TRUMPF

Laser Machining of High Strength Materials

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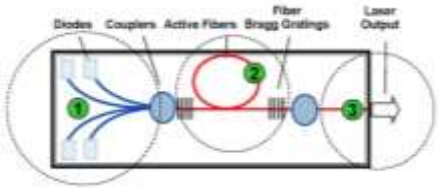
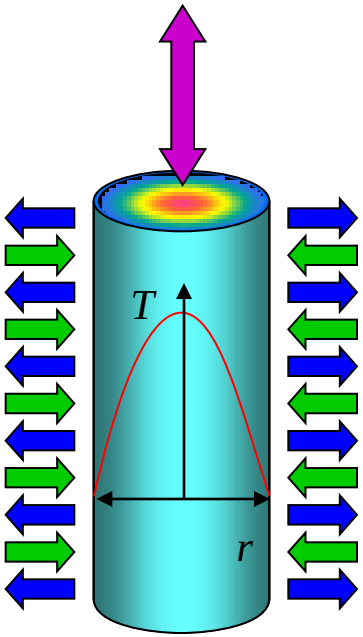
Outline

- Available industrial laser technologies
- Industrial beam delivery systems
- Applications

Laser type		Available power	Delivery fibers
CO_2		1,000..20,000 W	No fiber beam delivery available
Thin disk		1,000..20,000 W	50-1,000 µm
Fiber		1,000..20,000 W	50 – 300 µm
Diode		1,000..15,000 W	400-1,000 µm

Current Solid State Laser Concepts

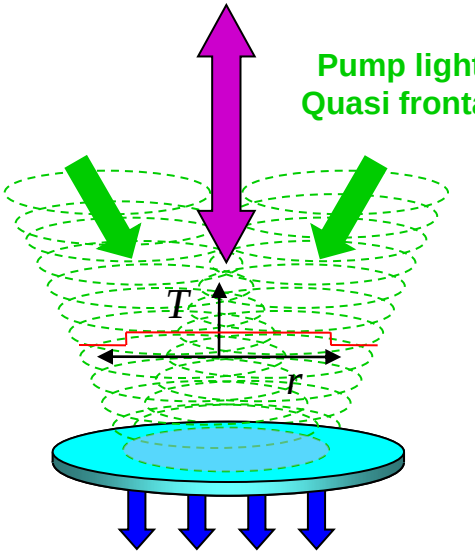
Rod Laser



- Parabolic temperature profile
- Cooling and Pumping
- lamp- and diode pumped

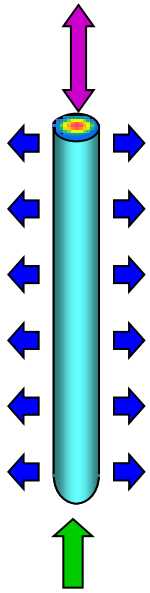
Thin Disk Laser

Laser Emission



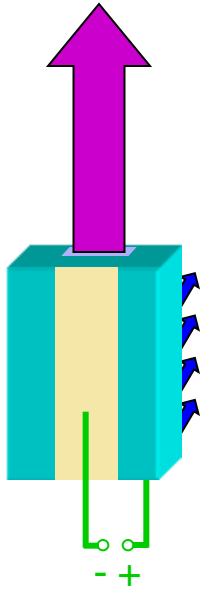
- Flat temperature profile
- Back-side Cooling
- Diode pumped

Fiber Laser



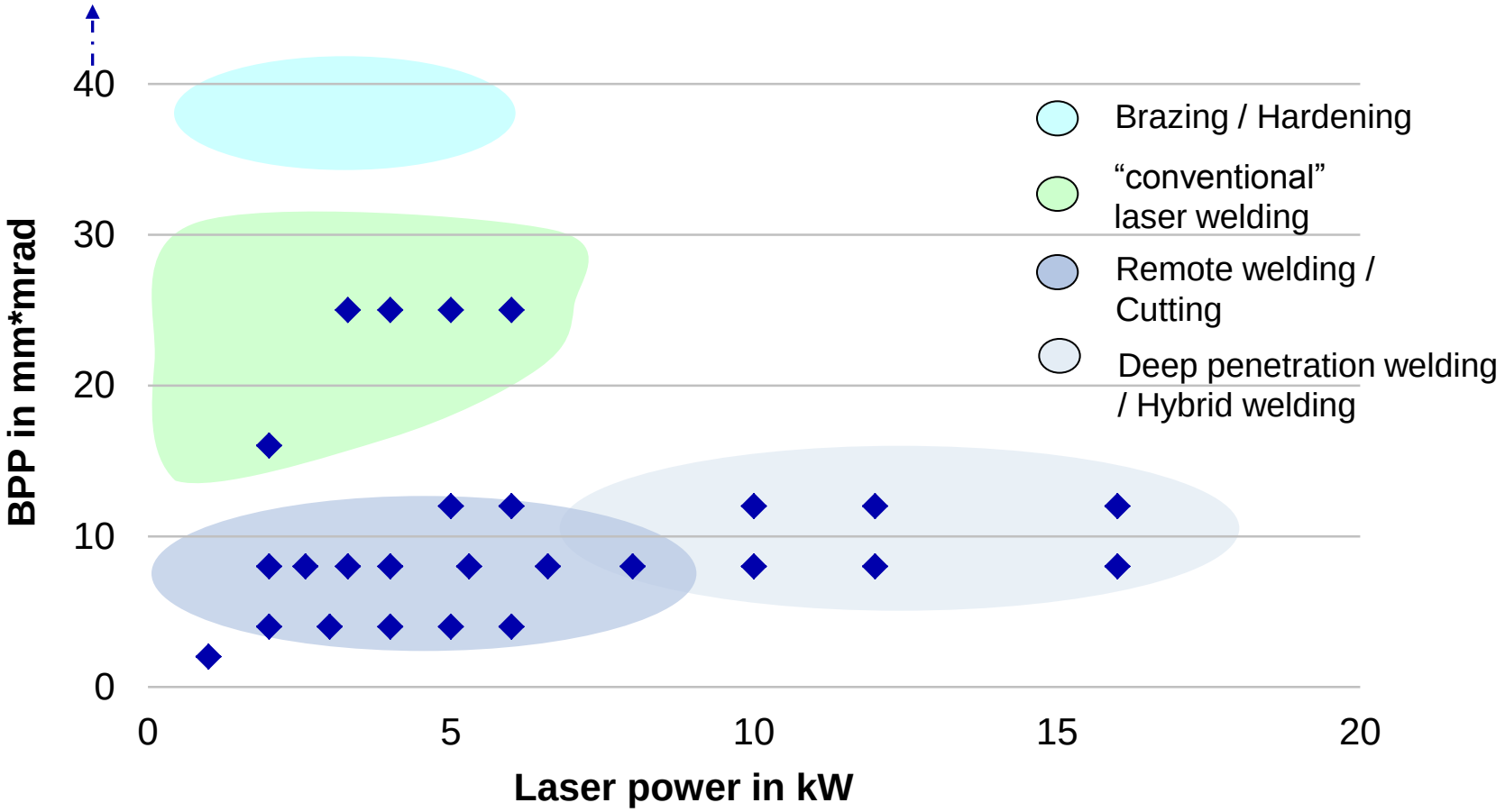
- Cooling via lateral area
- Side or endpumped
- Diode pumped

