Empa
Materials Science and Technology

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

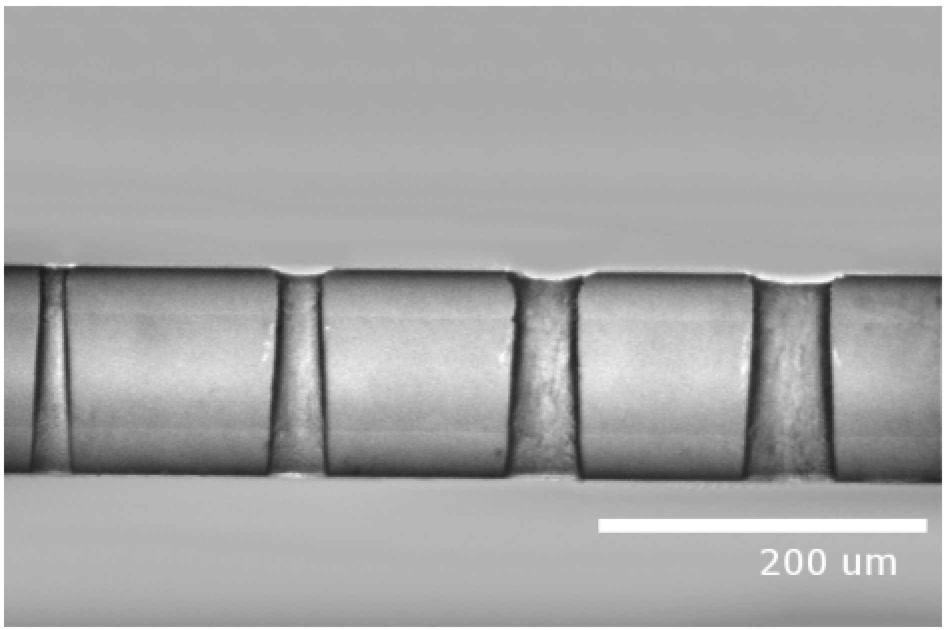
Laser Processing of Materials

Applications: Drilling & Cutting

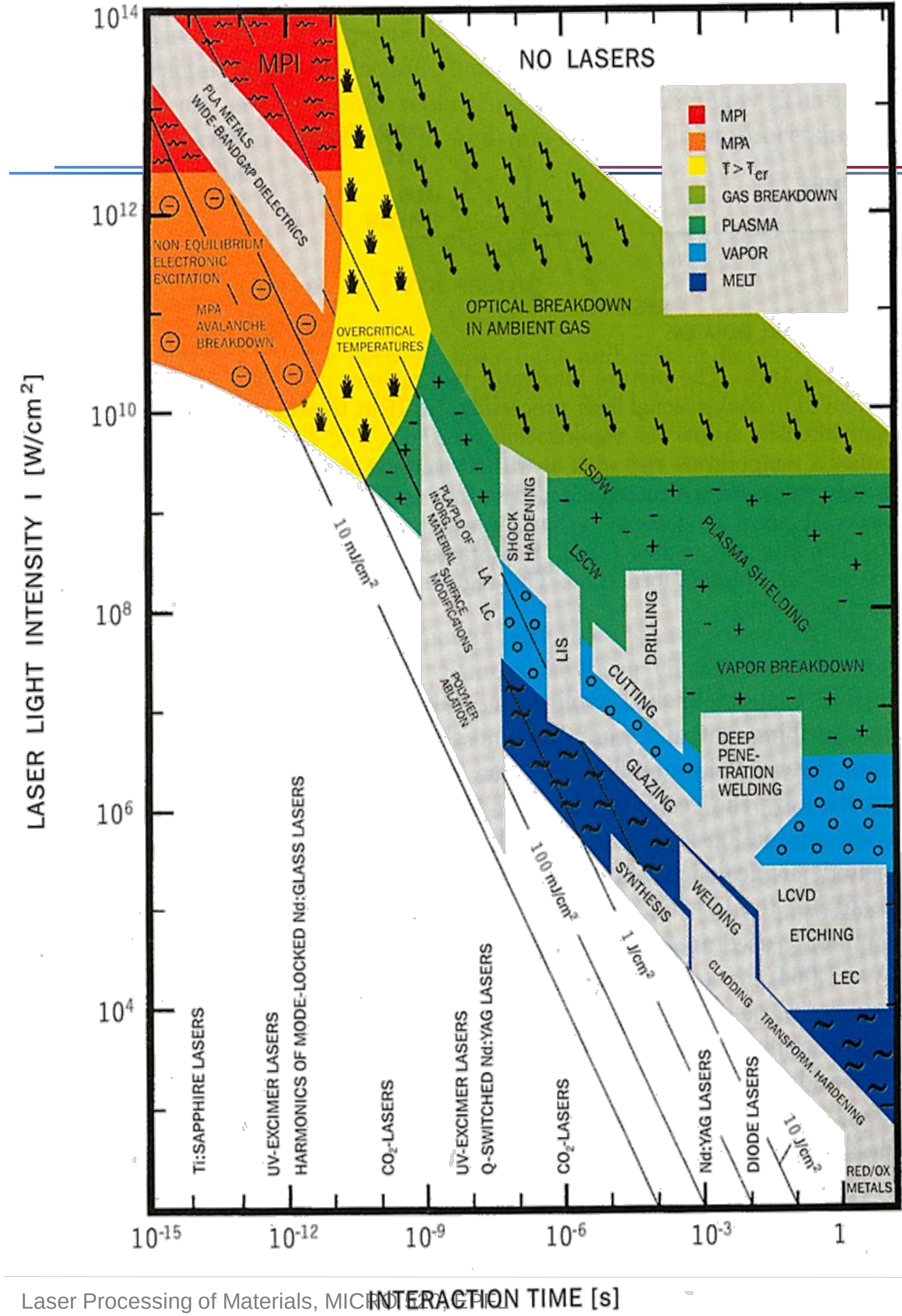
Patrik Hoffmann

Drilling and Cutting

drilling



liquid expulsion cutting

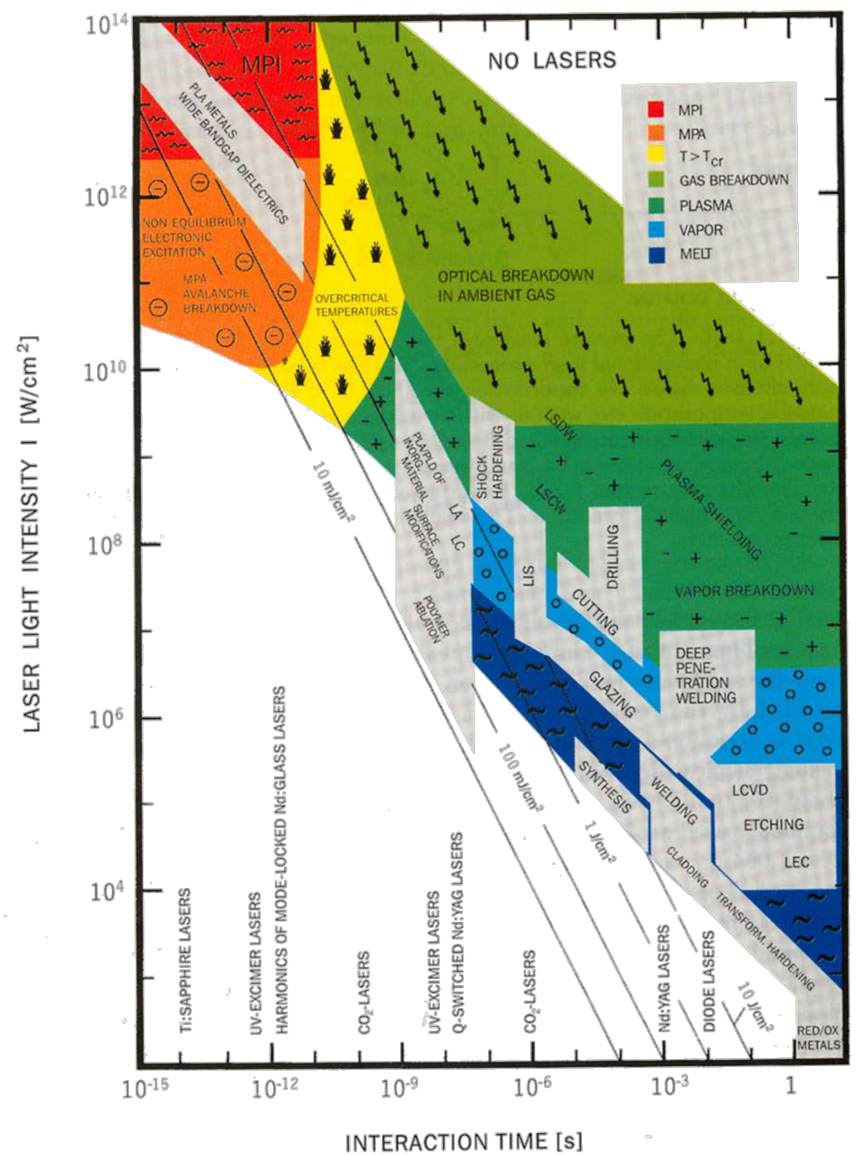


D. Bäuerle;
Laser Processing and Chemistry, 3rd ed.
Springer, Berlin, 2000

What kind of laser do you propose for bending / welding?

Application of lasers in materials processing:
Intensity-Time Diagram

- PLA/PLD – pulsed laser ablation/ deposition
- LA – laser annealing
- LC – laser cleaning
- LIS – laser induced isotope separation/IR – laser photochemistry
- MPA/MPI – multiphoton absorption ionization
- LSDW/LSCW – laser supported detonation/combustion waves
- LCVD – laser induced chemical vapour deposition
- LEC – laser induced electrochemical plating/etching
- RED/OX – long pulse or cw CO_2-laser induced reduction/oxidation



D. Bäuerle; Laser Processing and Chemistry, 3rd ed. Springer, Berlin, 2000

Laser Types: Pulsed & CW

Type of laser	Pulse length determined by	Typical pulse length	Characteristic pulse peak power
Continuous wave (cw)	-	∞	Ws – kWs
Free running laser	Pump pulse length (flash lamp)	100 µs – 1ms	kWs
Q-switched laser	Time constants of active material and modulating element	1 ns – 100 ns	MWs
Mode-locked laser	Number of coupled modes, pulse compression	10 fs – 10 ps	GWs

For which materials/cases CW/free running is OK?
When you would prefer Q-switched?

