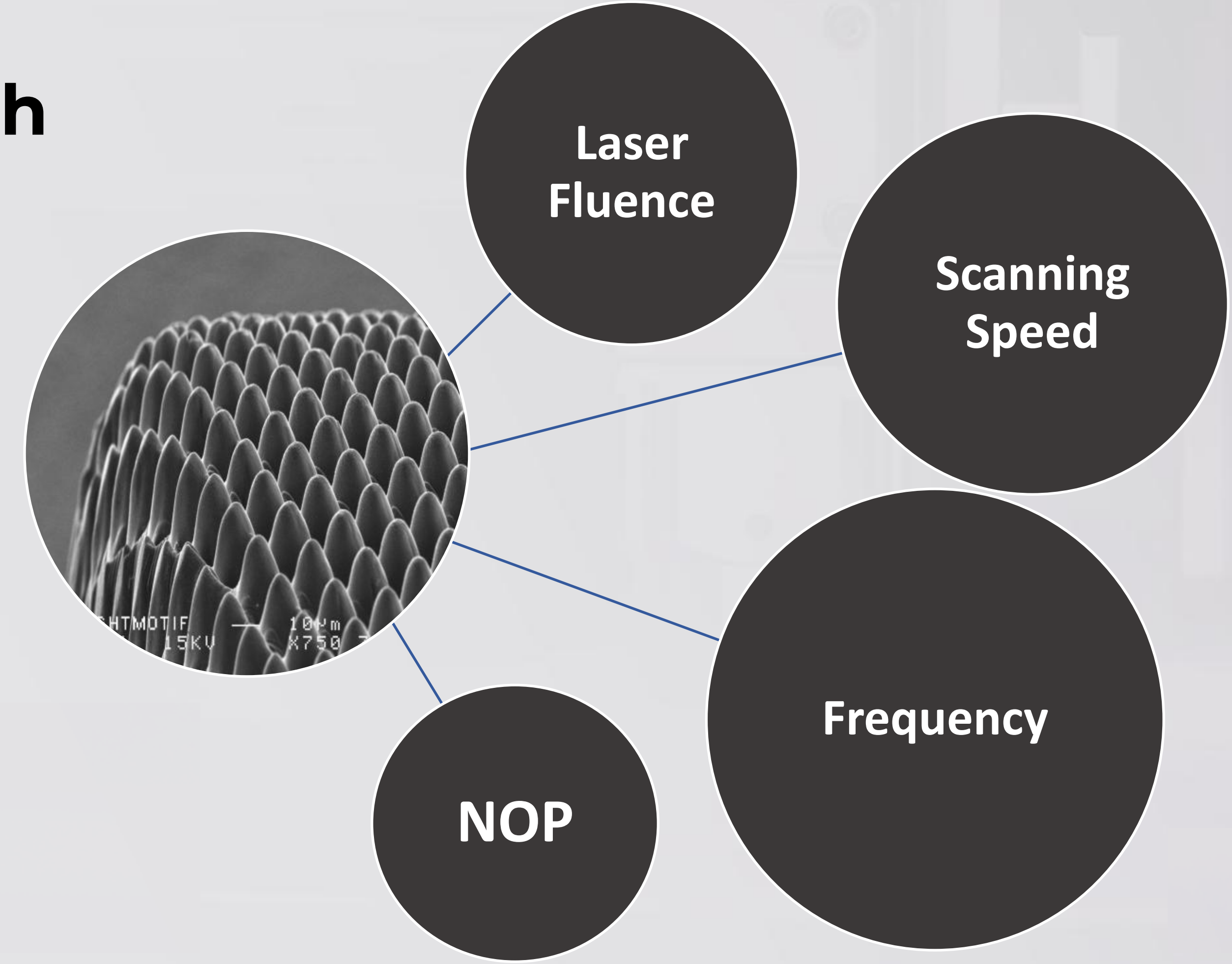




Lin Li, Minghui Hong, Michael Schmidt, Minlin Zhong, Ajay Malshe, Bert Huis in'tVeld, Volodymyr Kovalenko (2011). Laser nano-manufacturing – State of the art and challenges. CIRP Annals – Manufacturing Technology. 60.

4.2 Laser Texturing Techniques
Texturing Consideration Factors

- ✓ Time
- ✓ Surface Finish
- ✓ Cost

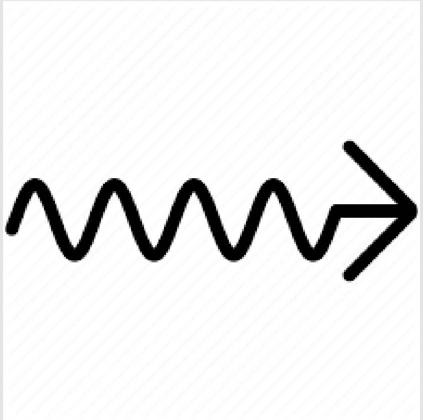


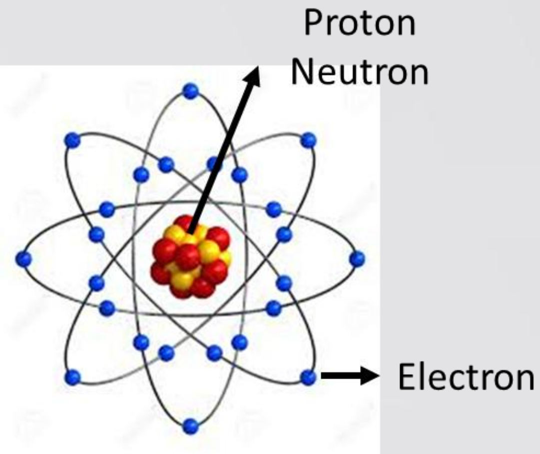
Source: Lightmotif

4.3 Theory of Photon Energy Transfer

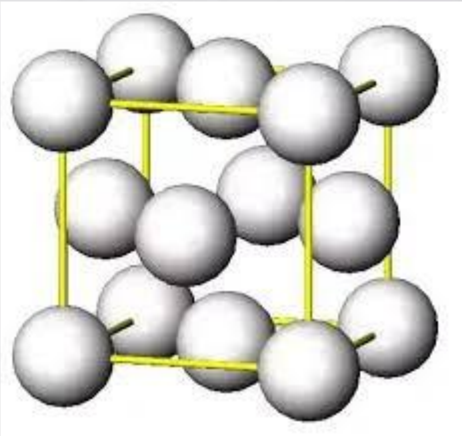
Cold ablation Femtosecond laser (pulse duration: x10^{-15}s) Picosecond laser (pulse duration: x10^{-12}s)	Thermal ablation Nanosecond laser (pulse duration: x10^{-9}s)

Photon Energy	Kinetic Energy	Thermal Energy





Dimitar Marinov



Quora

TW metals

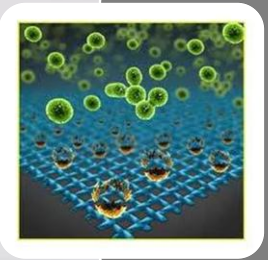
4.4 Laser Source and Capability

- Wavelength
  - UV (248nm, 355nm), visible (532nm), IR (800nm 1060nm, 1064nm)
- Pulse duration
  - Ultra-short (femtosecond, picosecond), Short (nanosecond, millisecond), CW
- Beam energy distribution
  - Gaussian, Top-hat
- Beam shape
  - Circular, Square, Rectangular
- Beam delivery
  - Fibre, Optics