Diode Laser

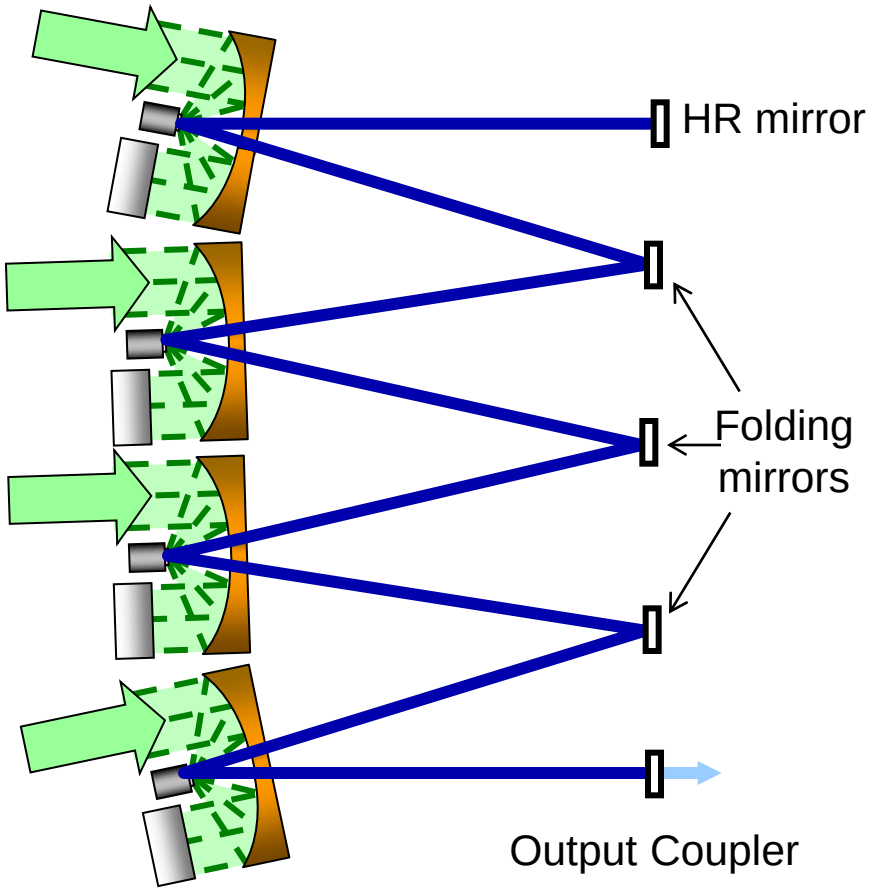


Direct conversion of current to light

Product Portfolio TruDisk Lasers

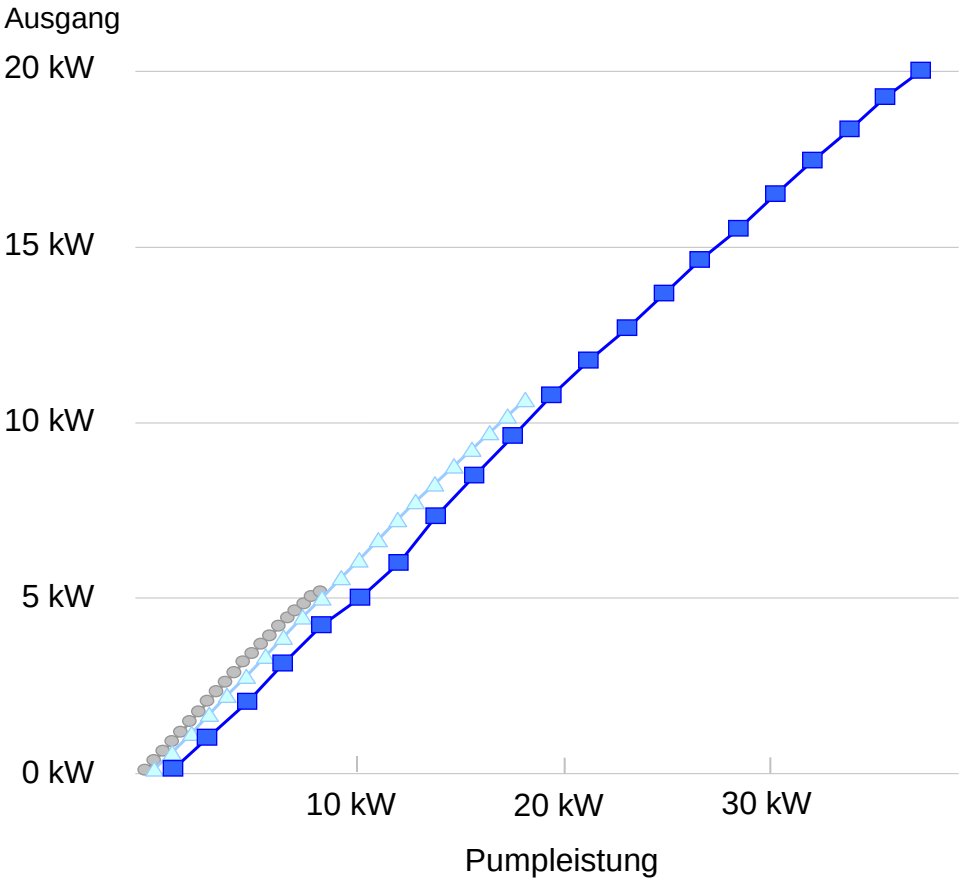


Power Scaling: Serial Coupling



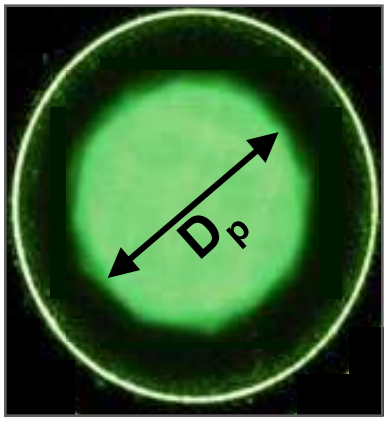
⇒ ***Intensitites are constant***

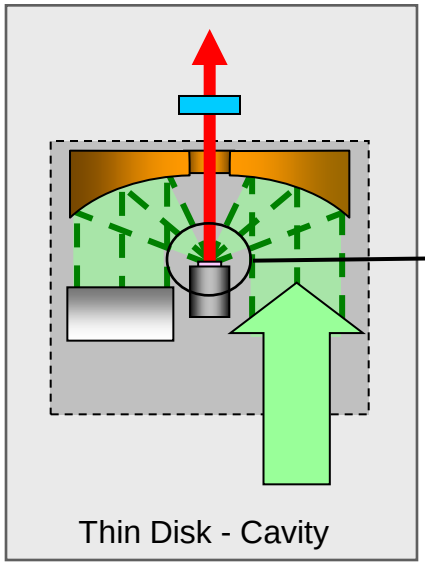
Power Scaling: Serial Coupling

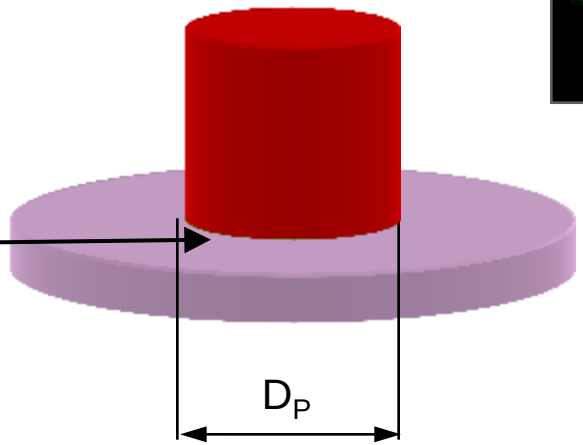


Power Scaling: Pump Spot Size

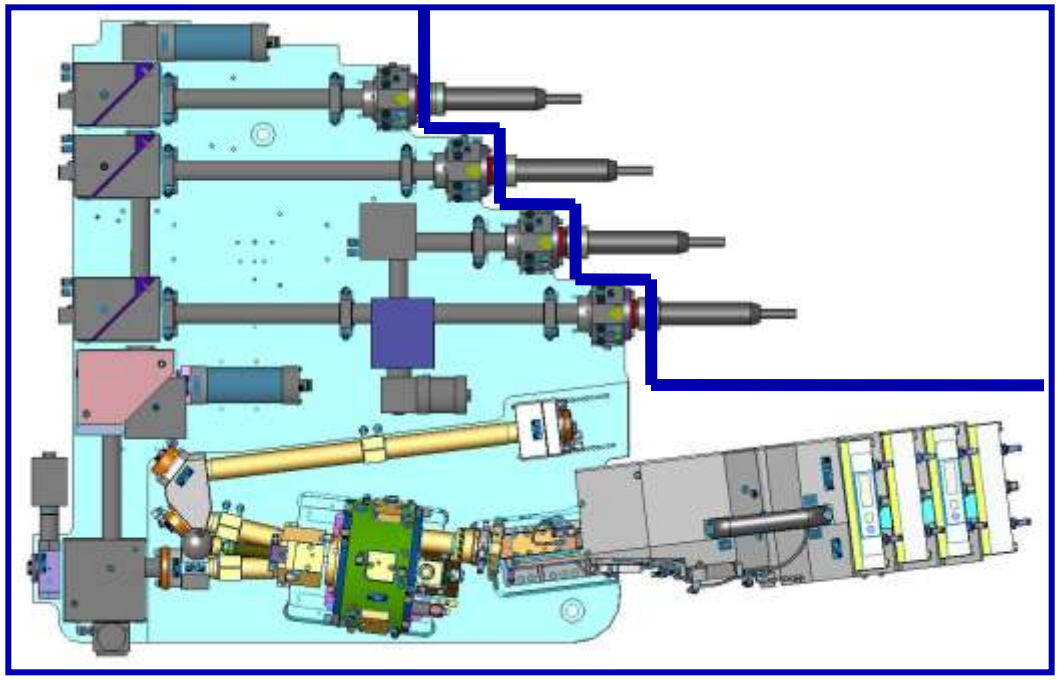
a specific laser power can be extracted per unit of area $\Rightarrow P_L \sim D_p^2$







TruDisk System Design and Advantages



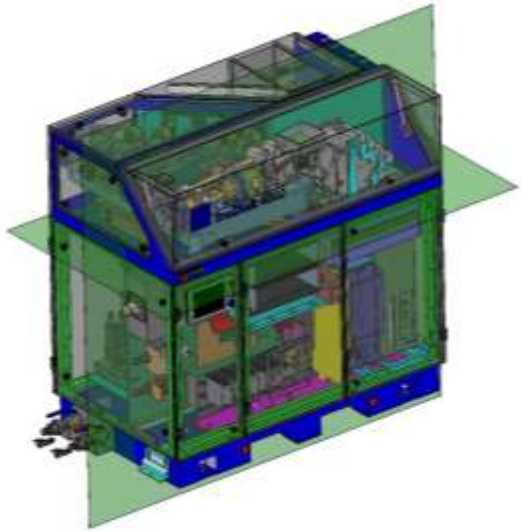
1. Modular configuration
2. Highest diode lifetime
3. Optimized/ Efficient resonator design
4. Insensitive to back reflections
5. Power feedback control
6. Industrial proven beam management

Advantages of a Modular Equipment Configuration

- Modular concept throughout the entire laser system (Beam generation, beam management, Control, chiller)
- Fast exchange of all components on site
- Monitoring of all components possible

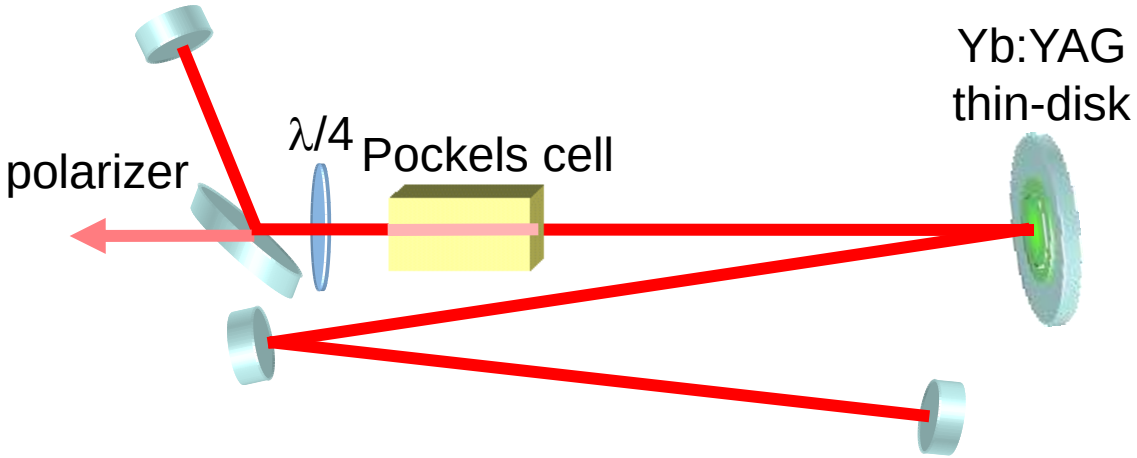
=> Minimizing downtime in case of failures

- Upgradeability e.g. of beam management possible on site
- No splicing needed



High reliability, minimized downtime and flexibility!