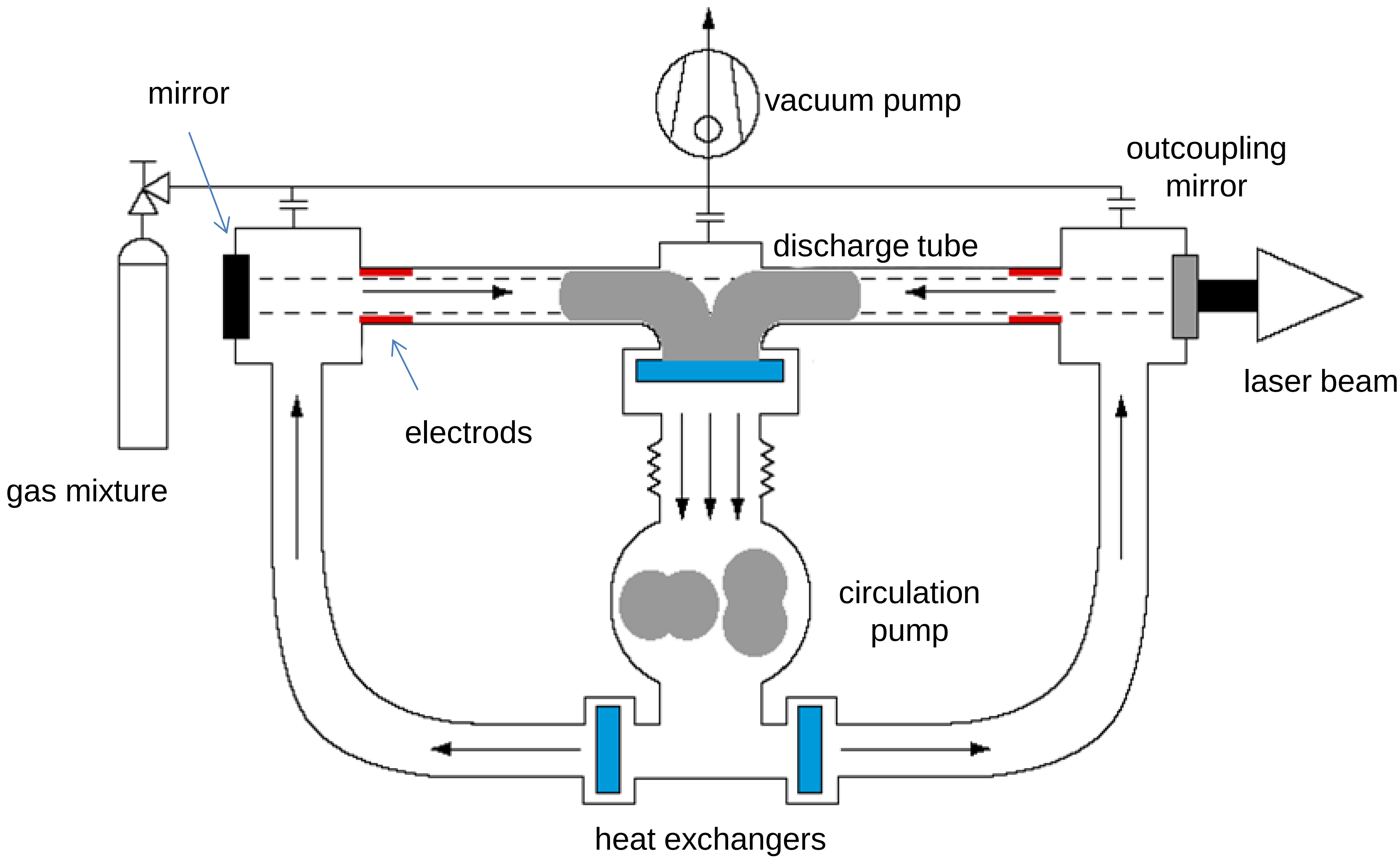
THINK HEAT!

Lasers used

Wavelength (nm)	Pulse Length (ns)	Type of Laser	Comments
~13	20	Mo ablation plume	not a laser
157	20	Excimer F_2	in vacuum
193	20	Excimer ArF	50% Abs m^{-1}
248	20	Excimer KrF	dangerous
266	CW / pulsé: 5–15 + 5 10^3 à 10^6	Nd/YAG 4x	relatively low power
308	20 - 300	Excimer XeCl	
351	20	Excimer XeF	
351	CW	Ar^+	
355	CW / pulsé: 5–15 + 5 10^3 à 10^6	Nd/YAG 3x	
364	CW	Ar^+	
488	CW	Ar^+	
514	CW	Ar^+	strongest Ar^+ line
532	CW / pulsé: 5–15 + 5 10^3 à 10^6	Nd/YAG 2x	
1064	CW / pulsé: 5–15 + 5 10^3 à 10^6	Nd/YAG	

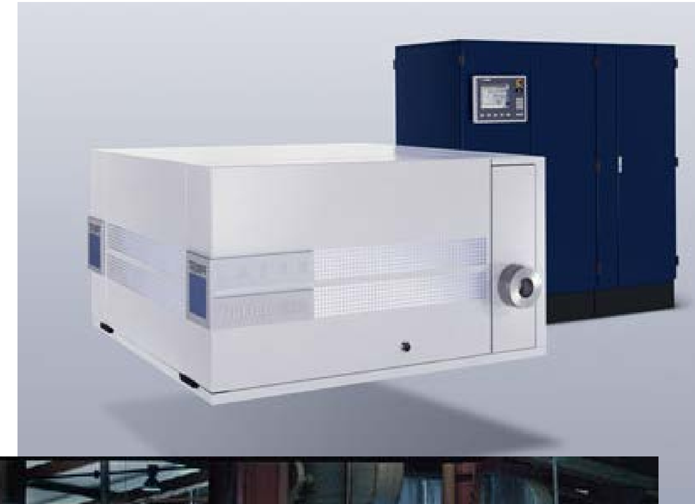
CO_2 Laser

scheme of high power CO_2 laser

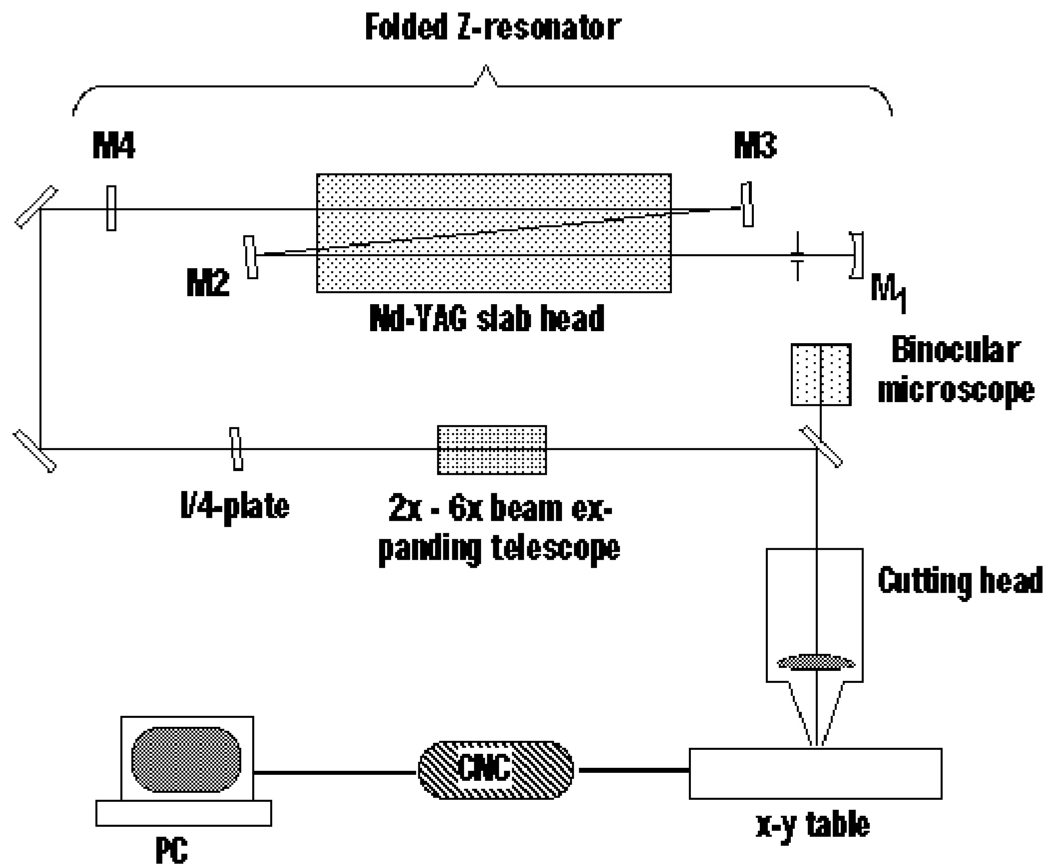


CO_2 Laser

- Mid-IR (9.6 and 10.6 µm)
- Very high power possible (100 kW CW)
- Very high industrial use: cutting/welding



Nd:YAG SLAB laser



Nd-YAG slab laser precision cutting facility, with computer interfaced CNC-controlled precision x-y table