4.5 Laser Texturing Applications

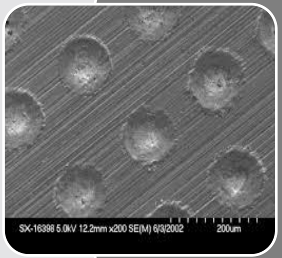
Self cleaning/ Anti-icing

- Domestic appliances
- Automobile
- Turbine/ Jet engine
- Aerospace and defence



Anti-microbial

- Medical



Tribology

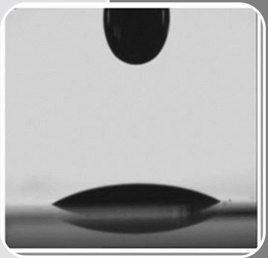
- Automobile
- Tooling
- Manufacturing

Adhesion

- Domestic appliances
- Turbine/ Jet engine
- Manufacturing

Anti-biofouling

- Marine



Hydrophilic Property

- Electronic manufacturing
- Biomedical field

Images from Google

FLASH
Flexible Laser-Based Manufacturing

5 – Laser welding

Flexible Laser-Based Manufacturing

Co-funded by
the European Union

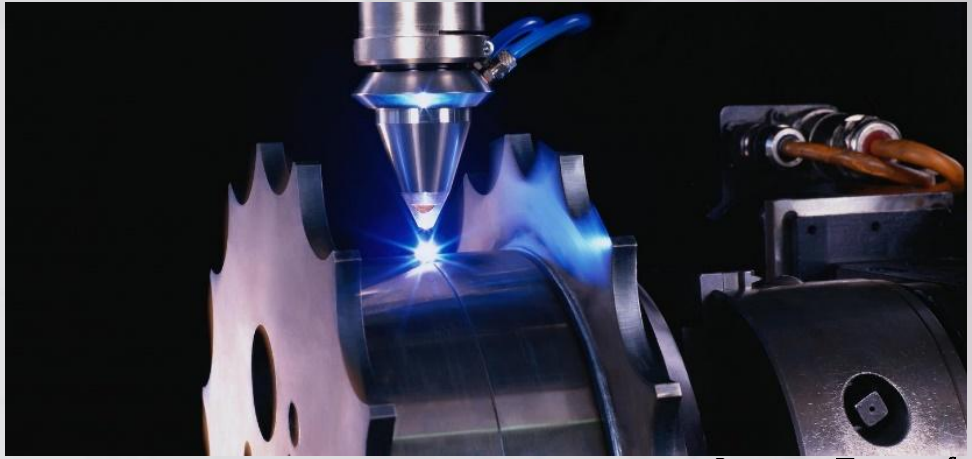
5.0 Overview

1. Introduction
2. Laser welding materials
3. Principles of laser welding
4. Laser welding parameters
5. Laser welding equipment
6. Laser welding technologies
7. Laser welding examples

5.1 Introduction

Why use lasers for welding?

- Ability to focus kW of power to <0.4mm spot diameter giving power densities $>$MW/cm^2
- High aspect ratio welds
- Controllable heat input
- Minimal distortion
- Very fast welding speeds
- Non-contact
- Single sided
- Automated
- Repeatable process



Source: Trumpf

Source: NTS Hermus

5.2 Laser Welding Materials

CARBON STEELS

- Readily weldable up to 0.25% C
- > 0.3% C more difficult
- Surface contaminates can produce porosity
- Weld generally equals base metal strength

STAINLESS STEELS

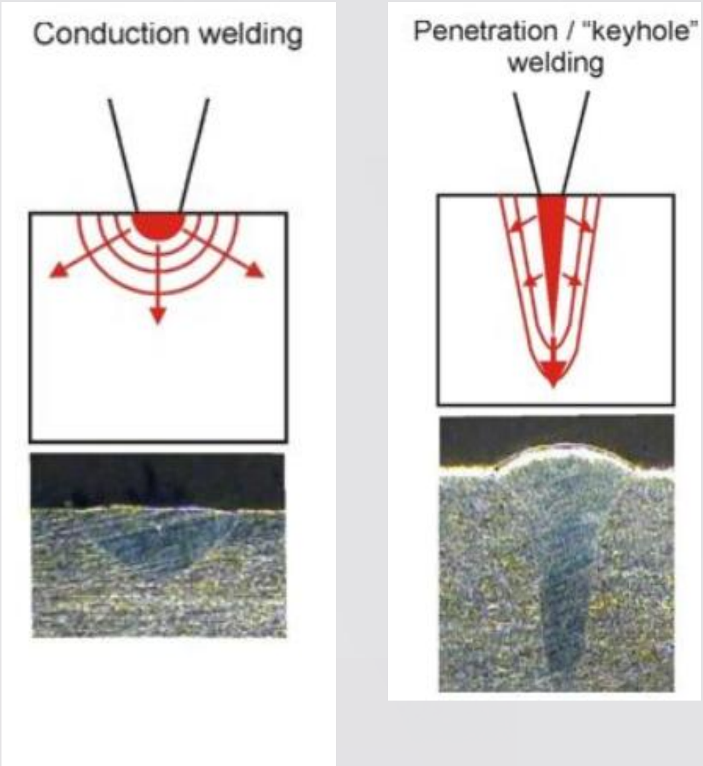
- Most alloys readily weldable:
  - All 300 series except 303, 303Se
  - Some 400 series
- Less heat required than for C steels
- Ni and Cr equivalents affect hot cracking
- carbide precipitation may be a problem in corrosive environments

Polymers (Not covered in this training)

ALUMINIUM ALLOYS

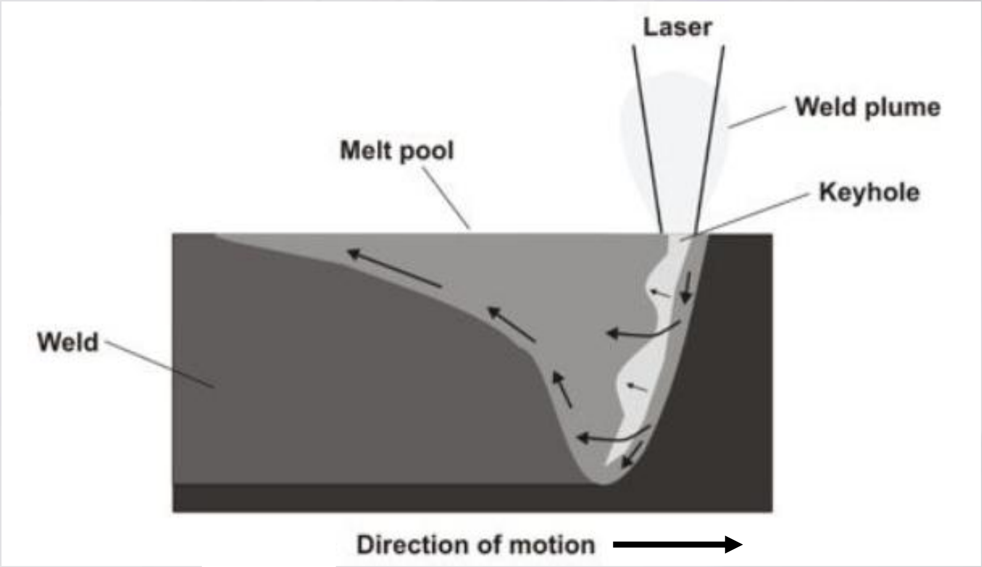
- Highly Reflective Material
  - Rapid heat conduction
  - Requires high power density
  - Low viscosity
- Surface oxides can be problematic
- Alloy specific: 1xxx, 3xxx, 5xxx, 6xxx series
  - some combinations may need filler metal