Excursion: Thin Disk based ns Laser

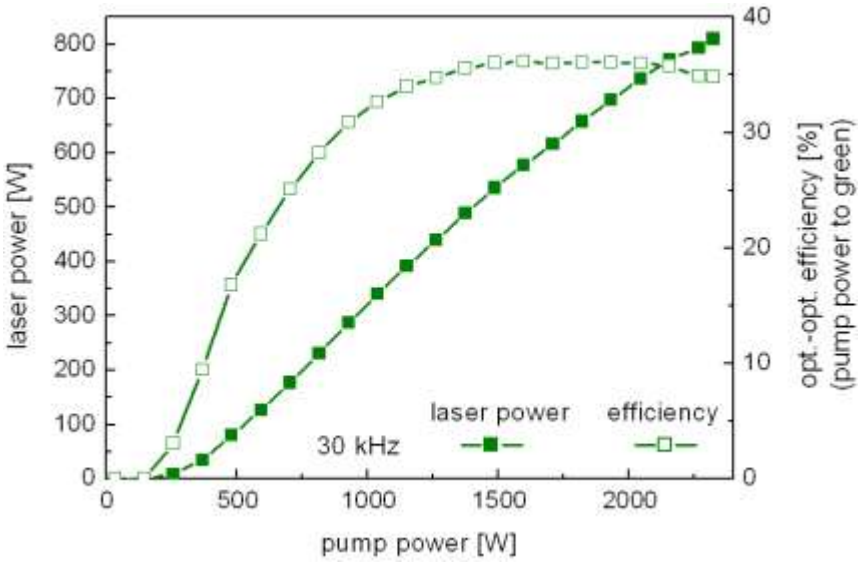


Laser Setup based on TruDisk platform

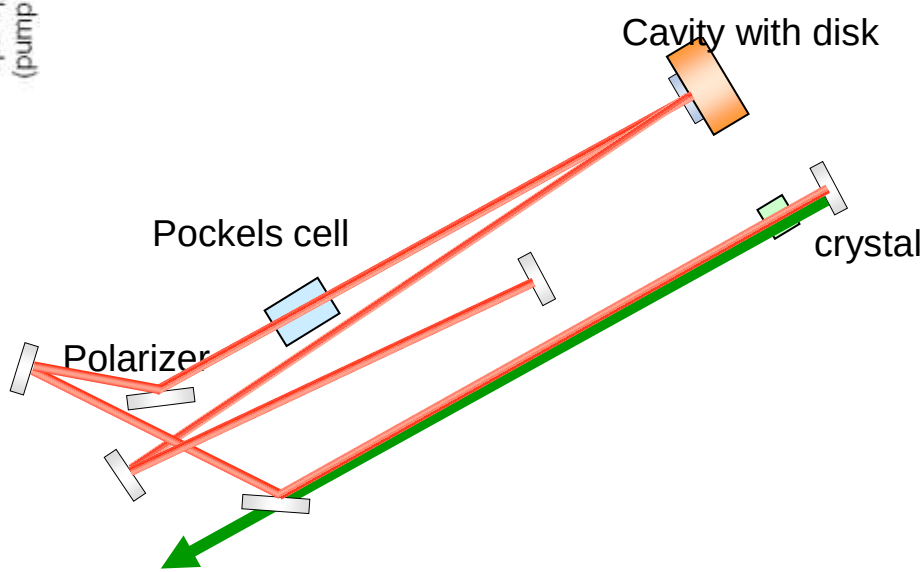
Pulse generation by Cavity dumping

⇒ Stable operation also at high repetition rate
⇒ Flexibility to realize various pulse durations
⇒ Pulse duration independent of operation condition

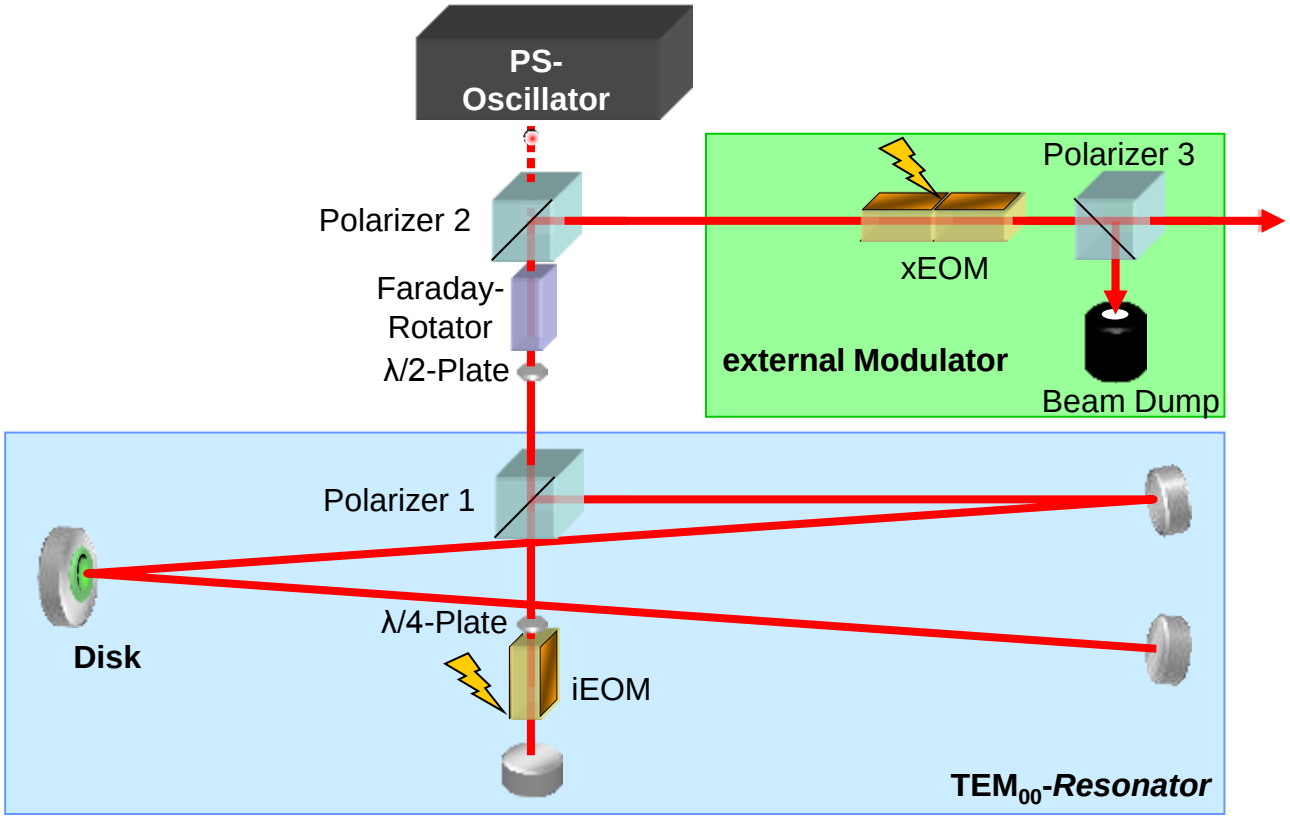
Thin Disk based ns Laser with cavity internal SHG



		TruMicro 7050	TruMicro 7250
Specifications	Power / W	750	400
	Wavelength / nm	1030	515
	Pulse duration / ns	30	300
	max. Pulse energy / mJ	80	10
	Repetition rate / kHz	5 - 100	20 - 100
	Fiber delivered	≥ LLK04	≥ LLK01
	Fiber exits	up to 4	up to 4
	Applications	Edge Deletion (PV), Cleaning, Drilling, Cutting	Cutting, Annealing, Drilling