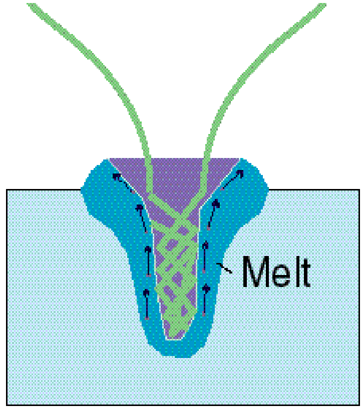
Constructed by Thomas Sidler LOA, EPFL

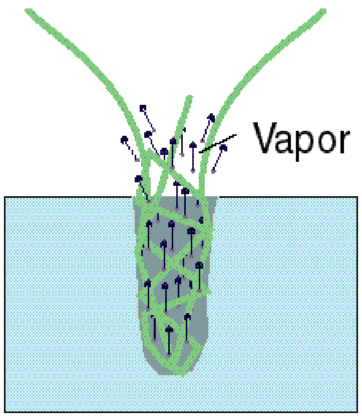
Laser Drilling

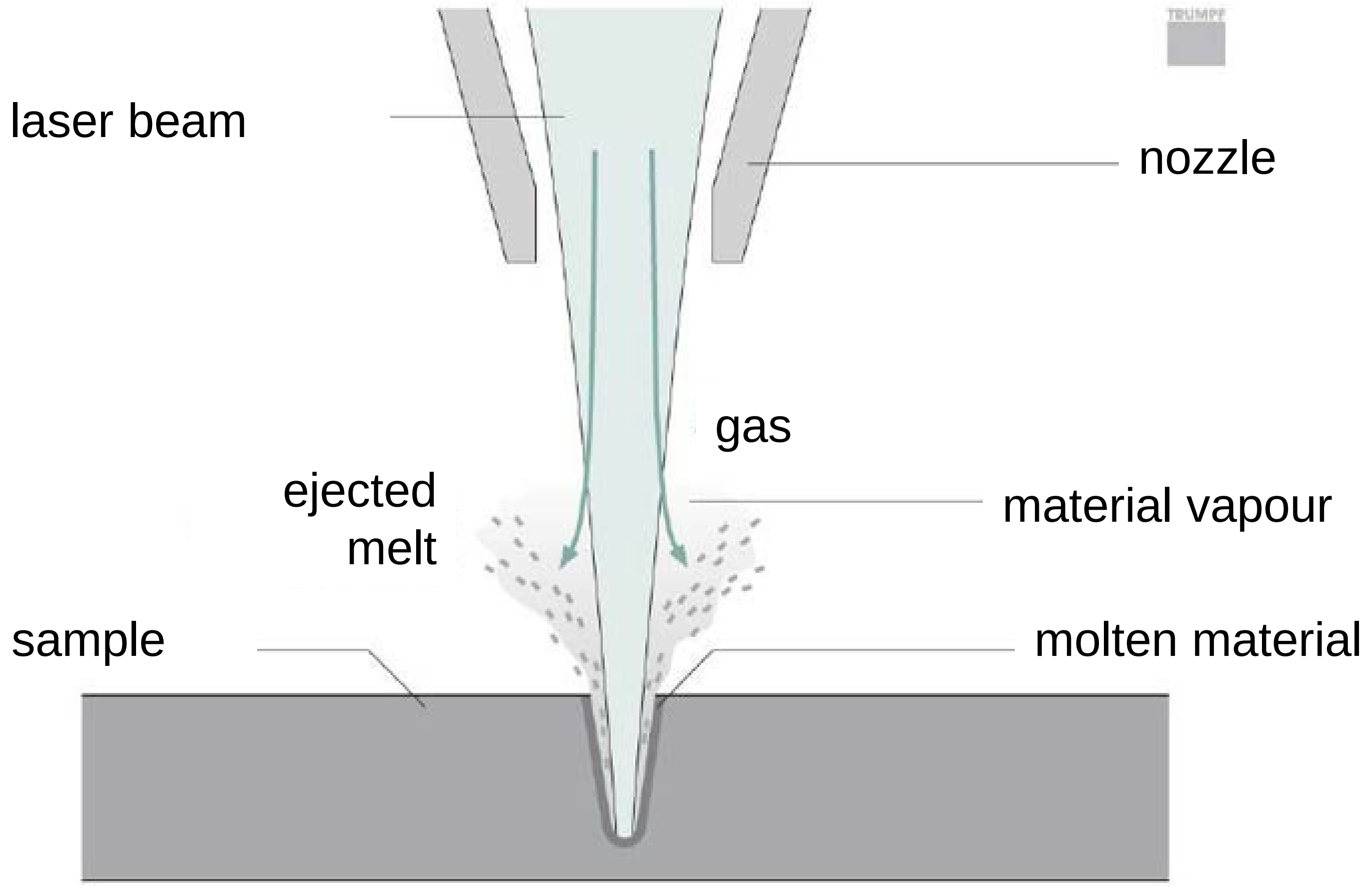
Laser drilling

- single pulse drilling
- multiple pulse drilling (percussion drilling) *(see ablation)*
- drilling by cutting *(see cutting)*