5.3 Principle of Laser Welding



Source: Amada Miyachi

Keyhole visualisation during welding

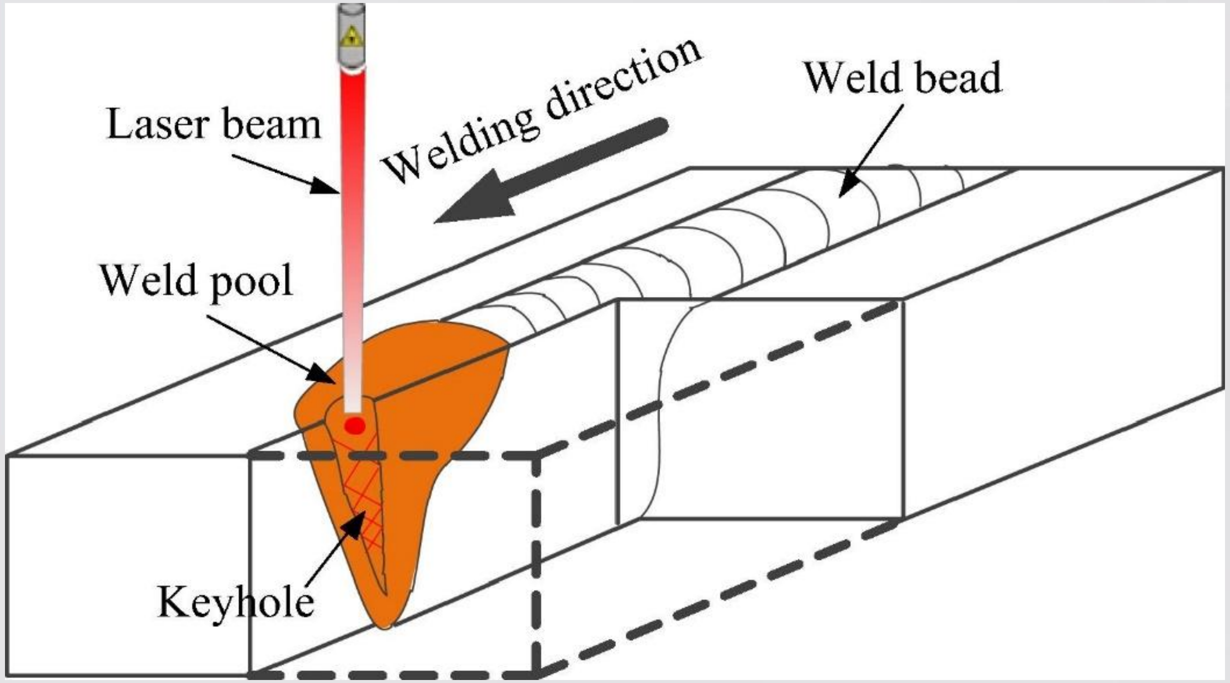


Source: Amada Miyachi

5.3 Principle of Laser Welding
Keyhole Welding

High average power
Focused beam
Small spot size

Sufficient power density to cause boiling



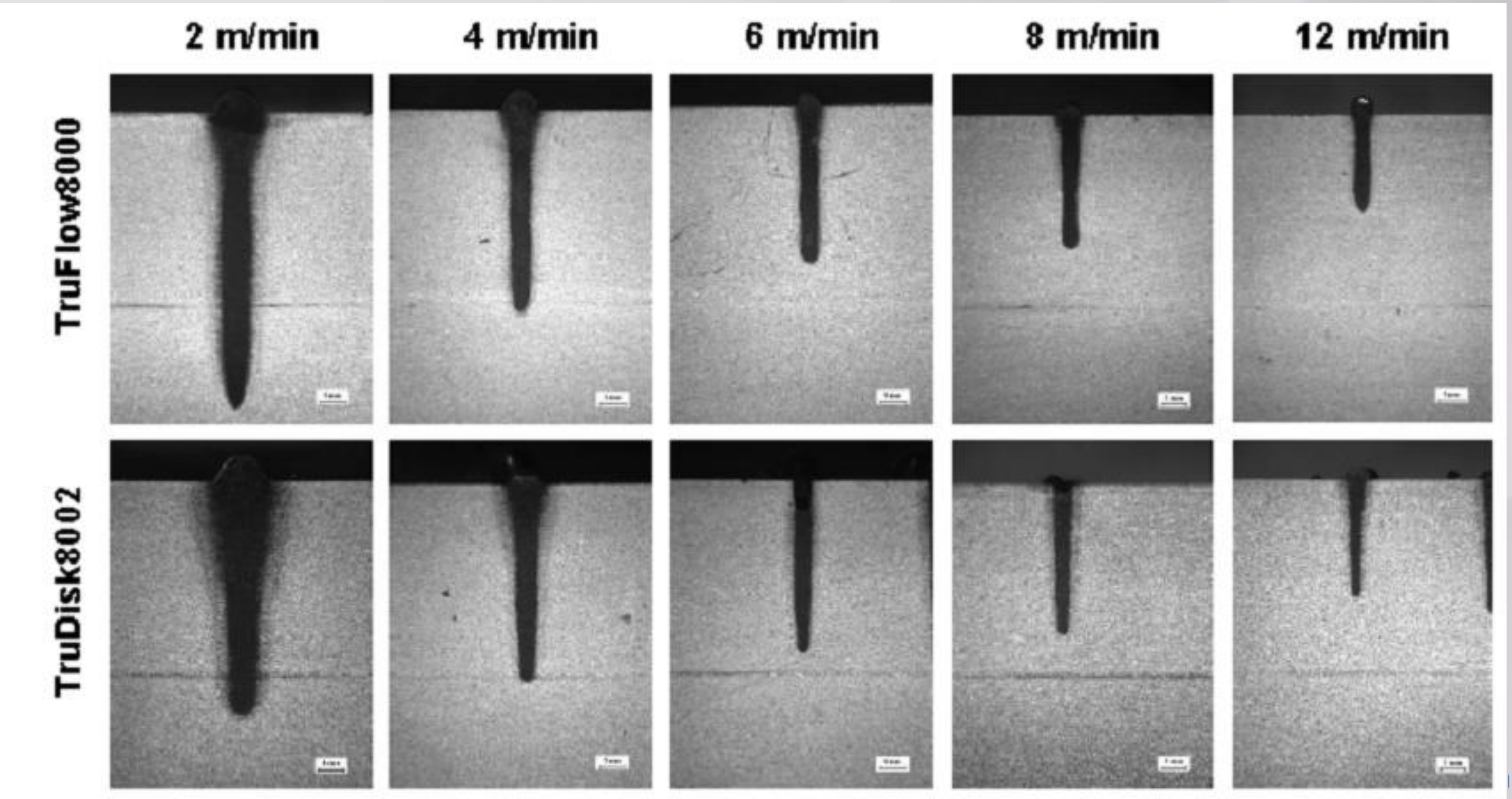
Source: Yuewei Ai et al.

- Surface tension of metal at different temperatures creates depression.
- Laser beam directed toward bottom by sidewall reflections

5.3 Principle of Laser Welding
Keyhole welding typical weld geometry

Higher welding speed = less penetration

These welds prove the concept above but are not suitable for production applications due to the narrow weld areas



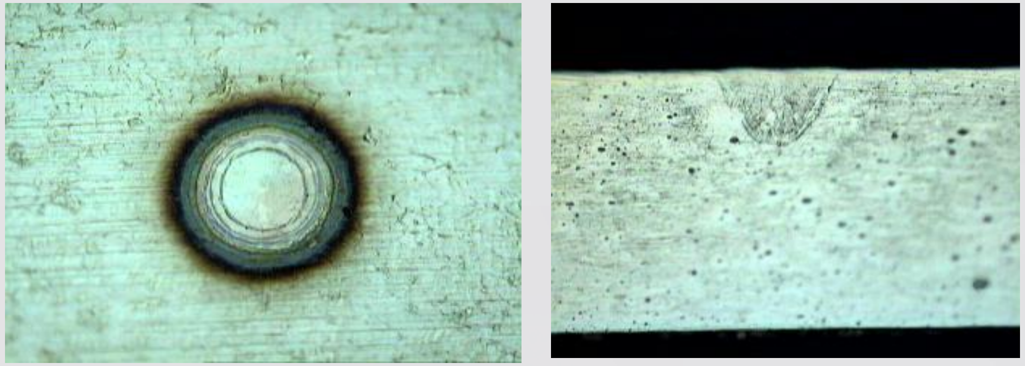
Source: Trumpf

5.3 Principle of Laser Welding
Conduction Mode Welding

- Peak power insufficient for penetration
- Energy absorbed and conducted radially from surface
- Smooth welds
- Aspect Ratios up to 1:1
- Best cosmetics.

5.3 Principle of Laser Welding
Conduction Mode Welding

- Low power density
  - Low average power
  - Large spot size
  - Defocused beam
- Less efficient due to reflections and heat conduction



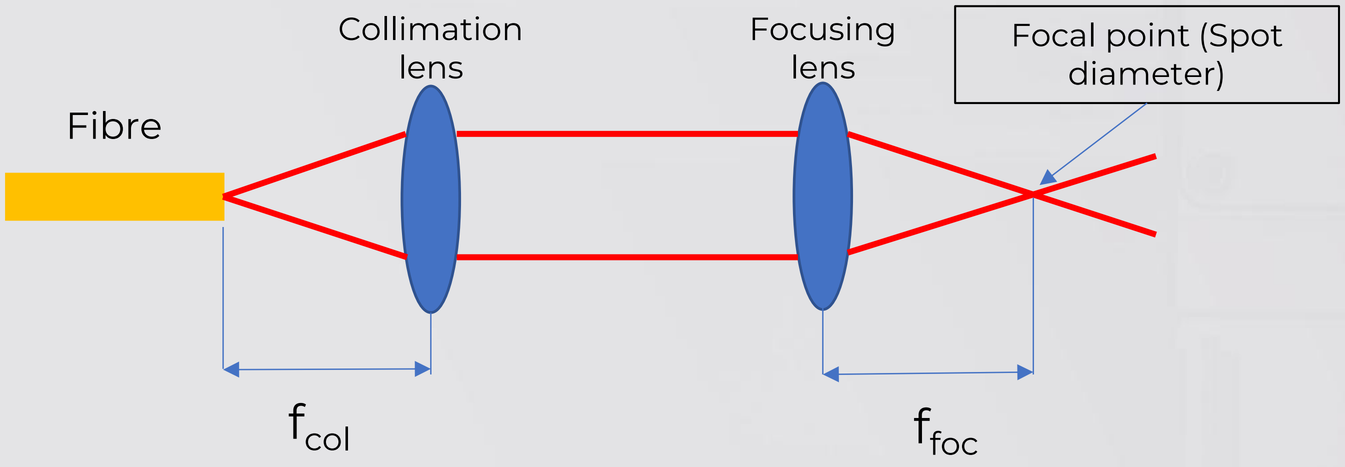
Spot weld (304SS)

$$\textit{Power Density} = \frac{\textit{Power}}{\textit{Spot Dia}}$$

5.4 Laser welding parameters
Key welding parameters

- **Power density:**
  1. Influences welding technique, penetration depth and weld width.
  2. Control of power density allows for precise control over the weld characteristics.
- **Pulse duration:**
  1. Influences the size of the heat affected zones (HAZ).
     - Short pulses minimize heat transfer to surrounding areas.
     - Longer pulses can lead to larger HAZ.
  2. Needs to be optimized to ensure minimal distortion.
- **Beam diameter:**
  1. Focusing to a smaller spot, increases penetration depth by increasing power density.
  2. Larger spots result in shallower welds but cover more of the surface in a shorter time.
- **Welding speed:**
  1. Higer speeds increases productivity but compromises penetration depth.
  2. Slow speed increases process control but extends production time.