Excursion: Thin Disk based ps Laser - Regenerative Disk Amplifier



Outline

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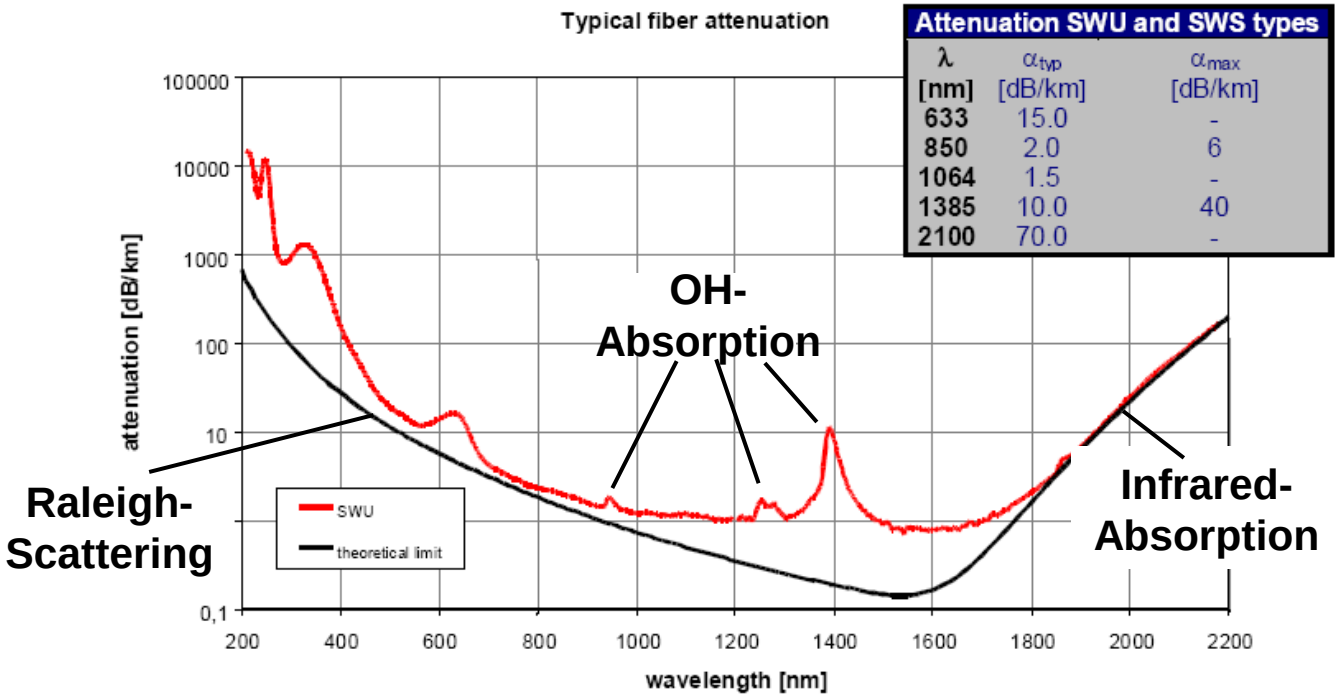
- Industrial beam delivery systems
- Applications

Beam Delivery Systems for Industrial Applications

Laser Light Cable (LLK): Delivery fiber with different core geometry
Fiber shape: Round or square

Absorption in Silica Fibers



Attenuation in optical fiber is caused primarily by both scattering and absorption, and for longer wavelengths IR absorption.

Beam delivery systems - losses

Fiber length [km]	0.1	1	3
Attenuation per length [per km]	1	1	1
Total attenuation [dB]	0.1	1	3
Input power [W]	20,000	20,000	20,000
Output power [W]	19,545	15,887	10,024
Power delivered	98%	79%	50%

Additional losses post fiber – Halocarbon fluids

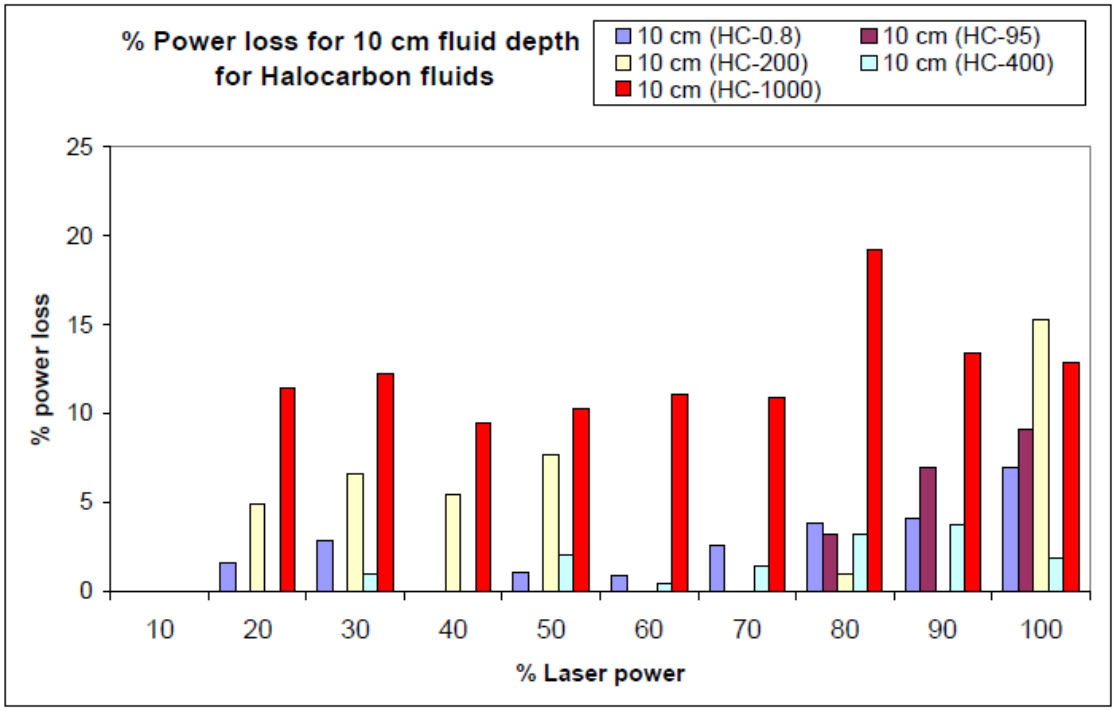
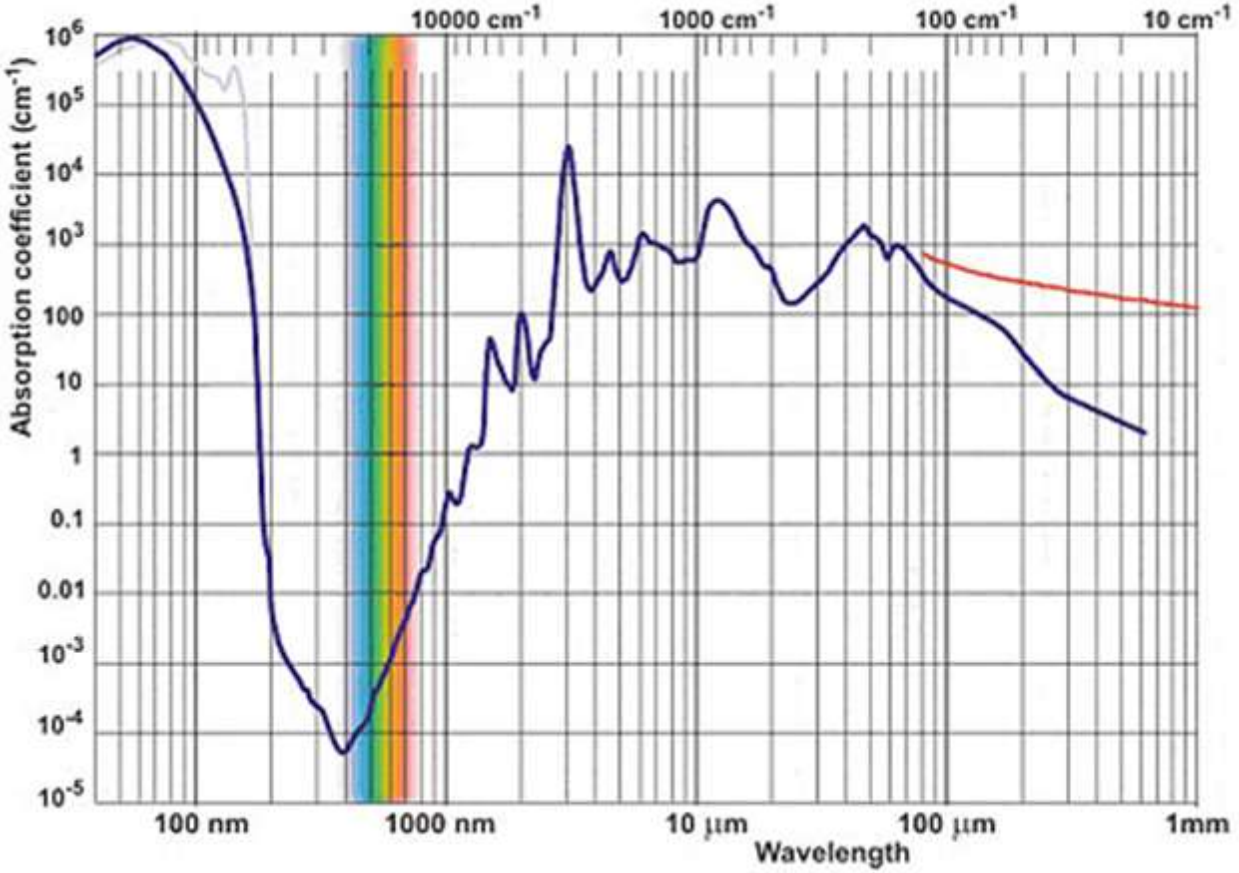


Figure 66. Percentage Loss in laser power for 10 cm fluid depth for various halocarbon fluids

Source: Laser Drilling – Drilling with the Power of Light - Gas Technology Institute, 2007

Additional losses post fiber – H_2O



Lambert law:

$$I = I_0 e^{-\alpha x}$$

Outline

- Available industrial laser technologies
- Industrial beam delivery systems
- Applications
  - Ultra short pulse applications
  - Sheet metal processing
  - Rocks