Laser Hole Drilling

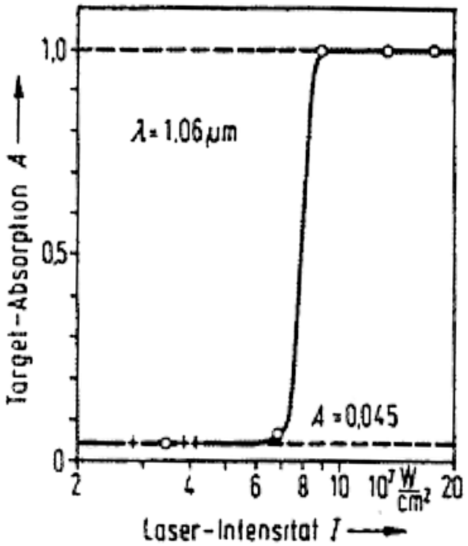


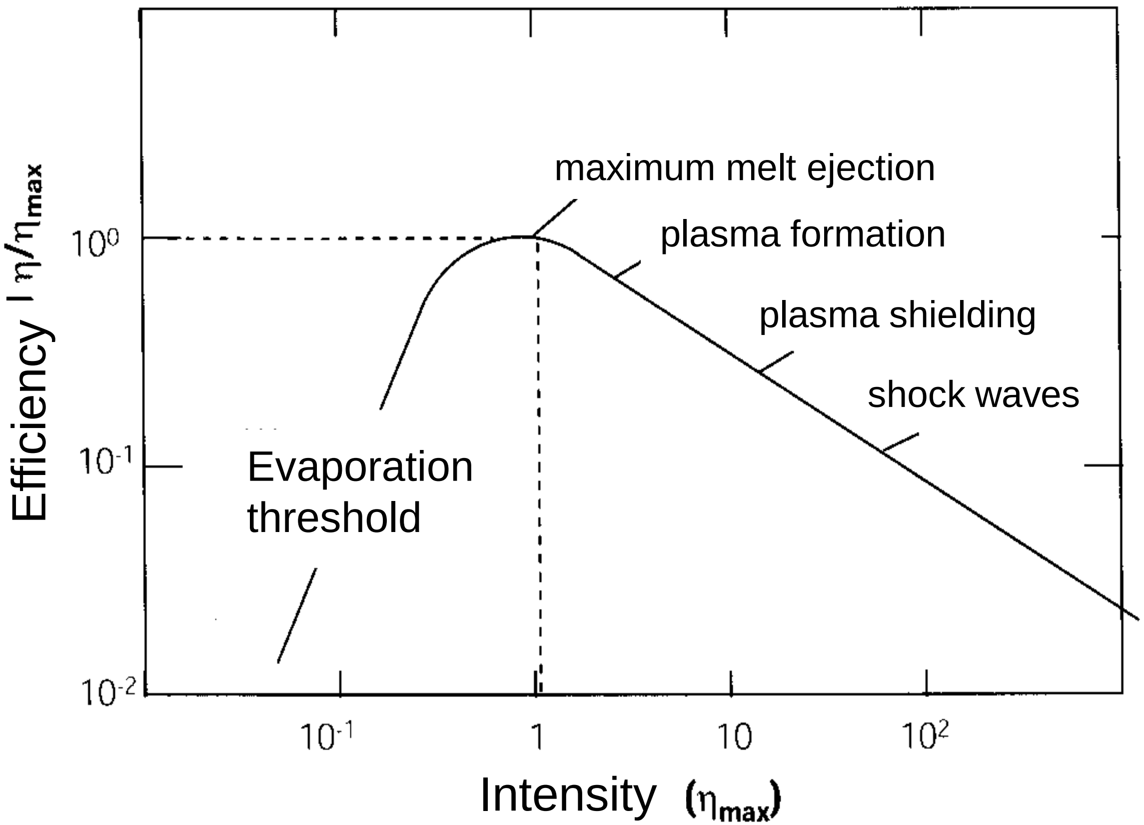




Laser Hole Drilling

absorption of Cu sample
vs. laser light intensity
Nd:YAG 1064 nm, 100ns

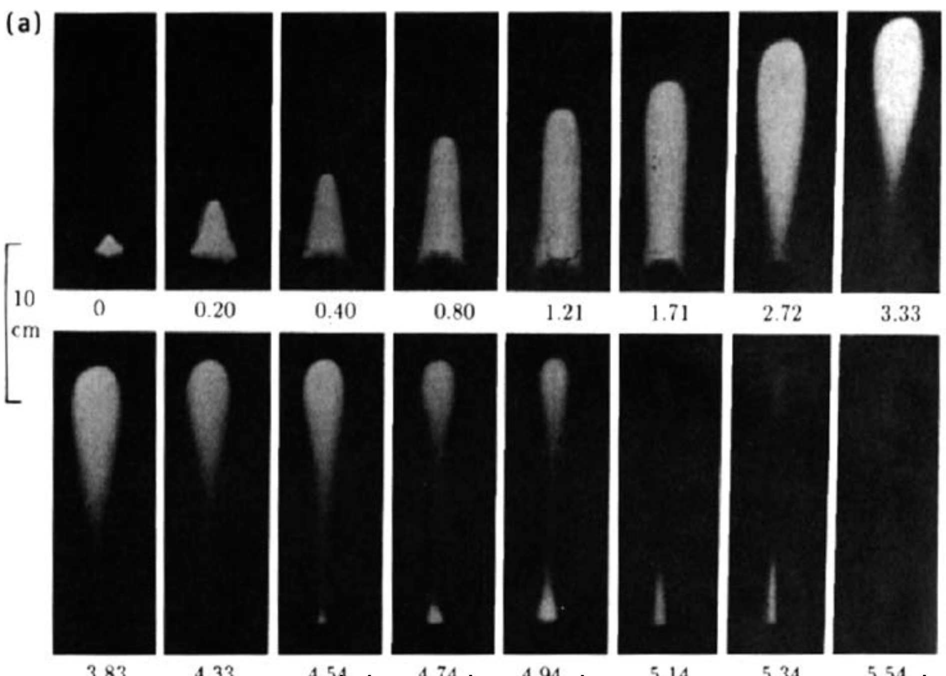




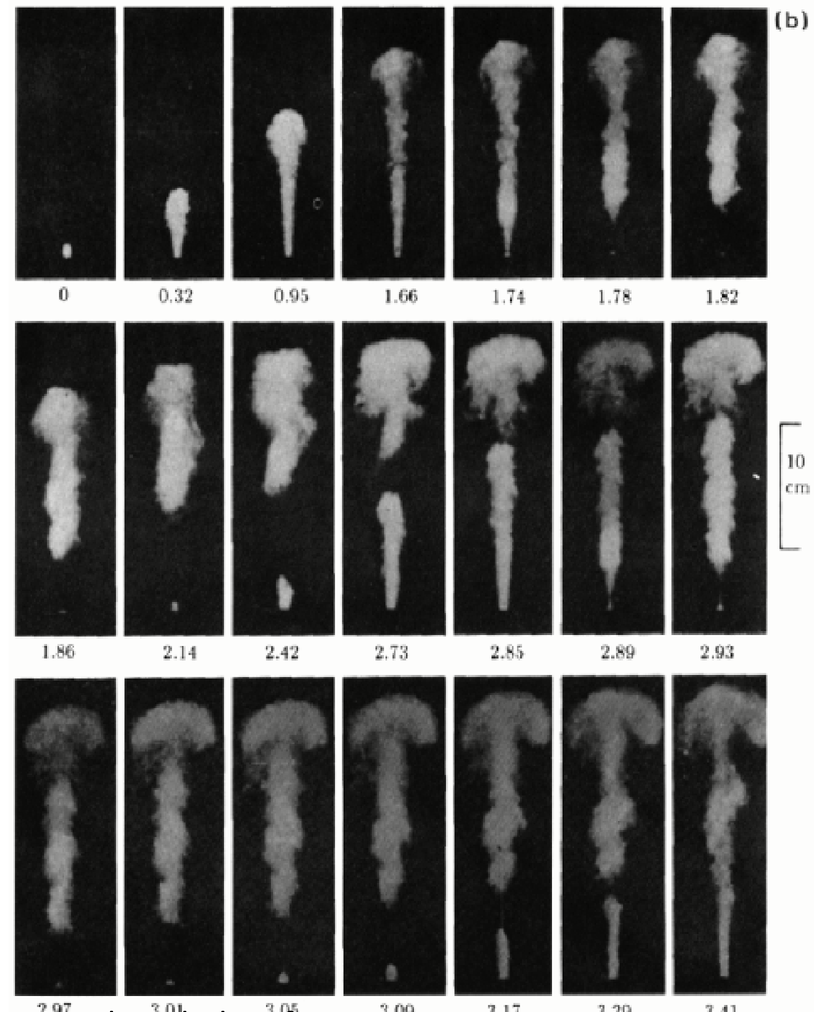
Plasma shielding of CO_2 laser

High-speed camera frames of LSAW's developed from (a) 2024 aliminium alloy and (b) alumina targets, irradiated by 5 ms, 1.5 MW/cm^2 CO_2-laser pulses (incident from above).

Aluminium

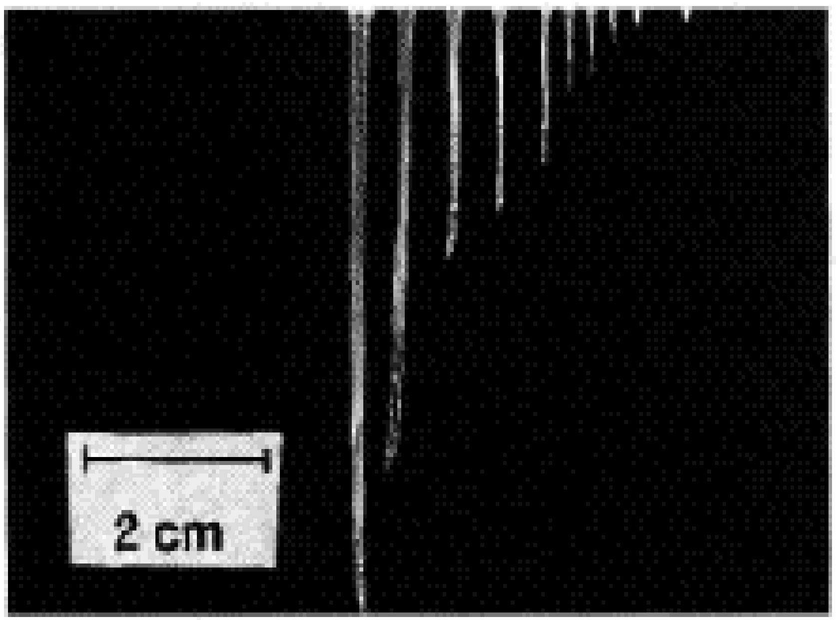


Alumina



Several decoupling and reignition events can be seen. Numbers below frames – time in ms.

Laser hole drilling



Hole in Perspex drilled by CO2-laser pulses of duration 10 ms to 5 s (from left to right), illustrating self channeling of the laser beam.

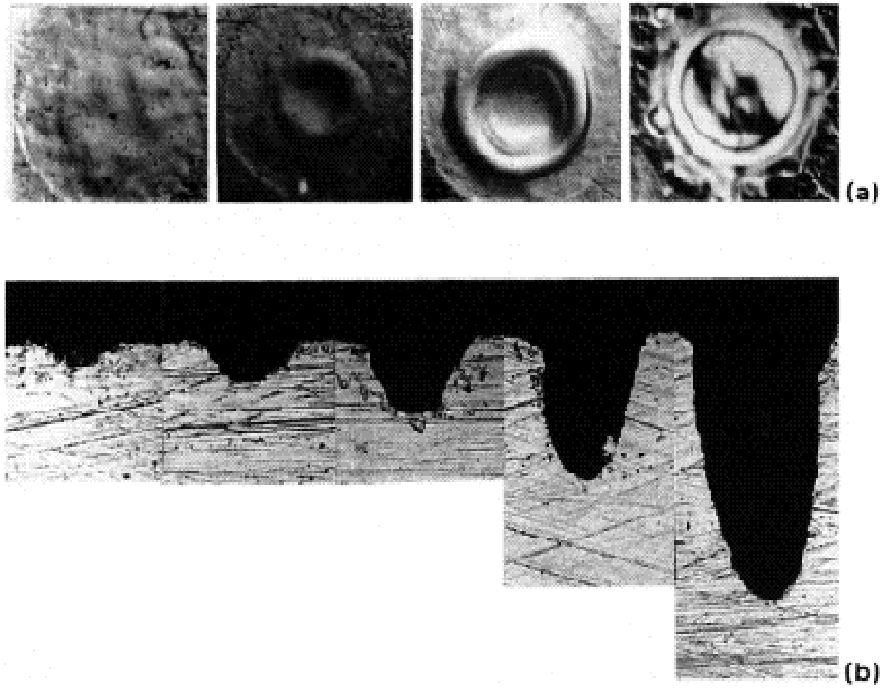
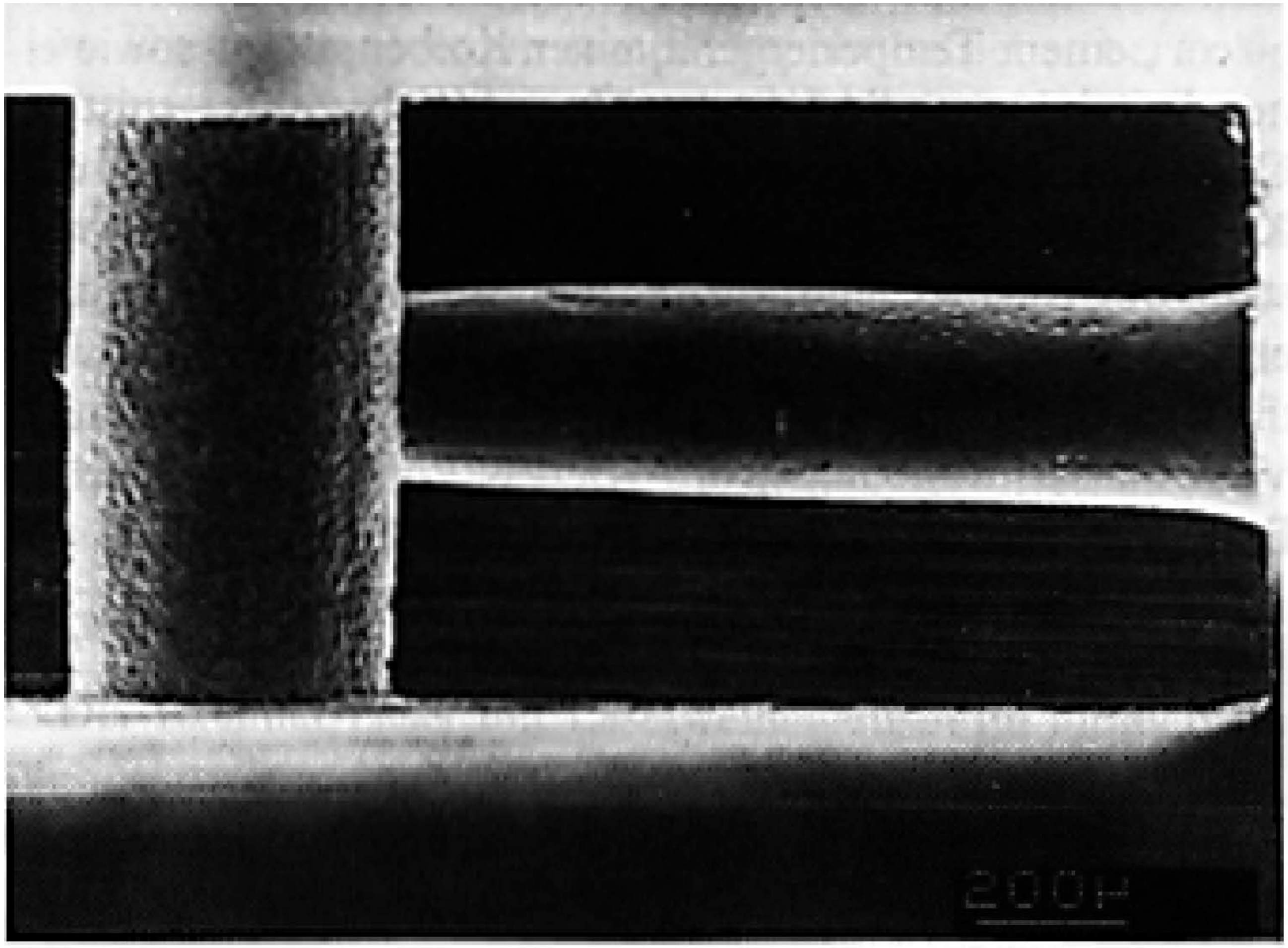