5.4 Laser welding parameters
Focus spot diameter and DoF



Focal length determines spot diameter and depth of focus

The spot diameter can be calculated (as below)

$$Spot\ diameter = \frac{Focal\ length\ (f_{foc})}{Collimation\ focal\ distace\ (f_{col})} \times Fibre\ diameter$$

Example:

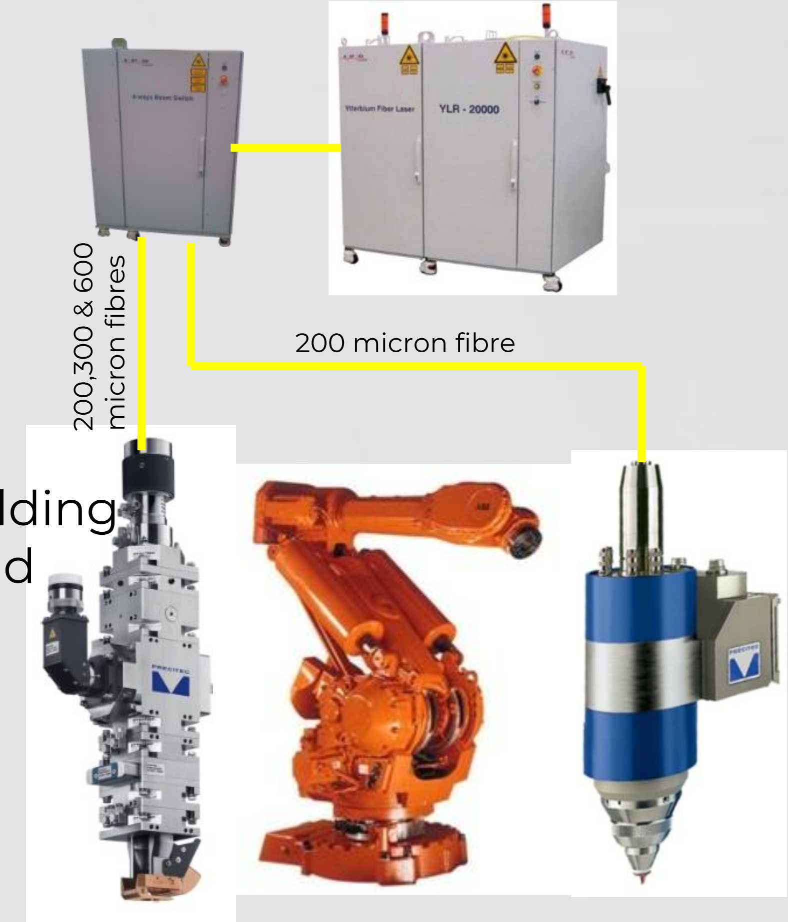
Focal length = 200 mm
Collimation focal distance = 200 mm
Fibre diameter = 0.4 mm

Spot diameter = 0.4 mm

The intensity of a laser beam is equal to its power divided by the area of which the power is concentrated

A 4 kW laser with a spot diameter of 0.4 mm has a power density of 3.2 MW/cm^2 (1 MW/cm^2 is needed for keyhole welding)

5.5 Laser welding equipment



200,300 & 600 micron fibres

200 micron fibre

Welding head

Cutting head

0.33, 0.5 and 1.0mm spot diameters

3.5m reach

0.1 and 0.2mm spot diameters

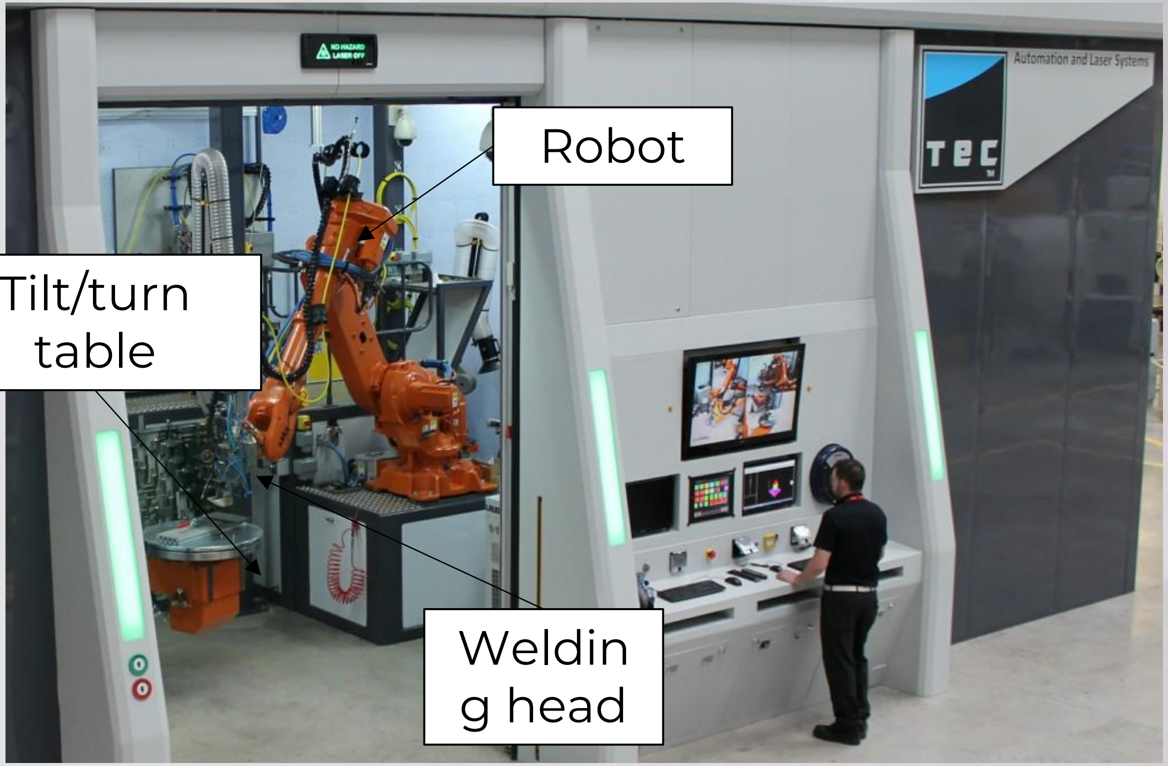
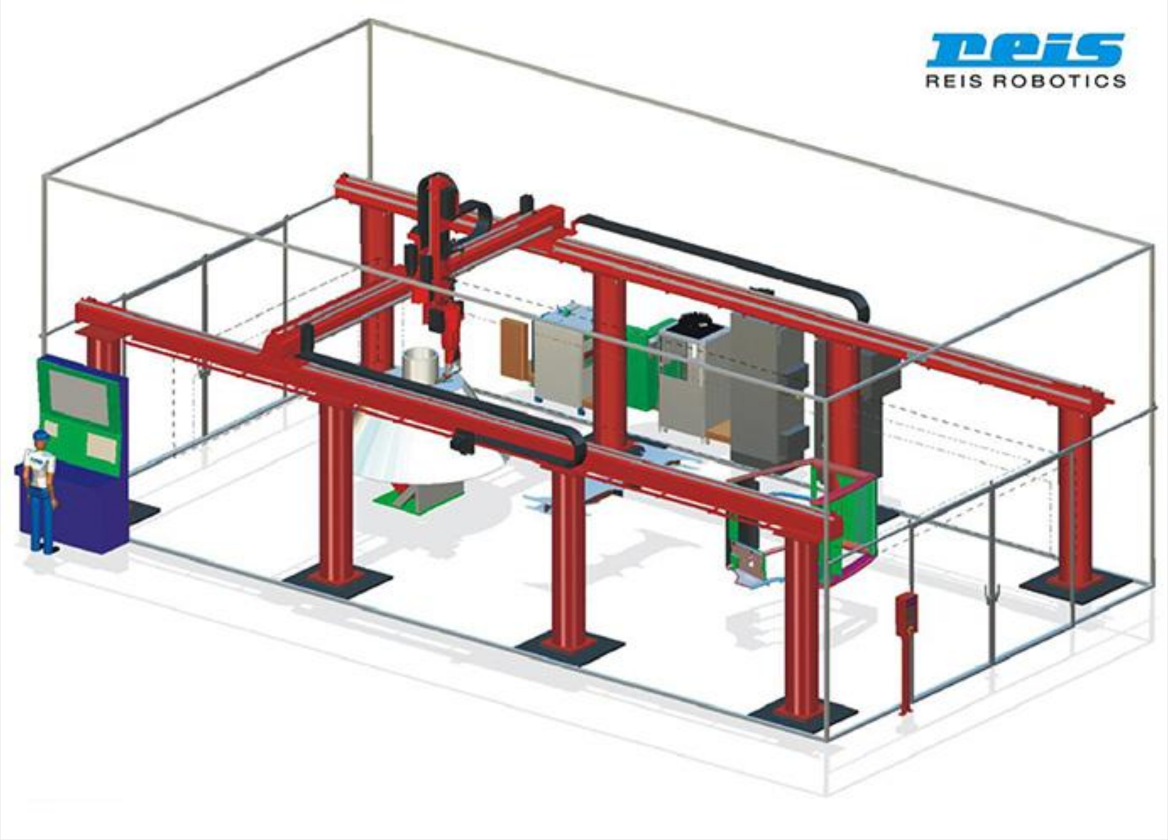