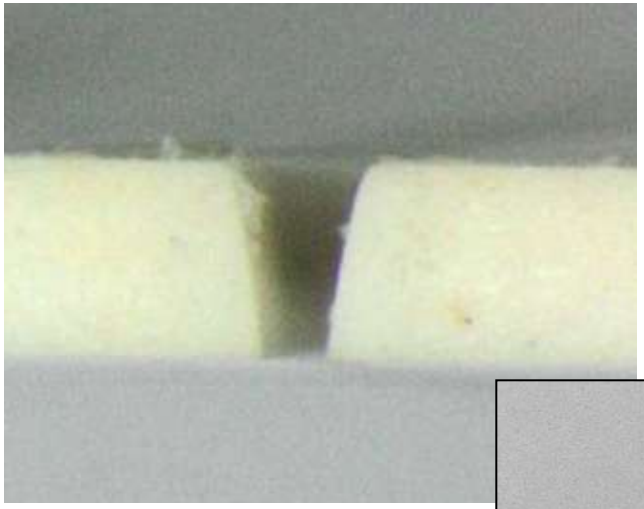
Cutting of Ceramics (Al_2O_3, ZrO_2)

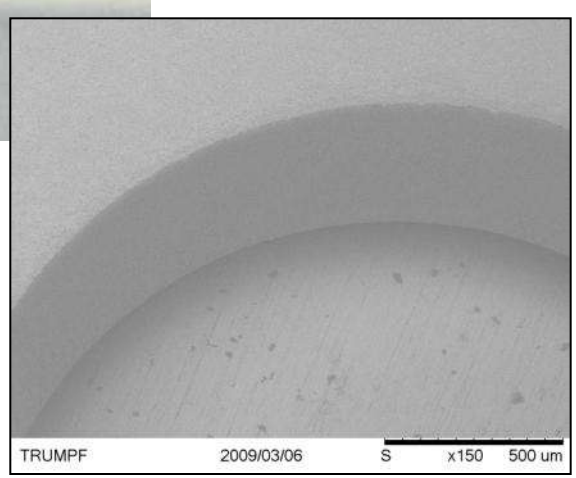
Request:

- Cutting of ZrO_2 ceramic
- Thickness: 0.3 mm
- No recast layer
- No micro cracking

Solution:

- TruMicro 5050
- 10 mm/s effective speed
- No recast
- No micro cracking
- 10° Taper





Drilling of Ceramics

Request:

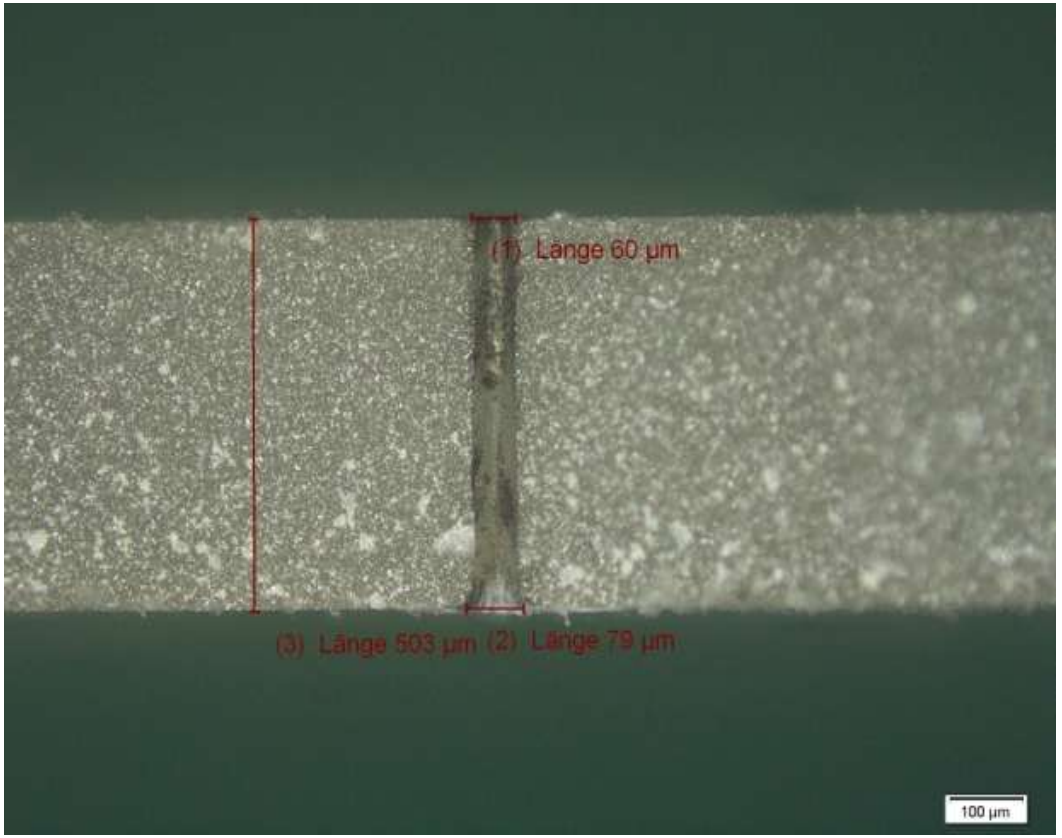
- Straight holes in AlN and Al_2O_3 ceramics
- Thickness 0.5 mm
- 60 µm diameter

Solution:

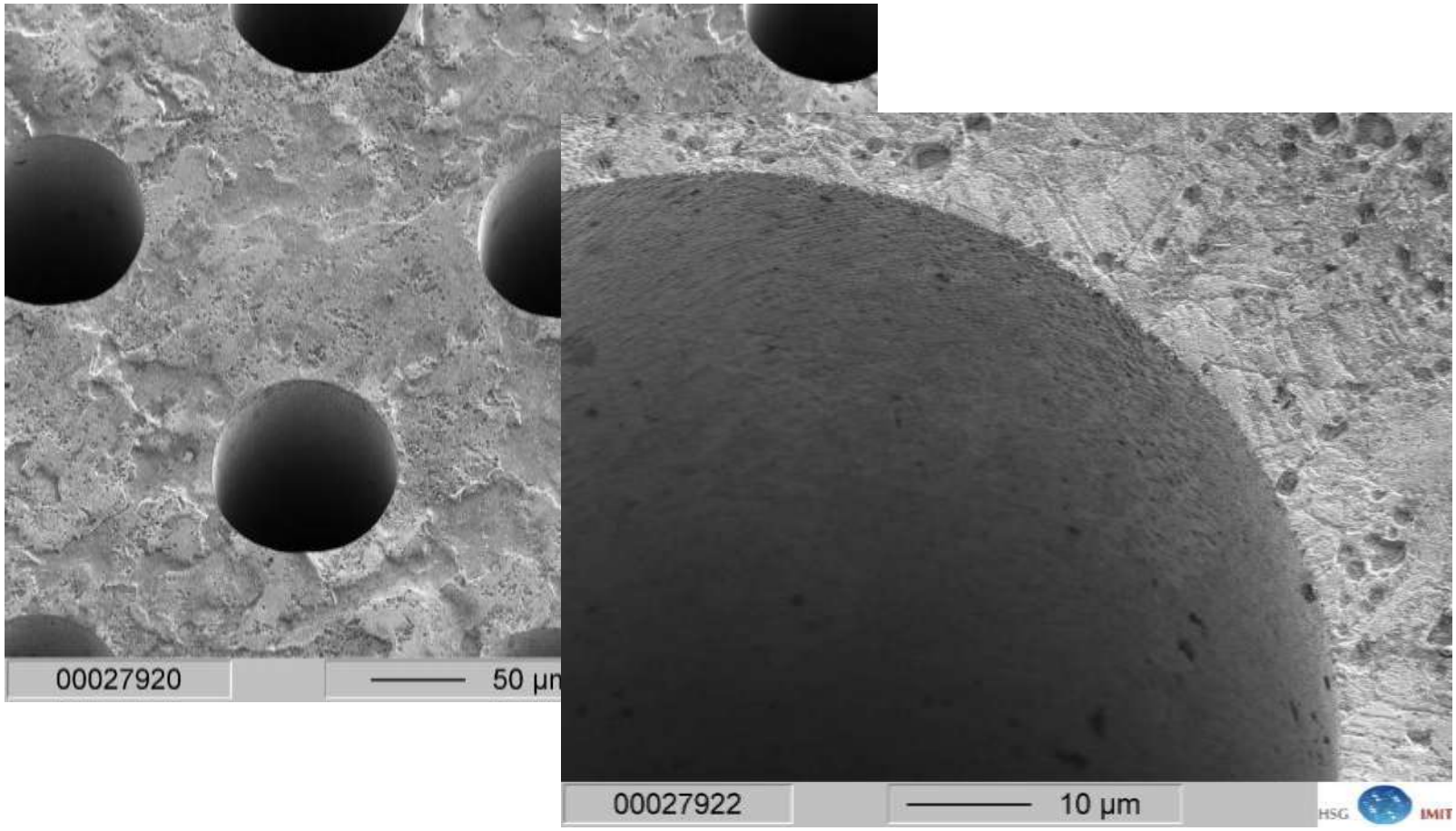
- TruMicro 5050 / 5070

Result:

- Almost straight hole
- > 20 holes / s
- No burr



Drilling of Steel



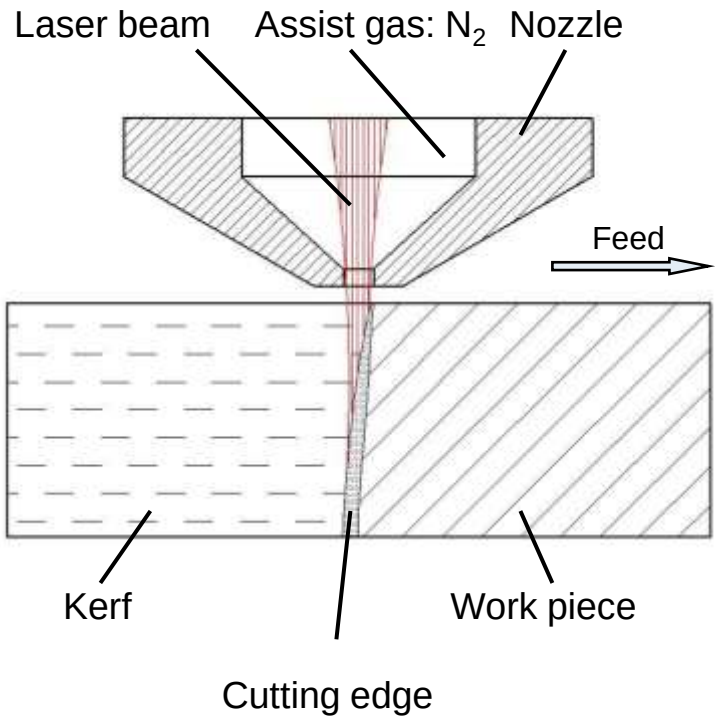
Laser Cutting Processes

- Laser fusion cutting with Nitrogen: Mild steel, Stainless Steel, Aluminum
- Oxidation cutting with Oxygen: Mild steel; up to 50 mm thickness
- High speed cutting with Nitrogen / air: Mild steel, Stainless Steel, Aluminum
- Sublimation (vaporization) cutting: Non metals