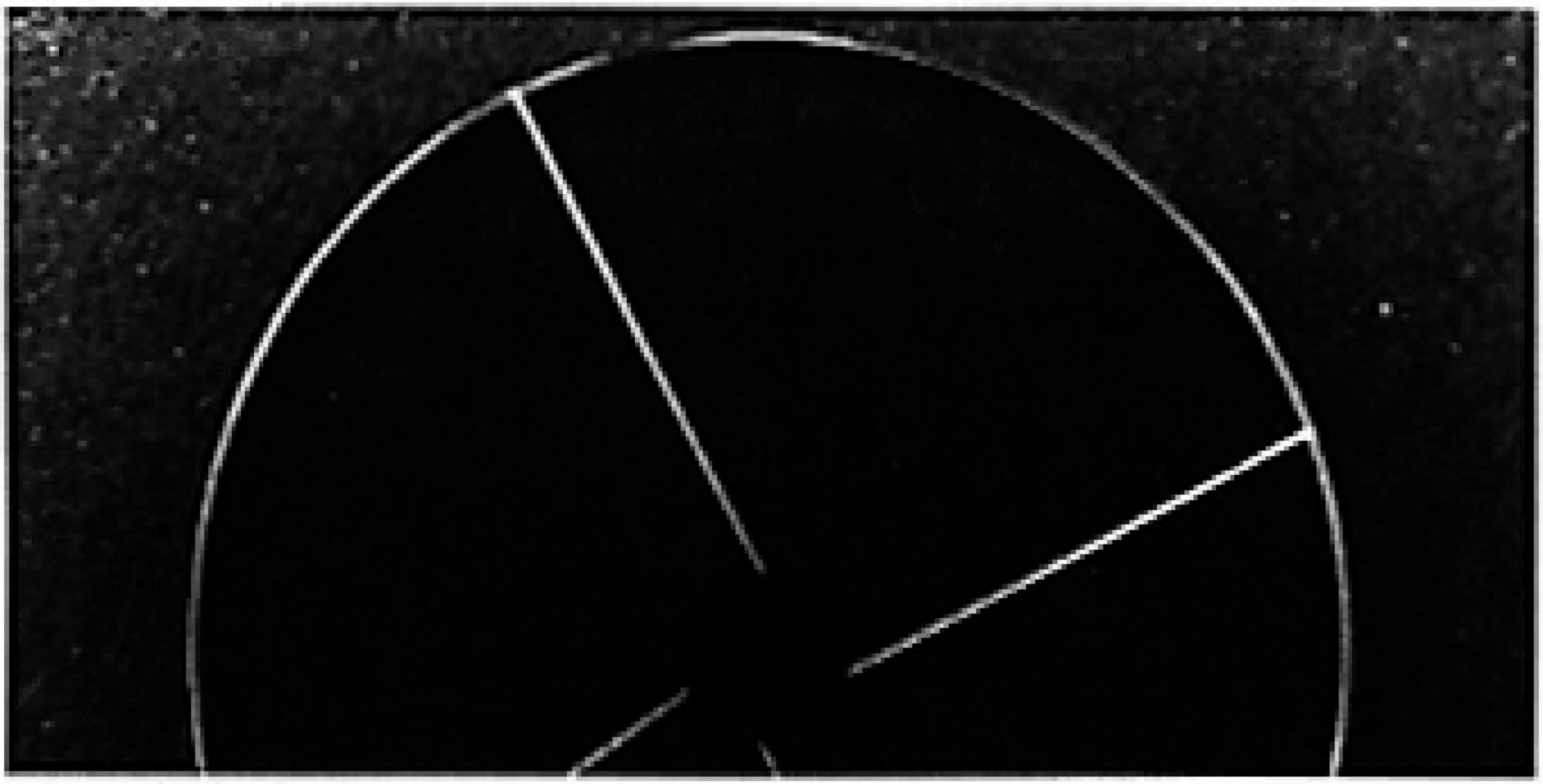
Illustration of melt ejection and hole drilling by 100 µs diameter Nd-laser pulses of rectangular temporal shape and variable duration: (a) early stages of melt ejection at 140MW/cm2 in copper after 330, 380, 520 and 720 ns; (b) hole profiles in steel at 20 MW/cm2, irradiated for 0.5, 1, 2, 5 and10 µs (always from left to right)

Laser drilling



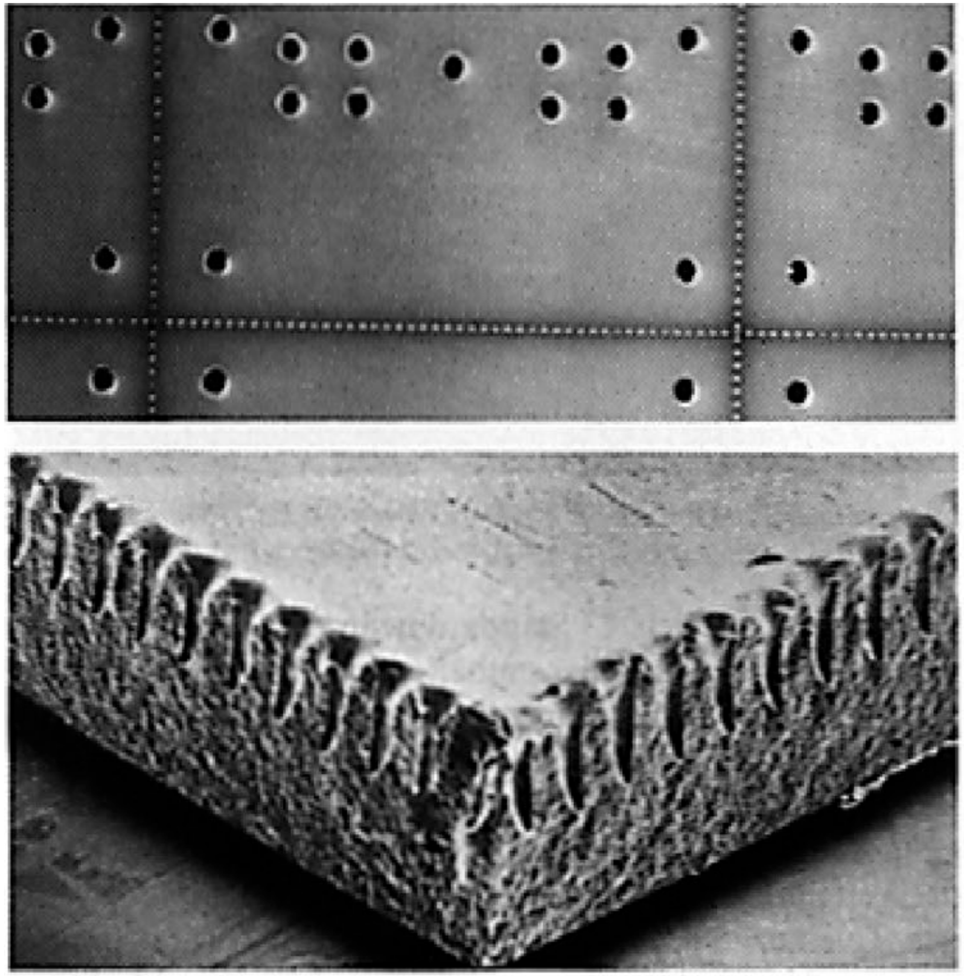
Crosssection of laser drilled hole (horisontal) and
EDM (electric discharge machining) fabricated hole

Laser drilling



Laser drilled holes in sapphire by pulsed Nd-YAG, 1064 nm.
Hole diameter under 100 µm, hole depth ~10 mm

Laser drilling



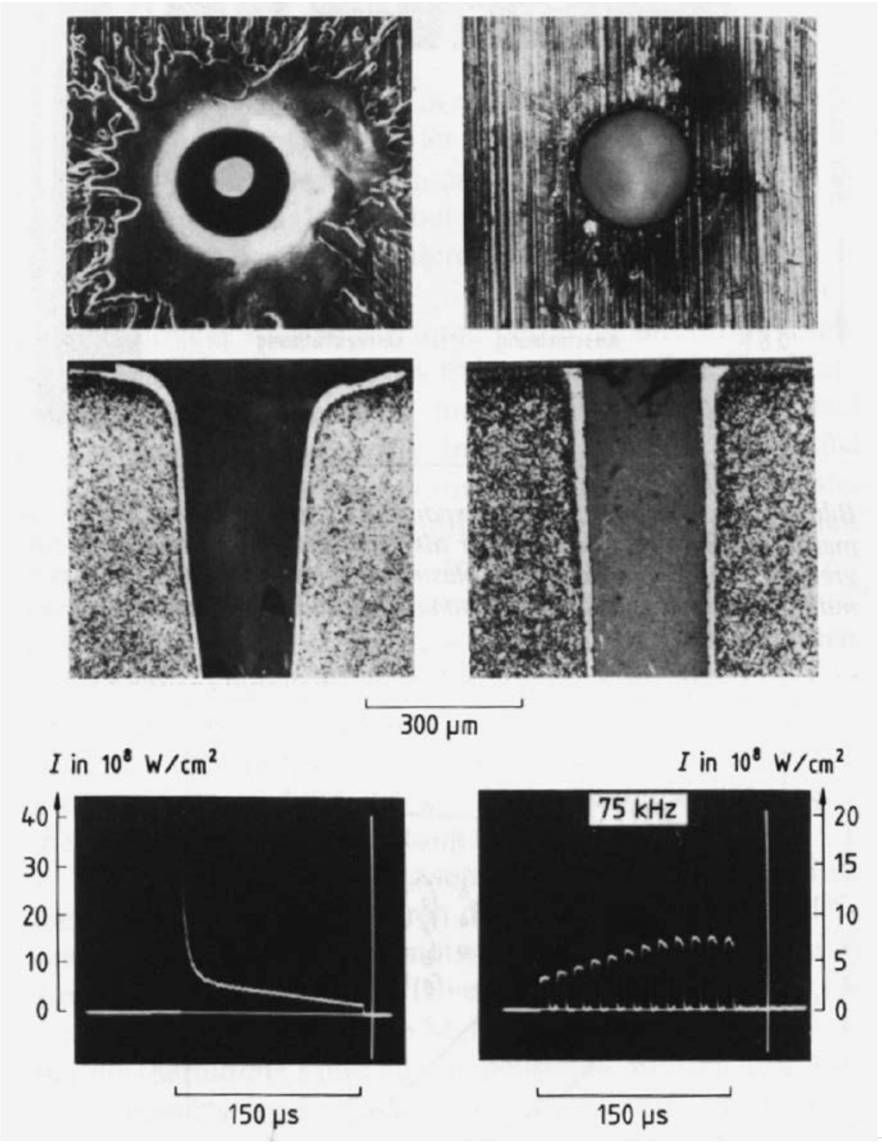
Drilling and scribing of ceramics with CO_2 laser