ABB tilt/turn table (1.5 ton) and single axis rotator (5 ton) and removable welding table

Source: Precitec, ABB, IPG Photonics

5.5 Laser welding equipment
Alternative motion systems



Gantry

Source: Reis Robotics

Workstation

Source: IPG Photonics

5.5 Laser welding equipment Welding head

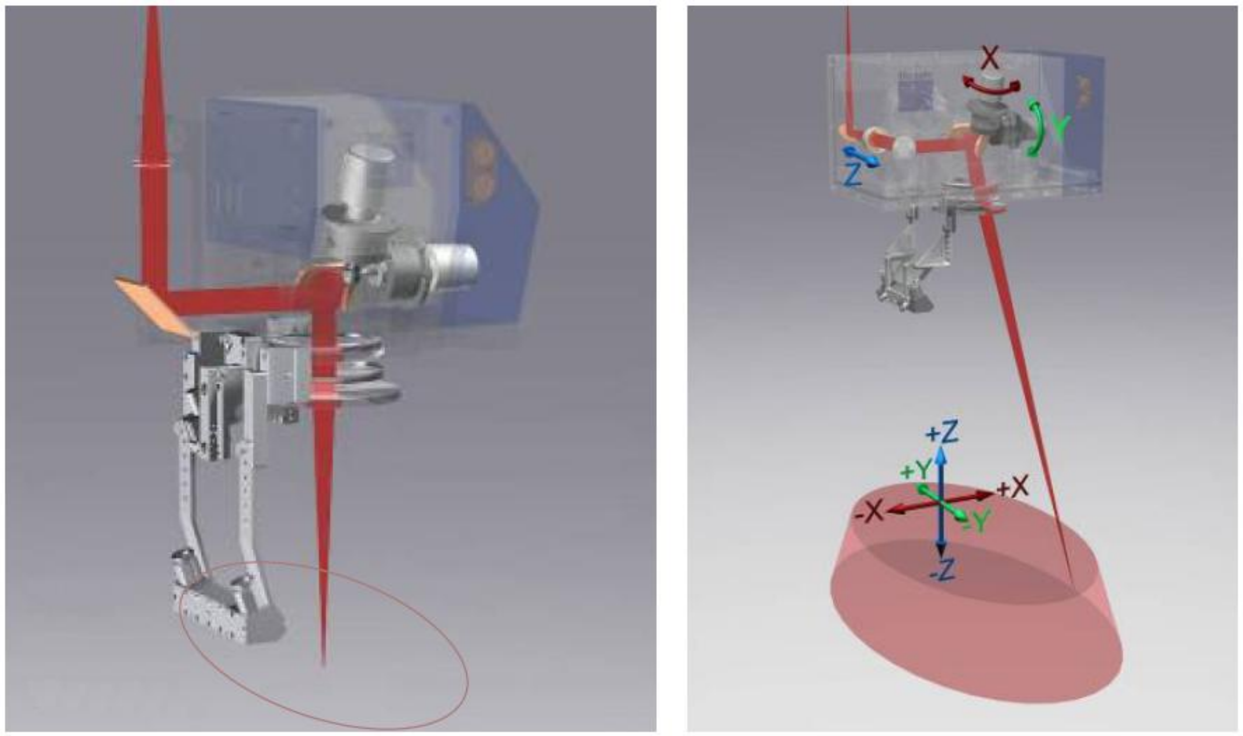
- A method of directing and shaping (focusing) laser energy to the workpiece so that welding can be carried out.

- Optics in the welding head can be either reflective (CO_2) or transmissive (solid state laser).

- Welding heads can include:
  - Process monitoring (camera systems, line scanners etc.)
  - Adjustable collimation (produce different spot diameters at the same focus)
  - Air knives (stop spatter damaging optics)
  - Head health check monitoring
  - Customisable processing (e.g. pinch welding or hybrid ARC welding)

Source: Precitec

5.6 Laser welding technologies
Remote laser welding

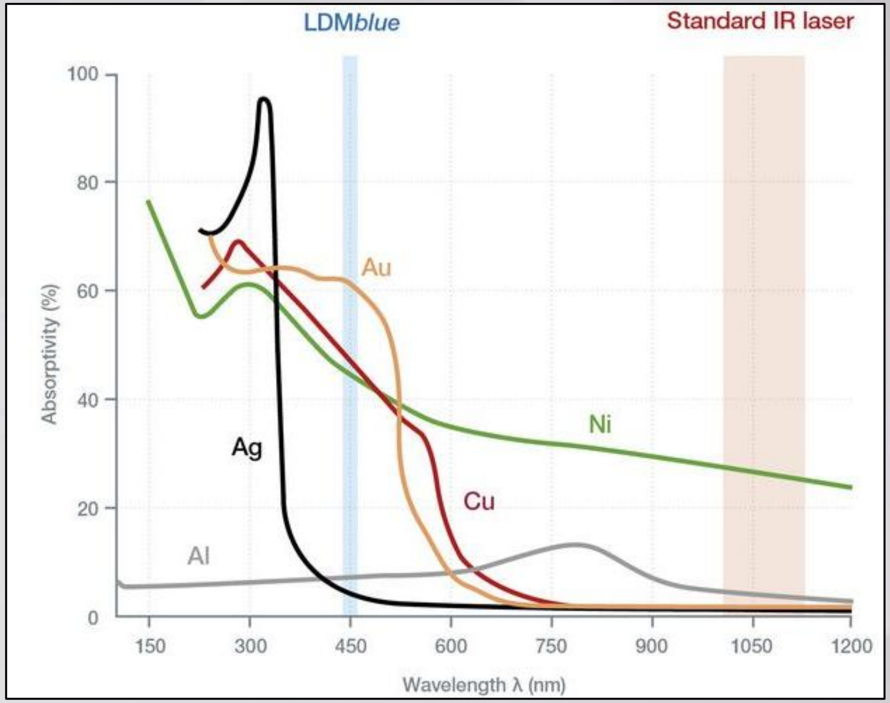


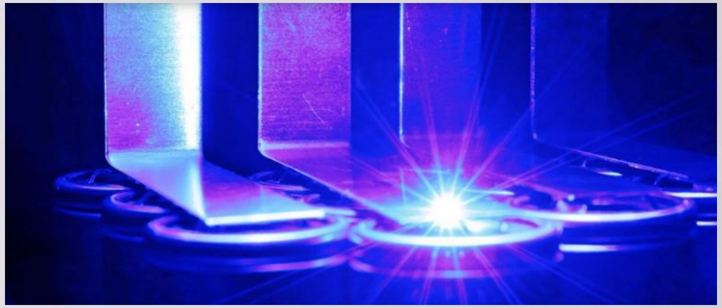
A method of reducing component cost by reducing robot movement time between welds...