Fusion Cutting with Inert Assist Gas

Process characteristics:

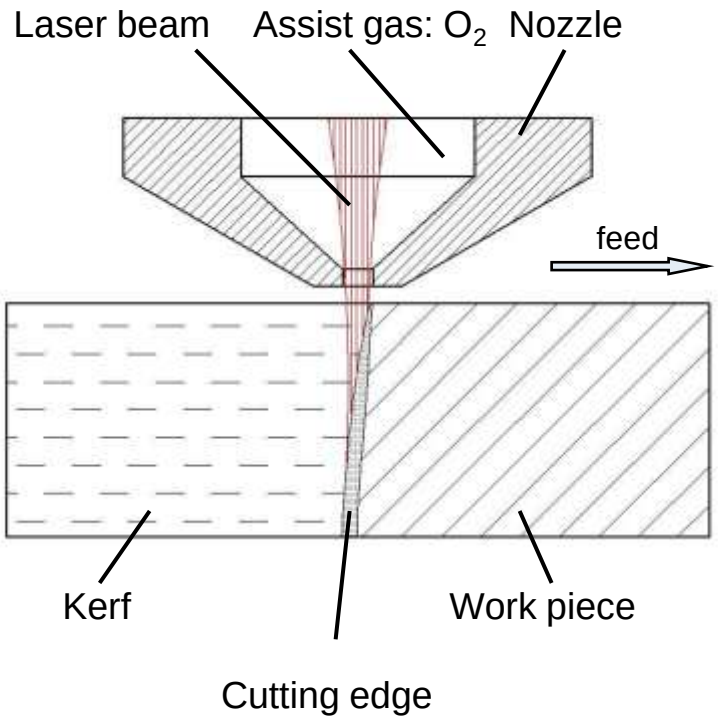
- No reaction between assist gas and melt pool
- Only laser supplies process energy
- High assist gas pressures required
- Mild steel can be cut w/o oxidation
- Work piece can be painted or welded w/o additional pretreatment



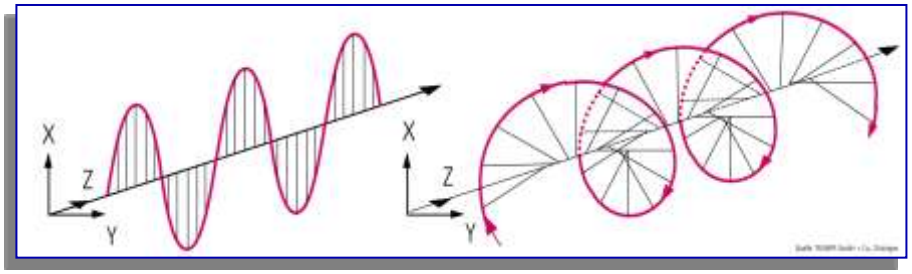
Oxidation cutting

Process characteristics:

- Oxidation process between meld pool and assist gas
- Available process energy equals sum of laser power plus reaction energy
- Laser heats up work piece to ignition temperature of Oxygen
- Process is sensible to surface conditions in thick material
- Absolute temperature of work piece needs to be minimized