Laser drilling

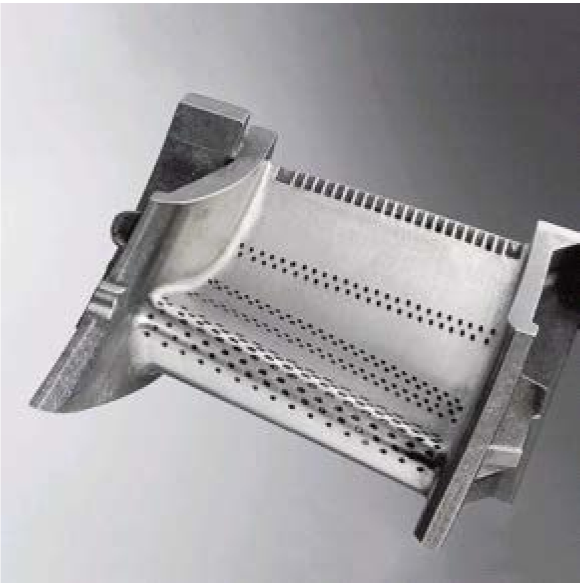
Influence of the temporal pulse form on the hole shape and material re-deposition

Left:
very high intensity in the beginning leads to the radial splashing

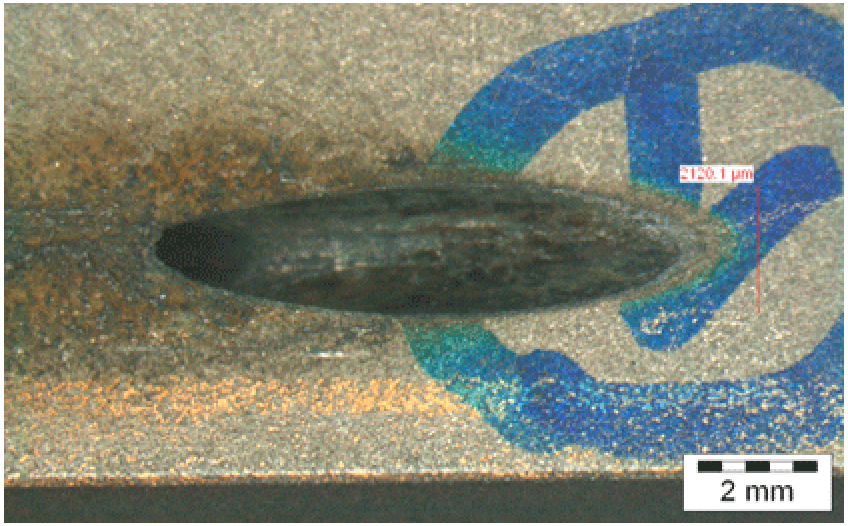
Right
Modulated, rising intensity –
cylindrical hole



Laser Drilling of Gas Turbine Blades



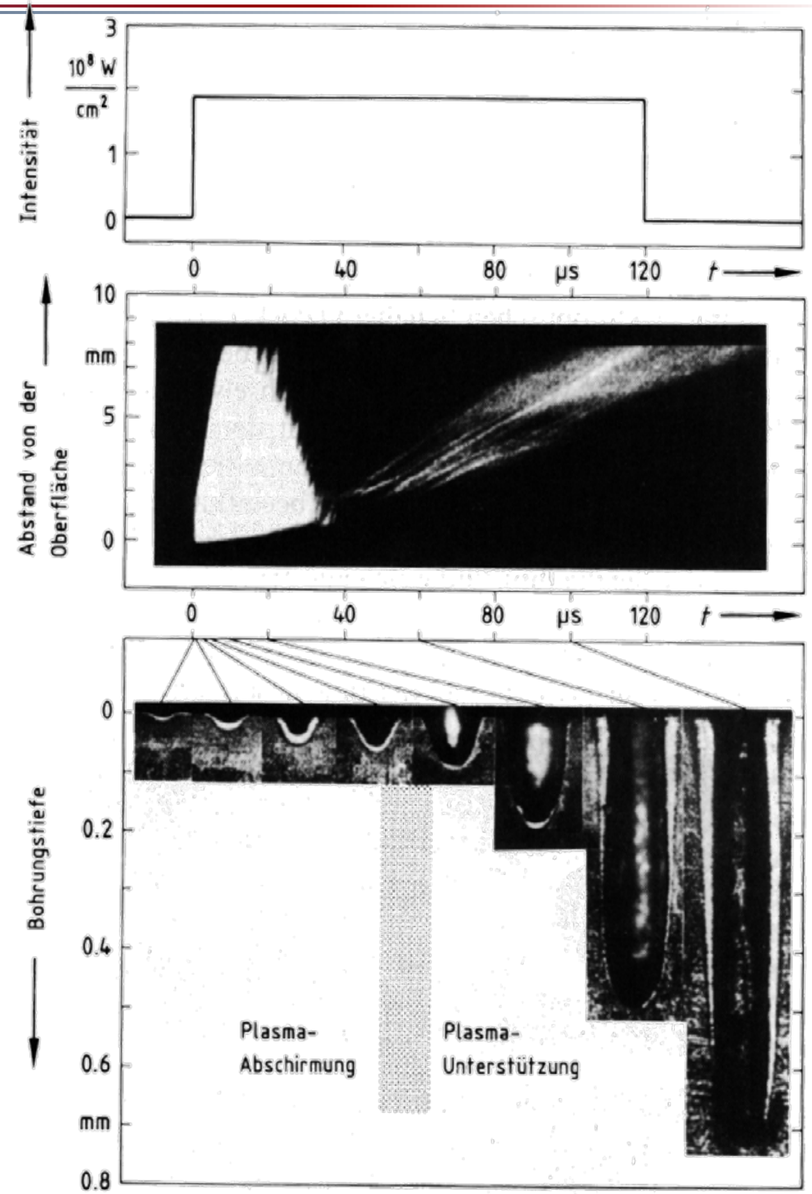
Entrance



Exit

Laser drilling

Laser power,
Plasma expansion,
hole geometry (cross-section),
as a function of processing time
(steel, 24 µm laser beam)



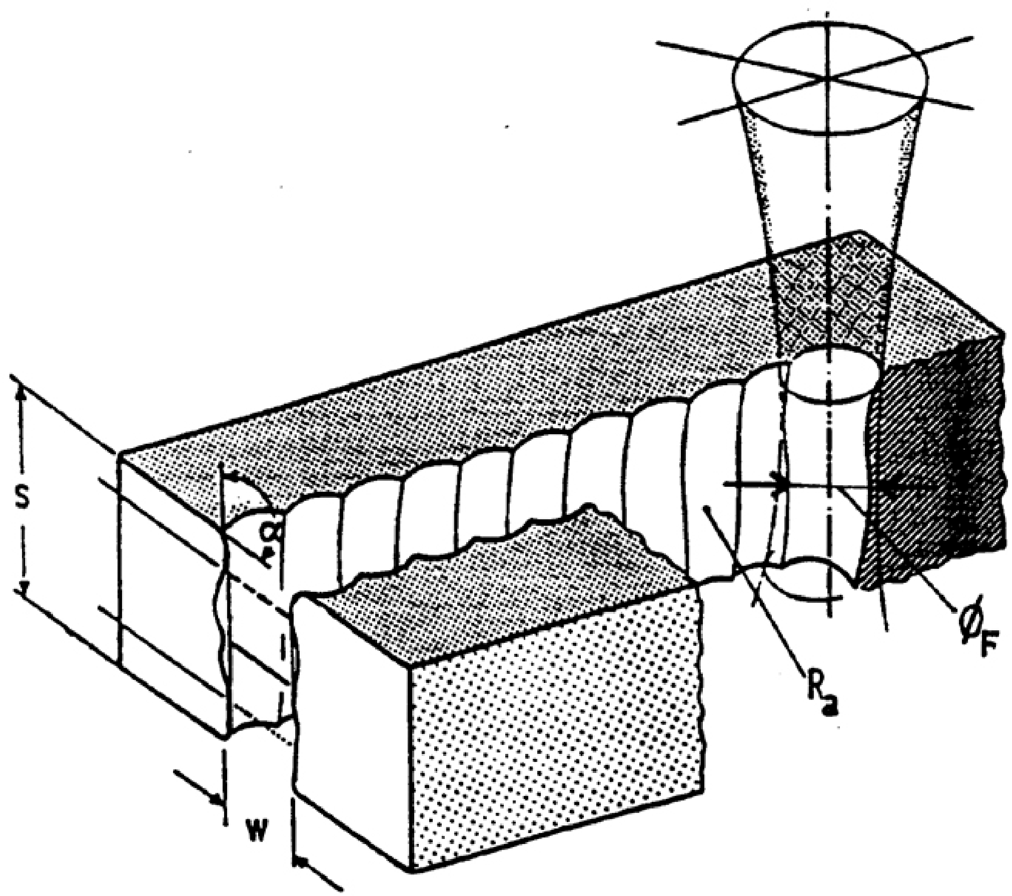
plasma shielding and
plasma supported regimes

Laser Cutting

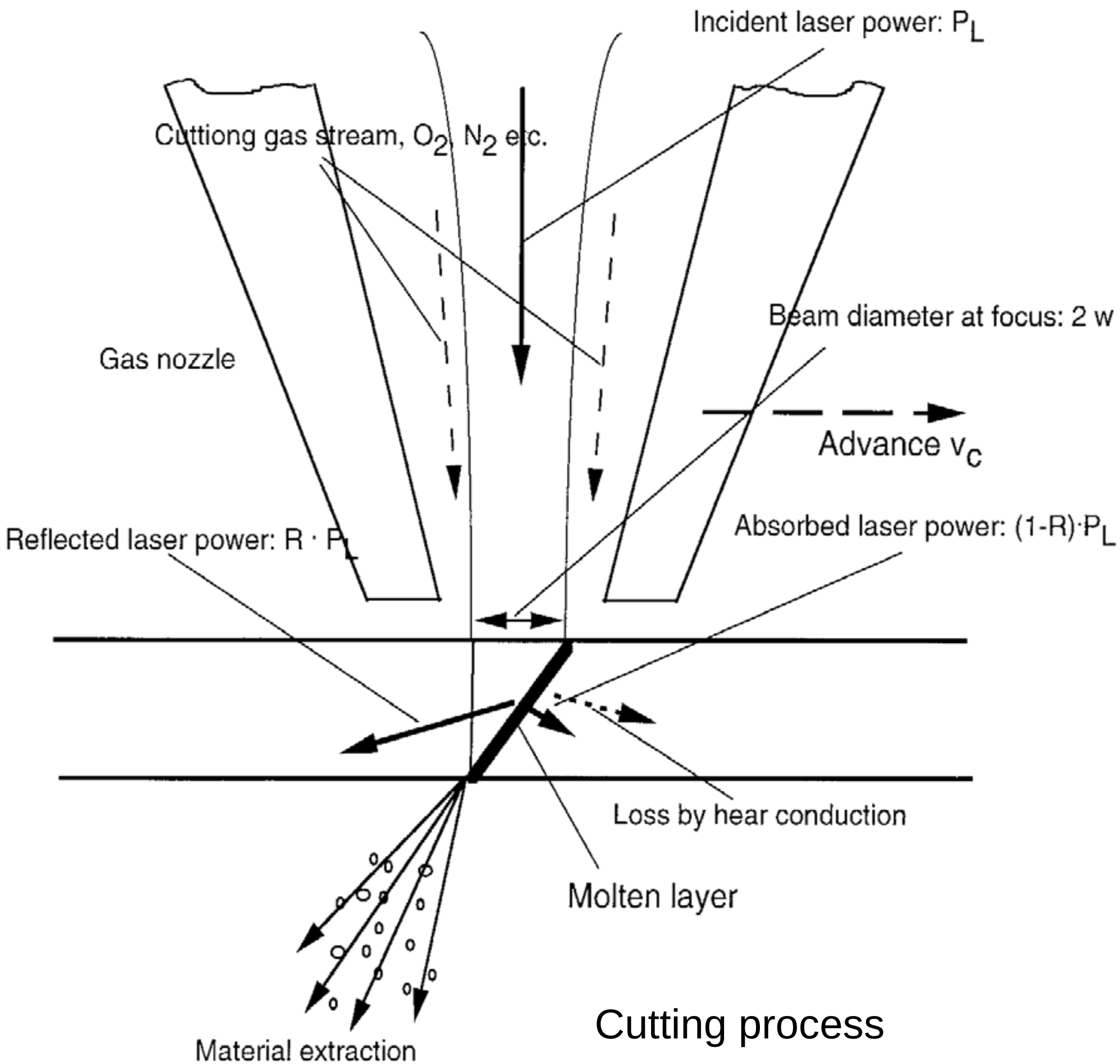
- Liquid Expulsion Cutting
- Cutting by Ablation