Source: Trumpf

5.6 Laser welding technologies
Laser welding technologies

- **Reflectivity/absorption**
  - Non IR – Blue (NUBURU, Laserline) or Green (Trumpf) laser
    - ➢ Developed to improve copper welding for e-mobility applications
  - Other IR – 10 micron wavelength (CO_2 Laser)
    - ➢ More stable for thick section welding
- **Laser welding in a vacuum**
  - ➢ Competitor to electron beam welding
  - ➢ No oxidation
  - ➢ Improved penetration
    - Reduced heat dissipation
    - Improved material flow

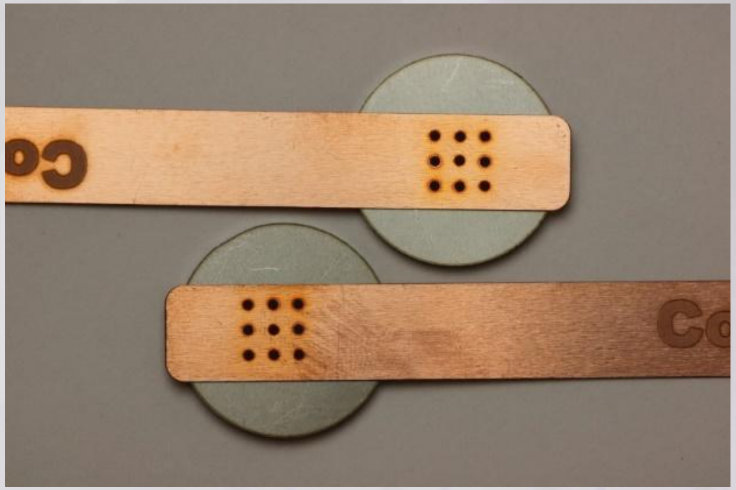




Source: Laserline

5.7 Laser welding examples
Battery welding

Source: Amada Miyachi



Source: SPI Lasers

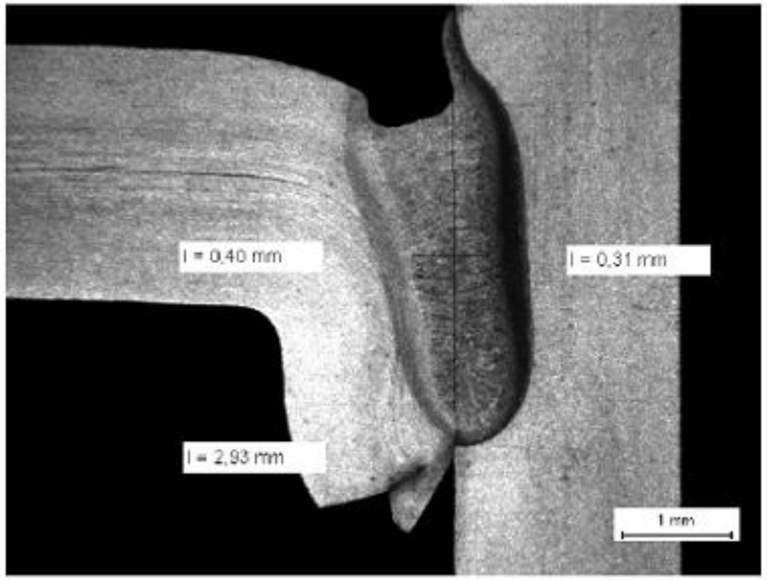
Source: Qnovo

Tesla Model S Battery: 600kgs, 85 kWh
6912 cylindrical 18650 cells.

Advantages:

- Low distortion
- Low heat input – Very important when welding batteries!
- Dissimilar materials
- High welding speed

5.7 Laser welding examples
Airbag



Laser:	TruDisk 8002
Power:	3500 W
Fiber diameter:	400 µm
Focus length:	f280
Focus diameter:	560 µm
Focus position:	-2 mm
Welding speed:	6.0 m/min

Advantages:

- ▶ constant welding penetration
- ▶ small heat input
- ▶ no process gas (He) necessary

Source: Trumpf

5.7 Laser welding examples
Aero engine – Potential solutions

- Structural engine module (Ti6-4) – previously cast:
  - In the order of: 1.3m dia x 1.2m.
  - Very limited suppliers globally.
- Laser welded from smaller sub-units:
  - Broader supply network.
- Requires conforming welds on varying thickness, including in-weld close-out zone.
- Fabrication enables previously unavailable component geometry:
  - Key enabler to engine performance.
  - Key enabler to engine cost targets.
  - Key enabler to engine weight targets.
- Stringent process development and material / workpiece control to achieve porosity limits.