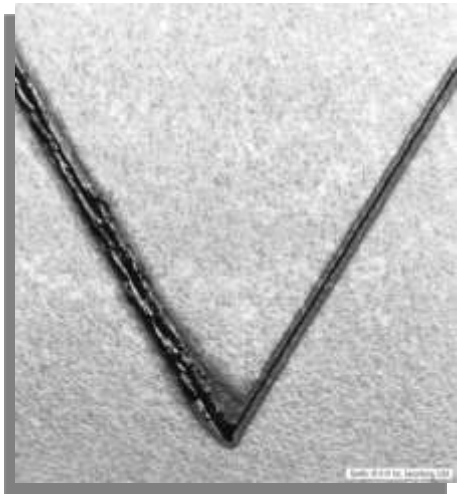


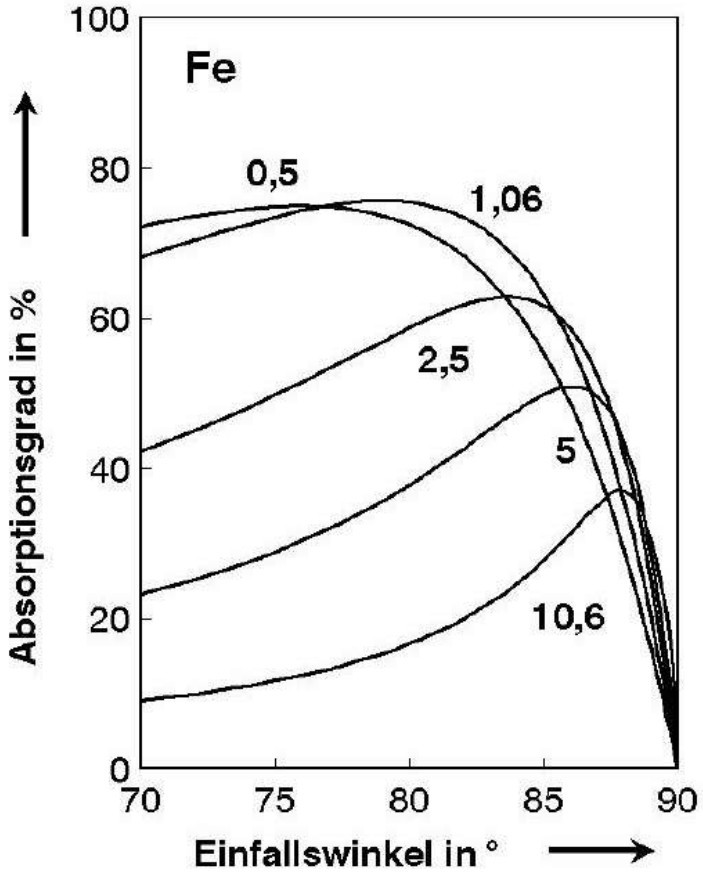
Other important characteristics



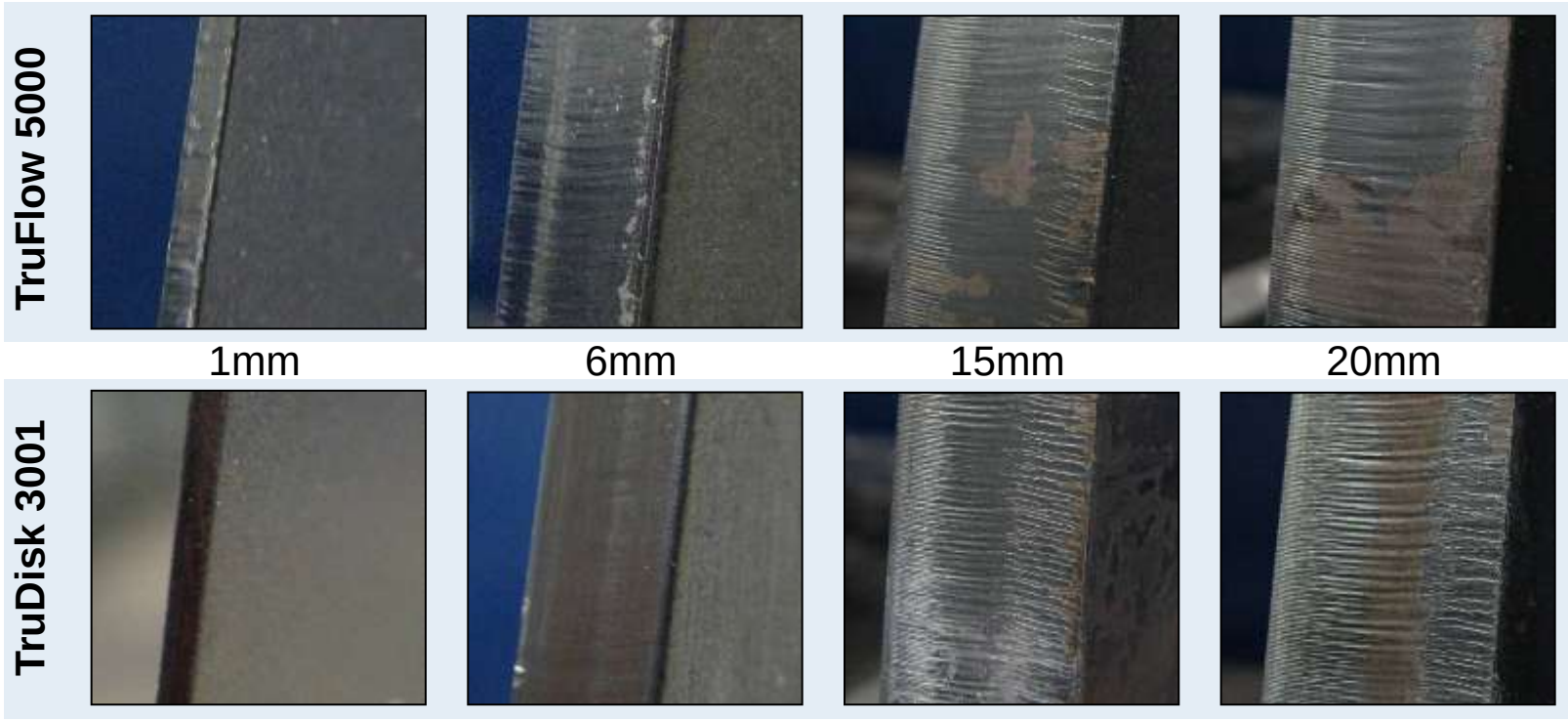
Linear polarized

Circular polarized

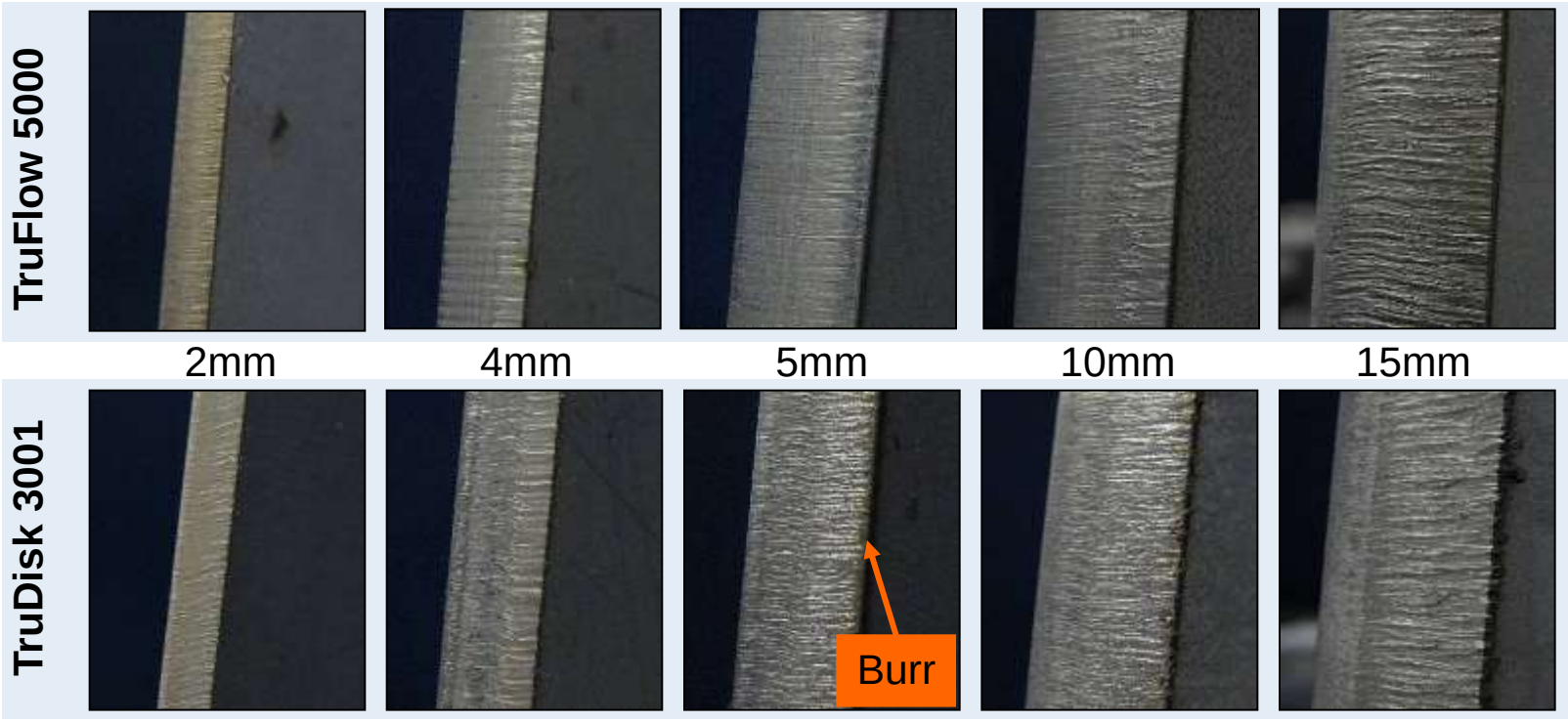




Cutting Mild Steel with Oxygen as Assist Gas



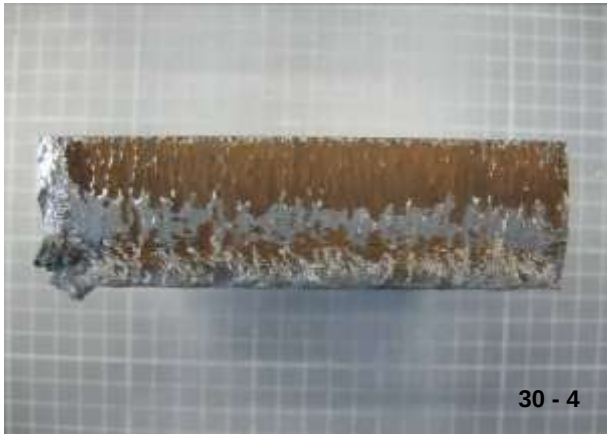
Cutting SS with Nitrogen as Assist Gas



Cutting Thick Stainless Steel with 1 µm Wavelength

Material: Stainless steel L316, Thickness : 30 mm

Power: 16kW
LLK Ø: 200µm
Speed: 300 mm / min
Spot diameter: 560µm
Gas Pressure: N_2 / 7 bar



Power: 16kW
LLK Ø: 200µm
Speed: 150 mm / min
Spot diameter: 200µm
Assist gas: None

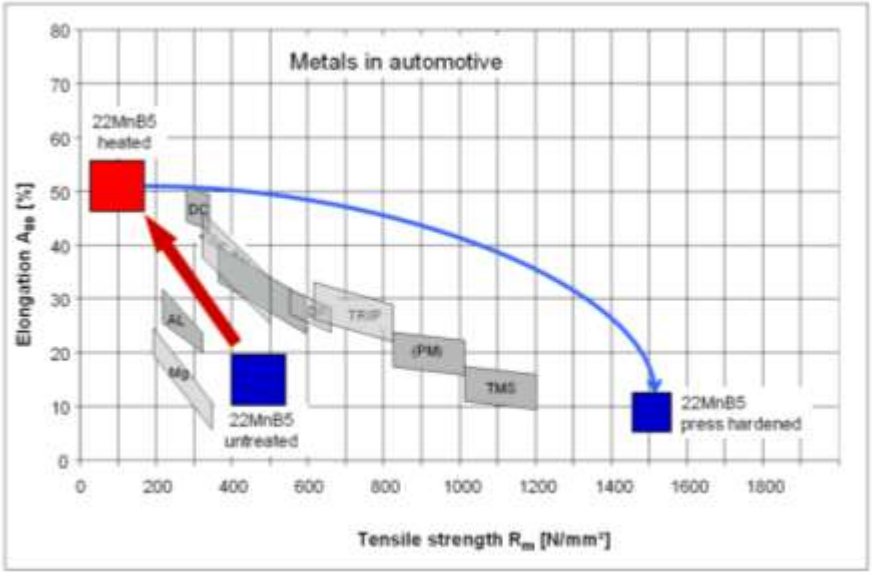
Cutting and welding of Titanium

- Liquid and hot Titanium is highly reactive
- Hardness increases and ductility decreases
- Use of Argon as process gas

Laser Cutting of Hot Formed Material

The tensile strength of 22MnB5 before processing is comparable to mild steel. When the material is heated it is very ductile, which allows great formability.

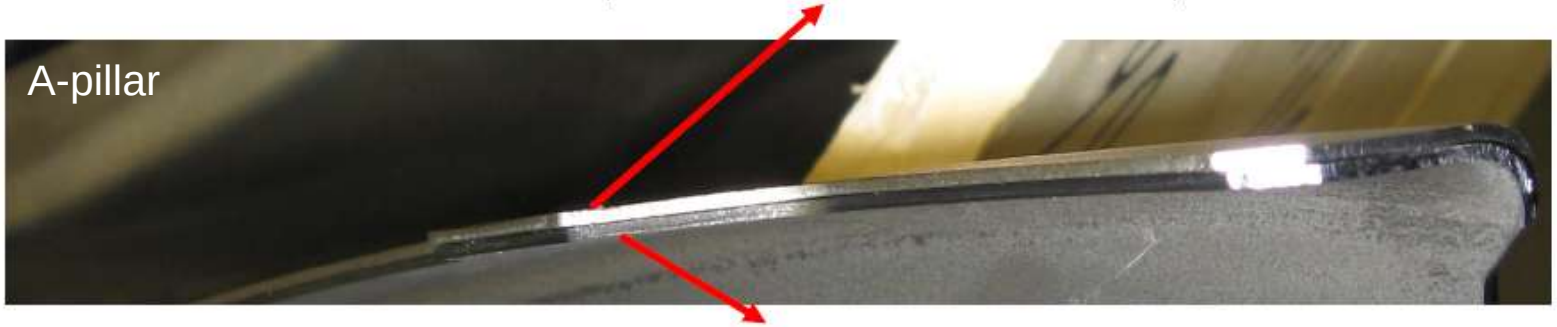
After quenching the steel it changes to be very hard and with a high tensile strength.