Laser cutting schematics

- Figure 3.4
  Characterization of a laser cut, after 4).
  W = kerf width
  α = conicity
  R_a = average roughness
  $\varnothing_F$ = beam diameter at focus

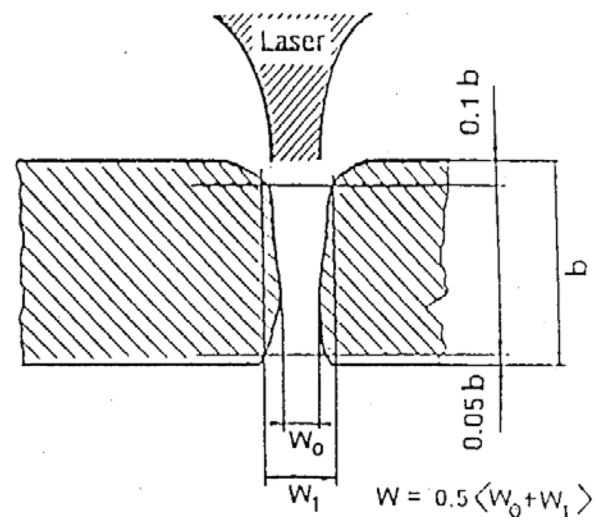


Laser cutting basics



Cutting process

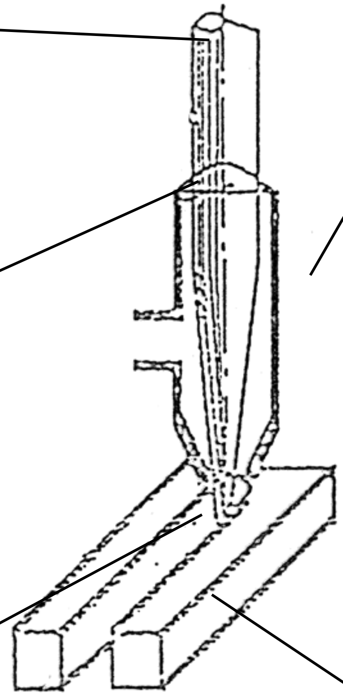
Resulting cut profile



Parameters of the laser cutting process

Laser beam:
•Power
•Mode structure
•Diameter
•Polarization
•Beam quality

Material:
•Surface
(reflection/absorption)
•Thickness
•Material properties
Density
Therm. Diffusivity
Therm.
Conductivity
Enthalpy

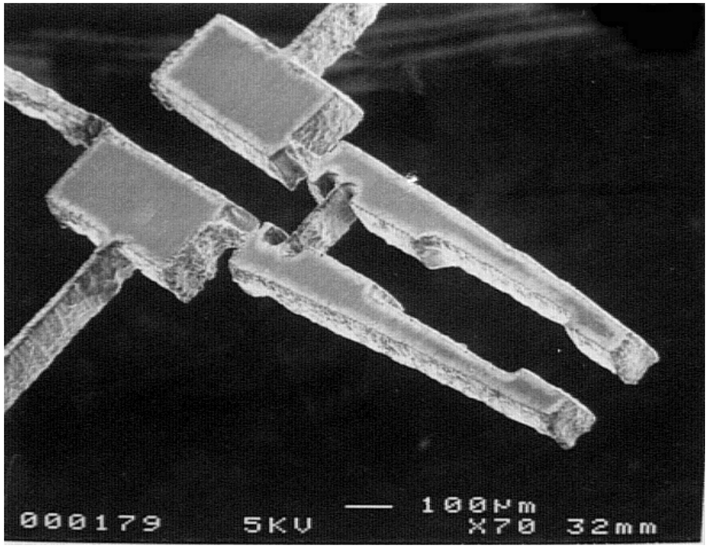


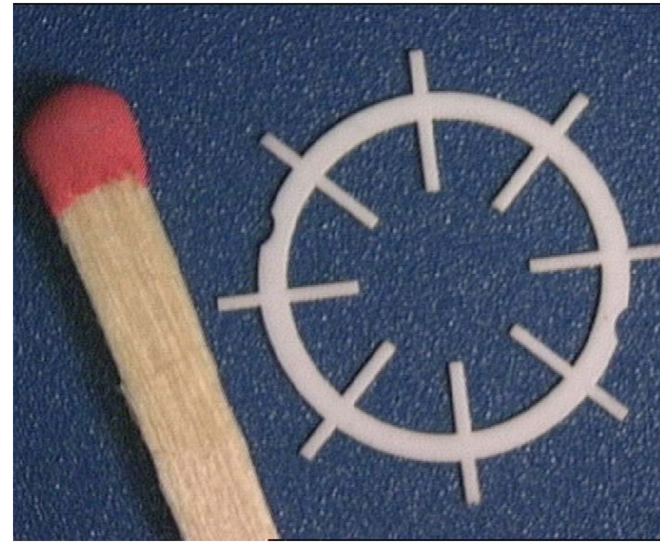
Optics:
•Focal length
•Focus spot
diameter
•…..

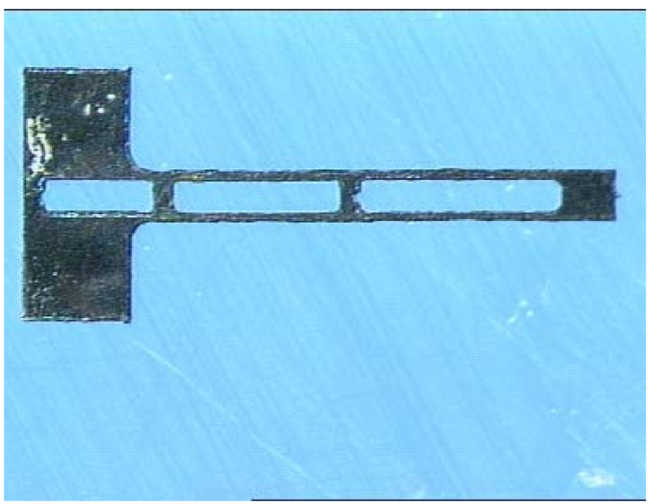
Nozzle:
•Shape
•Diameter
•Gas
•Gas pressure
•Gas flow

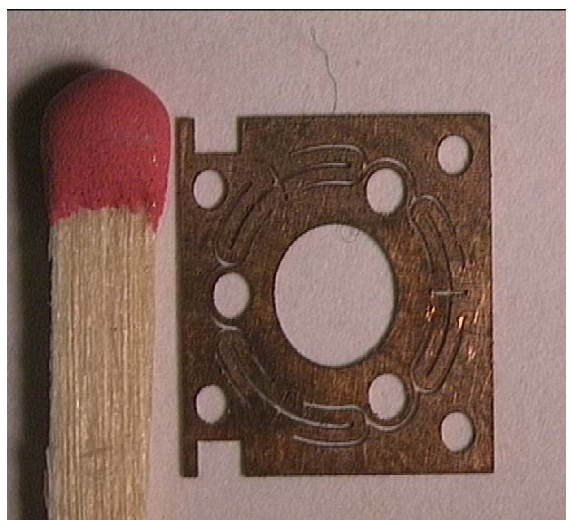
Quality parameters:
•Cut kerf width
•Striations / Roughness
•Heat Affected Zones
•Metallurgical conditions in
the cut kerf zone