Source: GKN / Aerospace Manufacturing and Design

6 – Water jet guided laser processing

Flexible Laser-Based Manufacturing

FLASH
Flexible Laser-Based Manufacturing

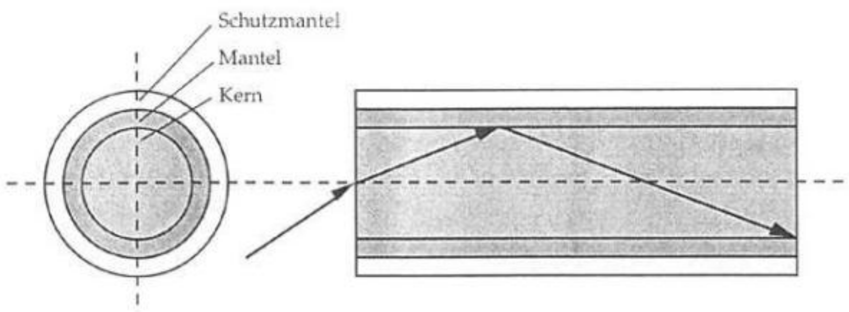
Co-funded by the European Union

6.1 Principle of water jet guided laser processing

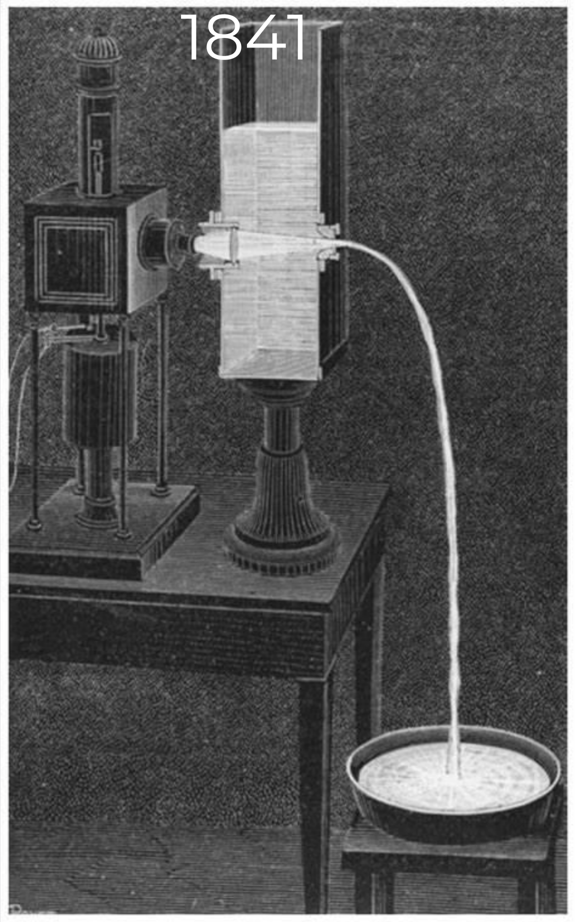
Colladon's Water

Fountain

Total internal reflection

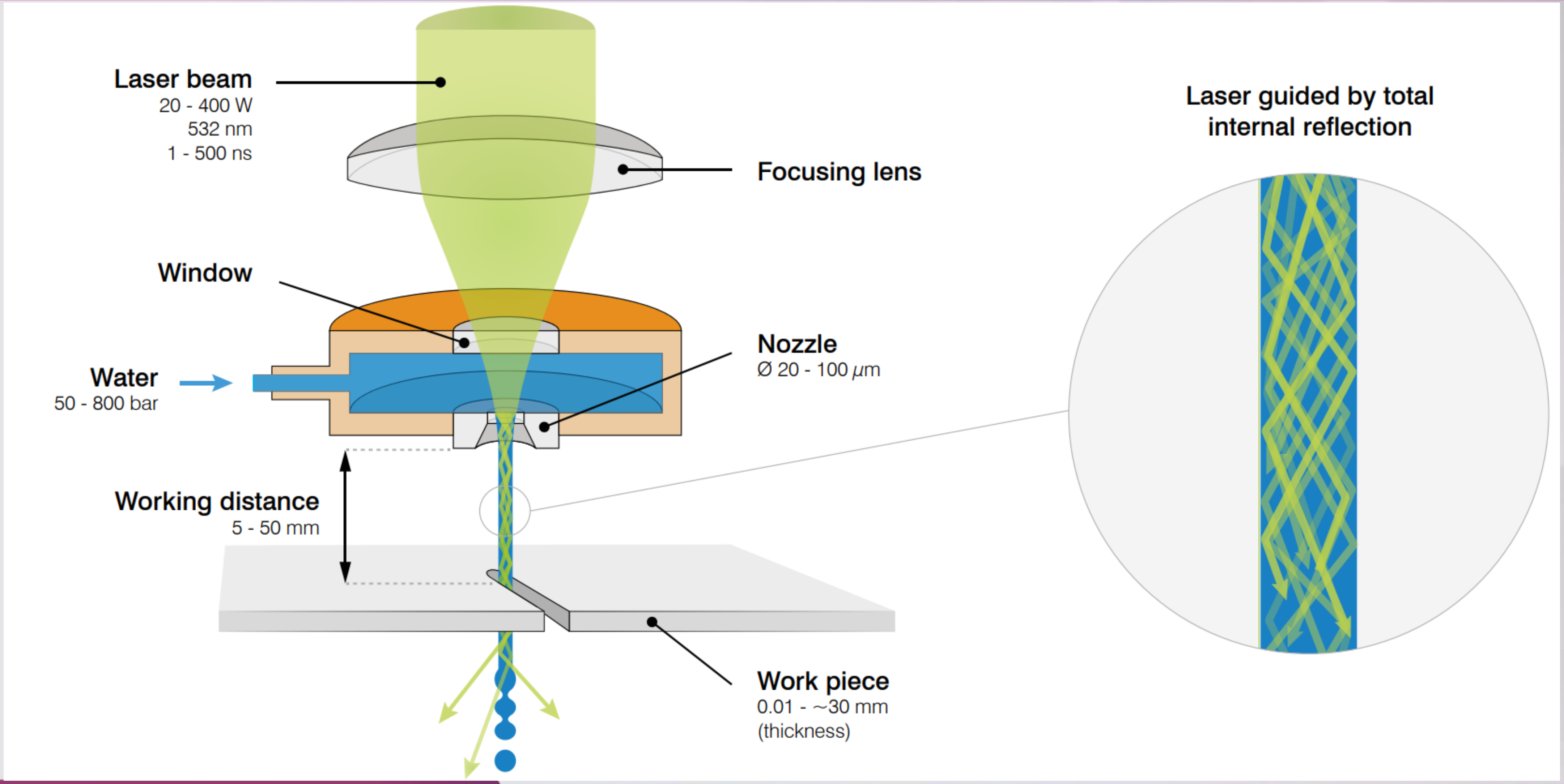


www.scientificamerican.com/article/the-colladon-fountain/



www.photo.elsoar.com/fountains-of-the-world-25-hq-jpegs-pictures.html
www.2id-events.com/fountain-show-in-dubai/

6.1 Principle of water jet guided laser processing

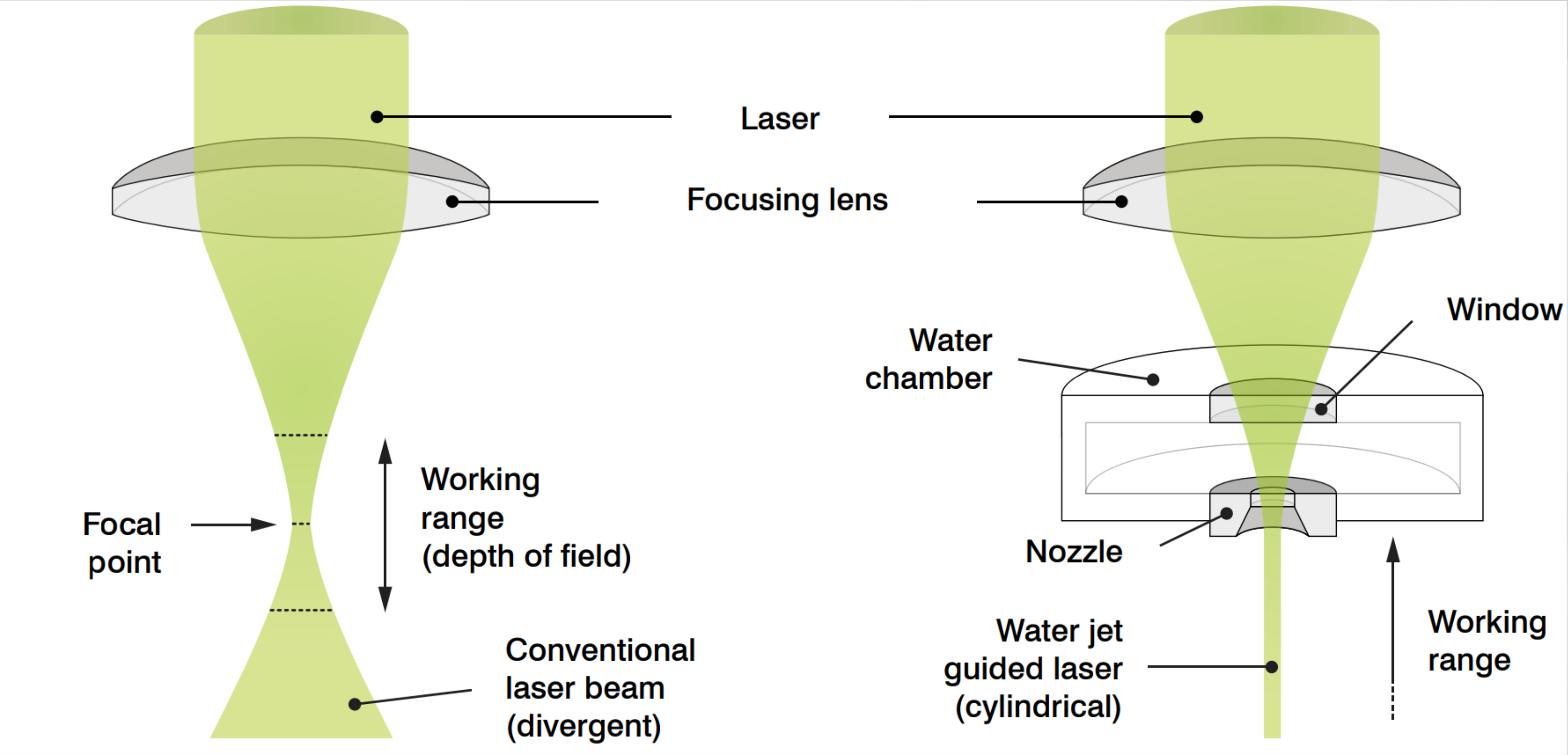


Web brochure TECHNOLOGY-2020.pdf (synova.ch)

6.1 Principle of water jet guided laser processing

Conventional laser

WJGL



(up to 10 cm)

[Web brochure TECHNOLOGY-2020.pdf (synova.ch)]

6.2 Technical Parameters

Laser:
- Diode-pumped solid-state pulsed Nd:Yag lasers.
- Pulsed operation in the micro- or nano-second range.
- Typical wavelength at 532 or 1064 nm.
- Average laser power ranges from 20 to 400 W.

Water:
- “hair-thin” water jet, with an approximate consumption of 10 liters/hour at 50-800 bar pressure.
- Helium shielding around the water jet.

Nozzles:
- Manufactured from sapphire or diamond.
- Diameter range of 20-100 μm.

Typical parameters:

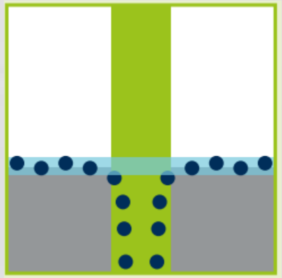
1. Average laser power – W
2. Pulse duration – ns
3. Pulse frequency – kHz
4. Water jet pressure – bar
5. Nozzle diameter - μm
6. Cutting speed – mm/s
7. Shielding gas flow rate – L/min

6.3 WJGL Technology

No focus adjustment required, depth of cut of up to several cm.

Water-cooling avoids thermal damage and material change.

Reduced taper & near parallel kerf walls due to cylindrical beam.



Thin water film eliminates particles deposition and contamination.

High aspect ratio processing due to small kerf width compared to material thickness.

High pressure jet expels molten material, reducing burr formation.