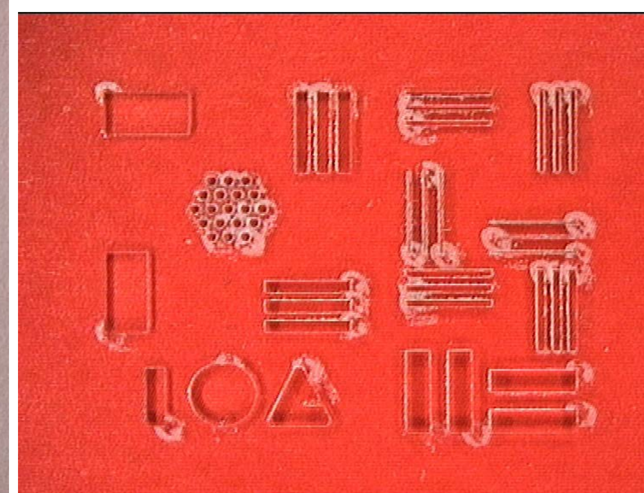
Nd:YAG laser cutting results





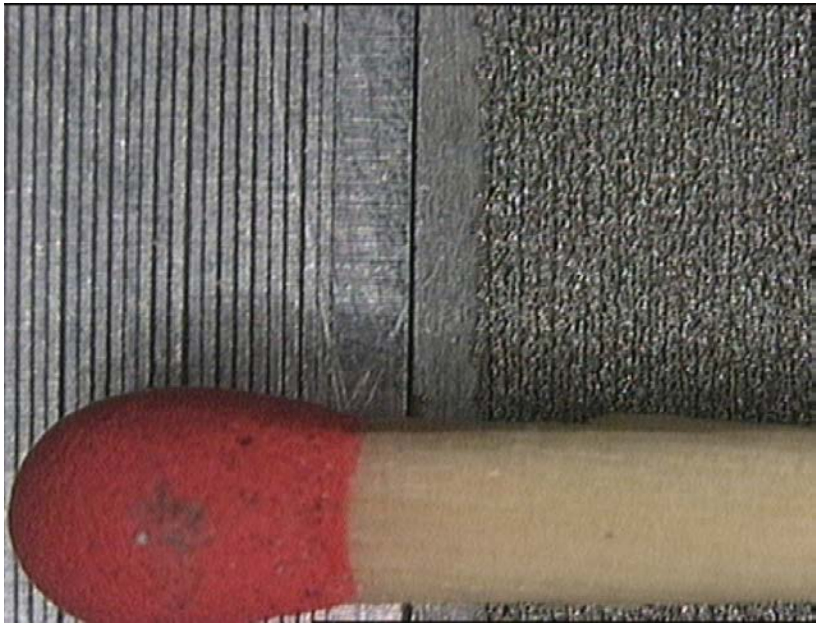




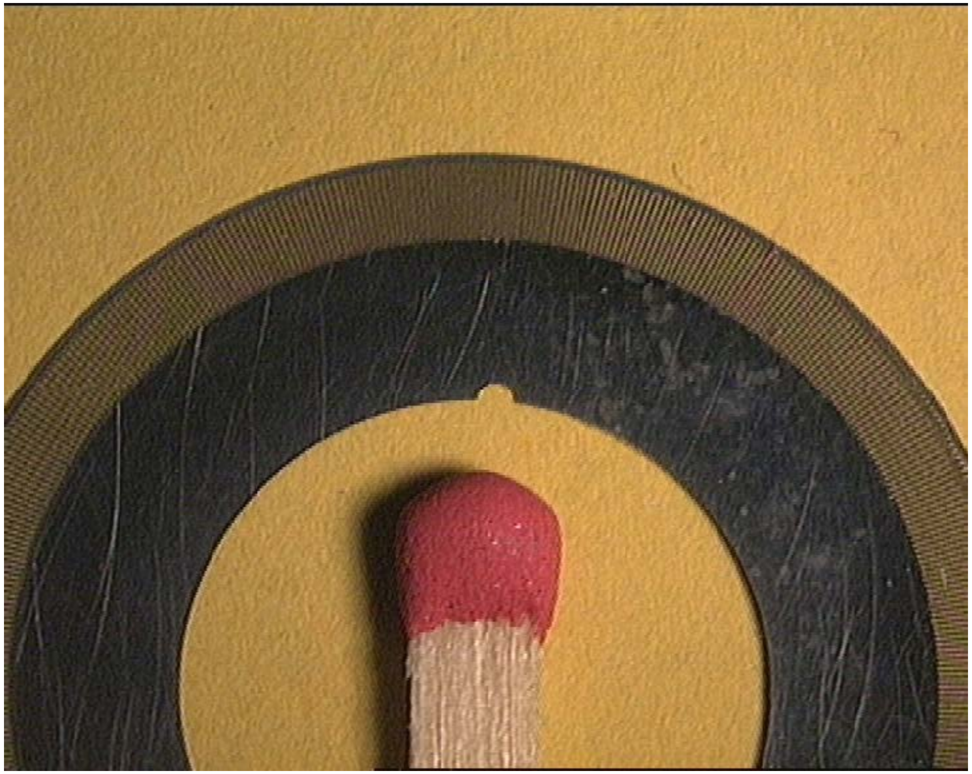


Examples

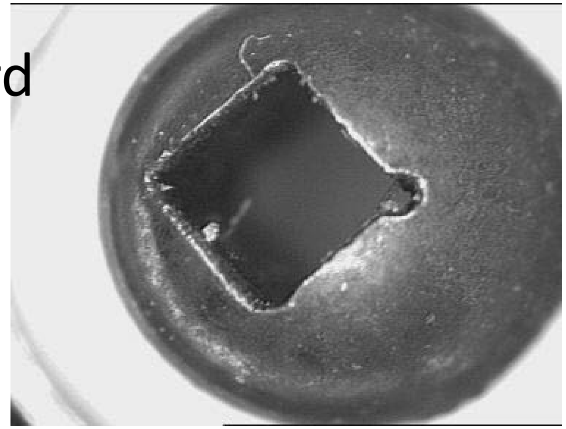
Aluminium cut in air



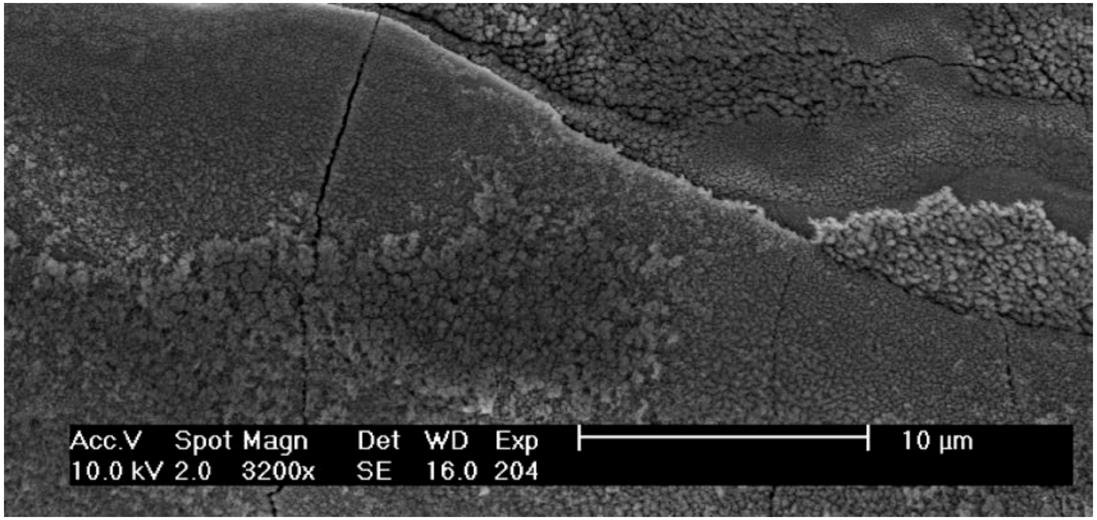
Molybdenum 50 µm

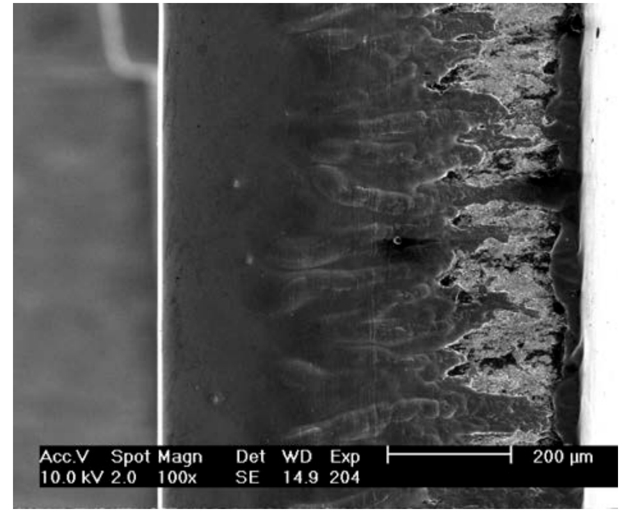


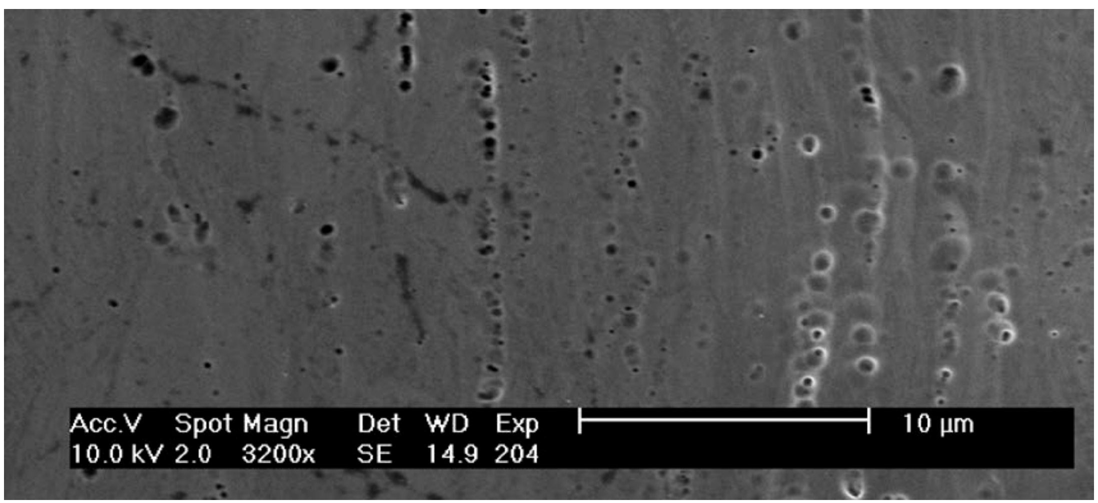
extra hard steel

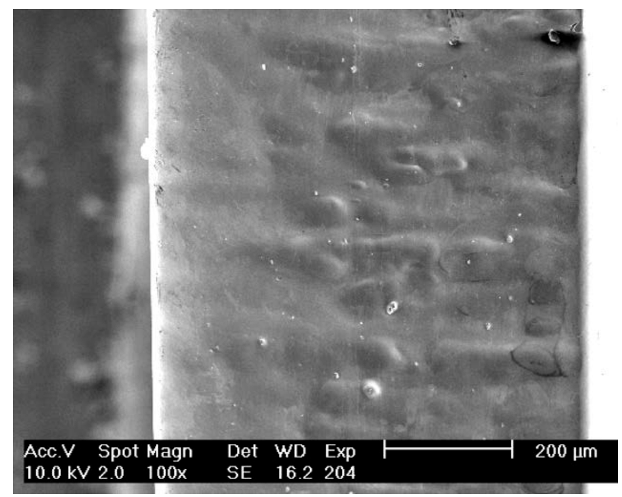


Laser cut stainless steel before & after electropolishing









Laser Cutting: Summary

- gas assisted liquid ejection cutting most economic
- oxidation might assist efficiency
- kerf width and heat affected zone thickness of about thermal penetration depth
- optimal speed of cutting with about 30% overlay
- aspect ratio kerf/material thickness 1/20 for metals and 1/40 for ceramics
- post treatments often necessary (biocompatibility, edge roughness)