[Web brochure TECHNOLOGY-2020.pdf (synova.ch)]

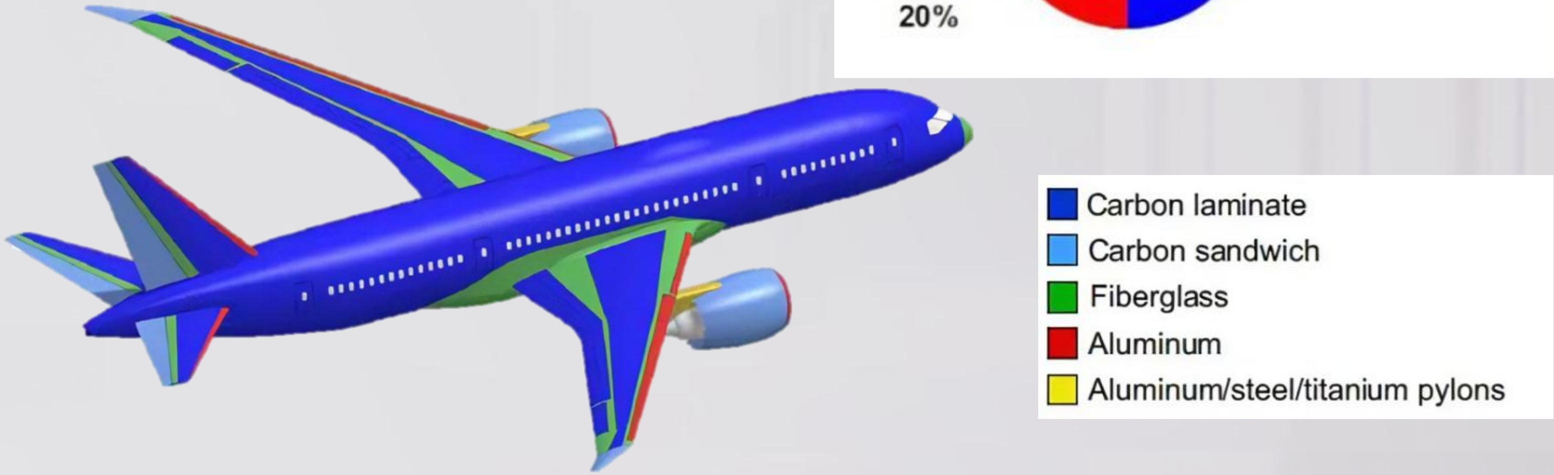
6.4 Possible machining operations

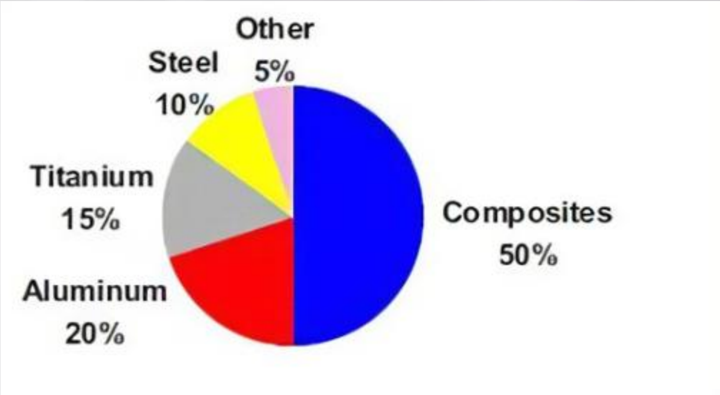
- 3D cutting
- Shaping
- Drilling
- Slotting
- Grooving
- Trenching
- Milling
- Slicing
- Engraving
- Profiling

6.5 WJGL applications Aerospace

Carbon fibre reinforced polymer

Ceramic matrix composites



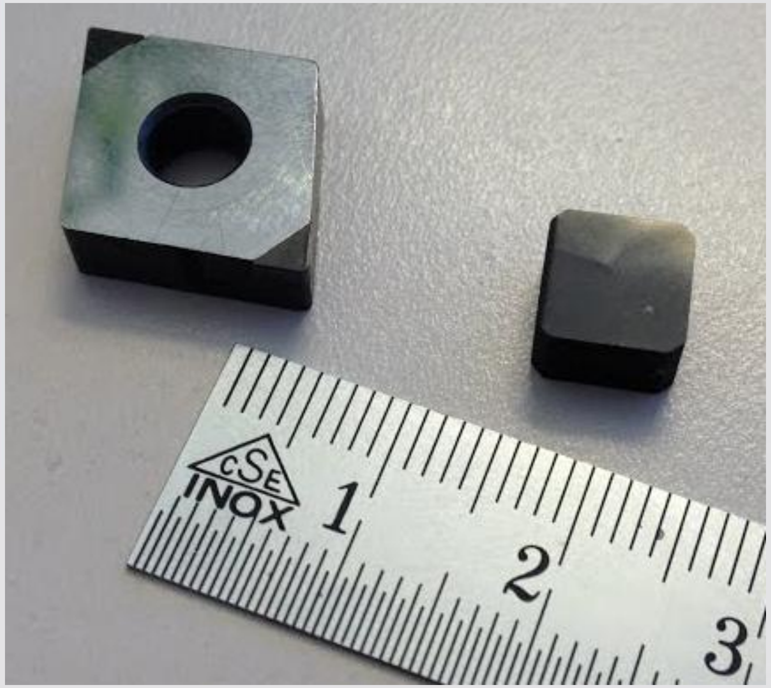


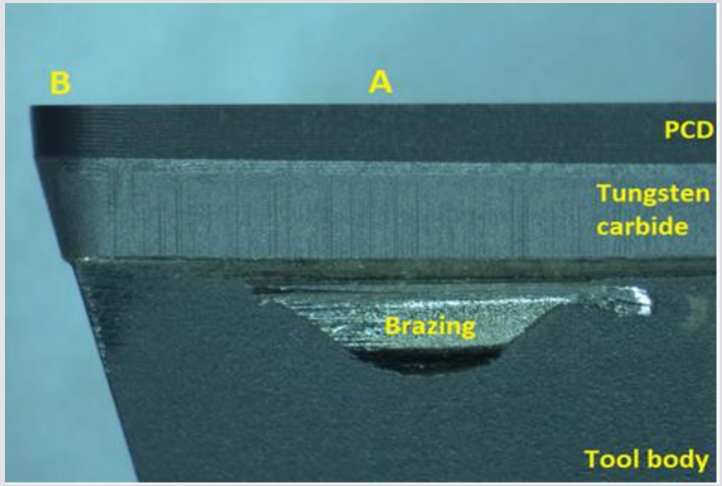
Roeseler Sarh, Kismarton (2007). Composite structures: the first 100 years. 16th Int. Conf. Compos.

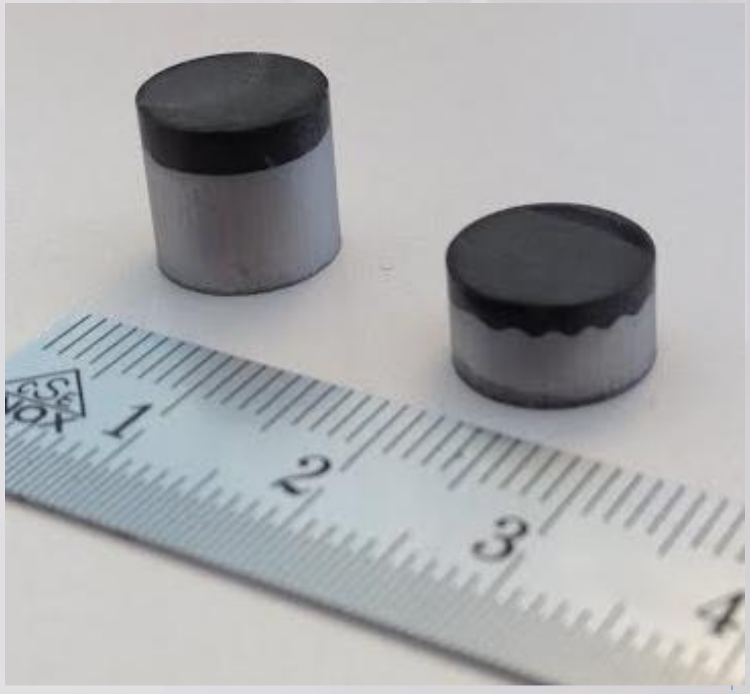
6.5 WJGL applications
Tool manufacture

Polycrystalline diamond tungsten carbide

- Tooling inserts
- Drill bits







www.synova.ch/applications/tool-manufacturing.html

6.5 WJGL applications
Diamond Shaping

FLASH
Flexible Laser-Based Manufacturing

Any Questions?

"If there are any questions or if something needs further explanation, please, **don't hesitate to ask!**"

Thank you.

flashlaserproject.eu

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. **Project Number: 101138380.**