Laser Cutting of Hot Formed Material

1. High pressure Nitrogen cutting
2. Air cutting with Industrial compressed air
   → reduced gas consumption (example A-pillar: 100 l/part air vs. 177 l/part N2)
   → reduces gas cost

N2, clean edge



Compressed air cut, slightly darker colored edge but no loose particles or scale

Reservoir Type Rock Processing

- **Goal**: Increase drilling speeds, reduce drill bit replacements, enable penetration of granite (same penetration rate of laser beam for soft and hard rocks)

- **Material**: Rocks penetrated for natural gas extraction are shale sandstone, limestone, granite

- **Processes**: Spalling, melting, vaporizing

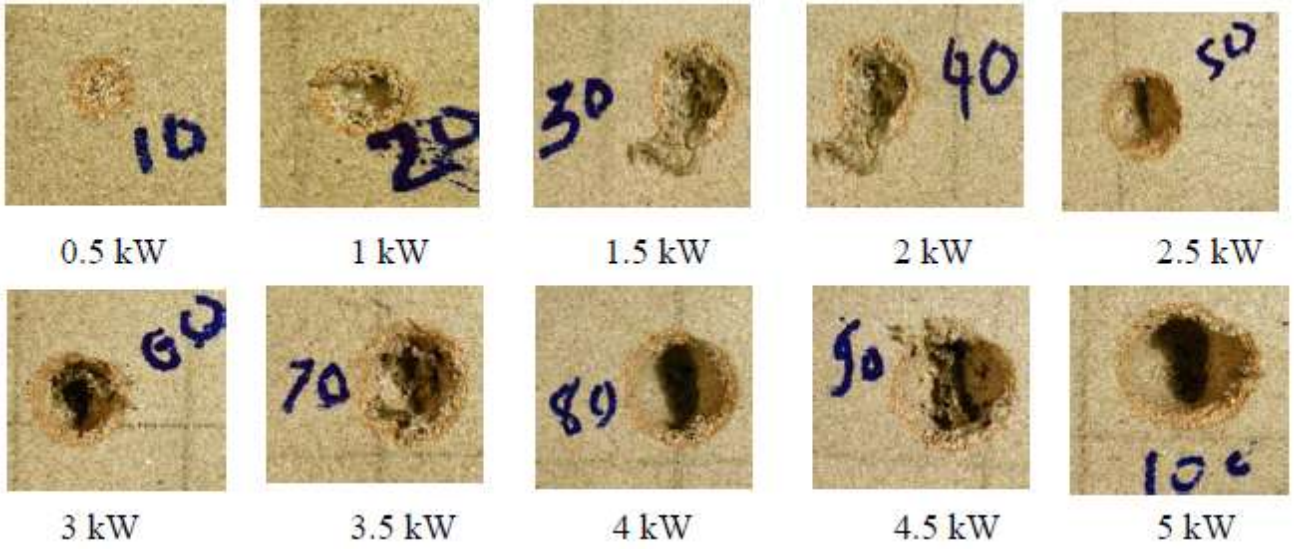
- **Key aspects**:
  - Specific energy (kJ/cc) required to remove rock (energy input/volume removed)
  - Spalling is most efficient for drilling
  - Minimize reflection and scattering of beam to maximize absorption in rocks

- **Secondary effects**:
  - Melting of rock
  - Beam absorbing exsolved gases
  - Induced fractures in surrounding rock

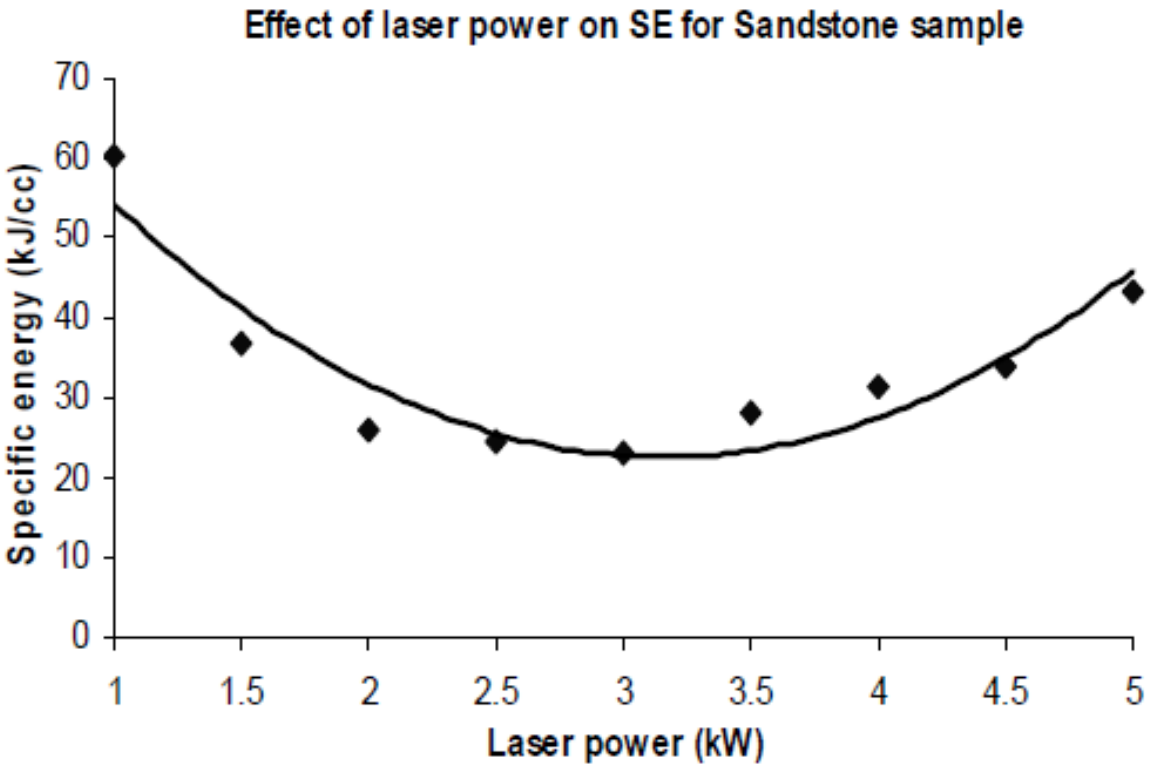
Sandstone

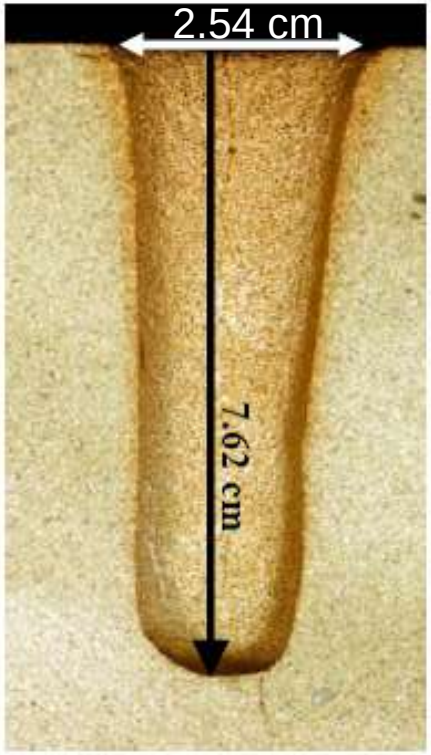
Source: Laser Drilling – Drilling with the Power of Light - Gas Technology Institute, 2007

- Process: Spallation
- Laser power: 0.5 .. 5.0 kW cw
- Spot size 8.9 mm
- Purge: Air 75 to 100PSi
- Exposure time: **8s**



- Material: Berea sandstone
- Same expose time and spot size
- Melting at 3 kW and above
- Below 3kW no melting but less spallation





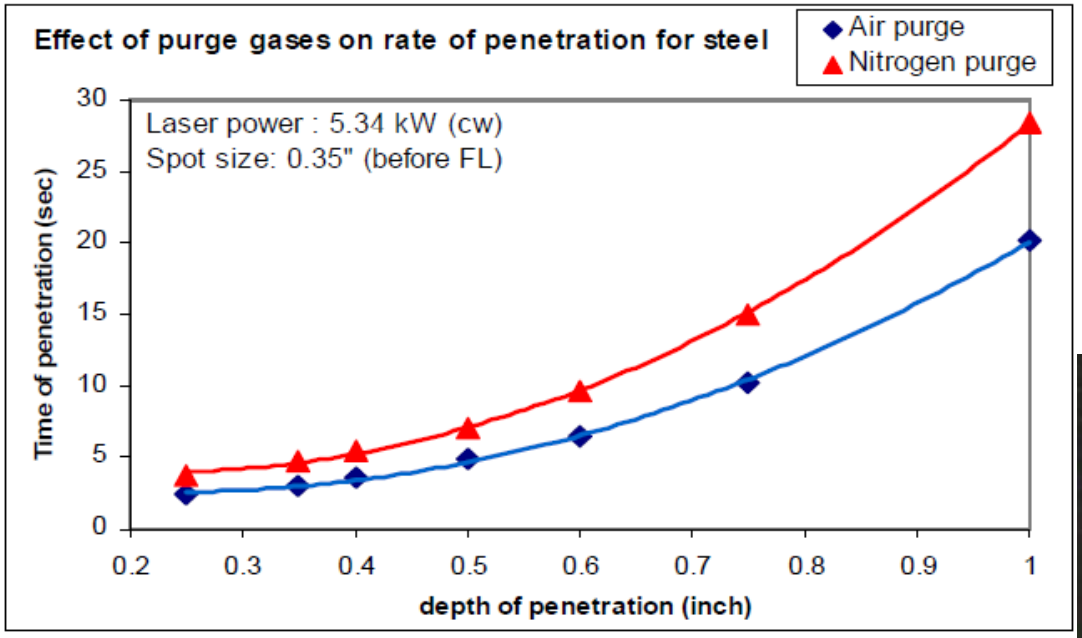
Cross-section of a hole in Sandstone by spallation (3 kW, 62s)

Limestone

- Limestone has a different chemical composition as sandstone
  ➔ different interaction with laser beam
- Thermal dissociation produces CO_2
- No melting observed up to 5 kW

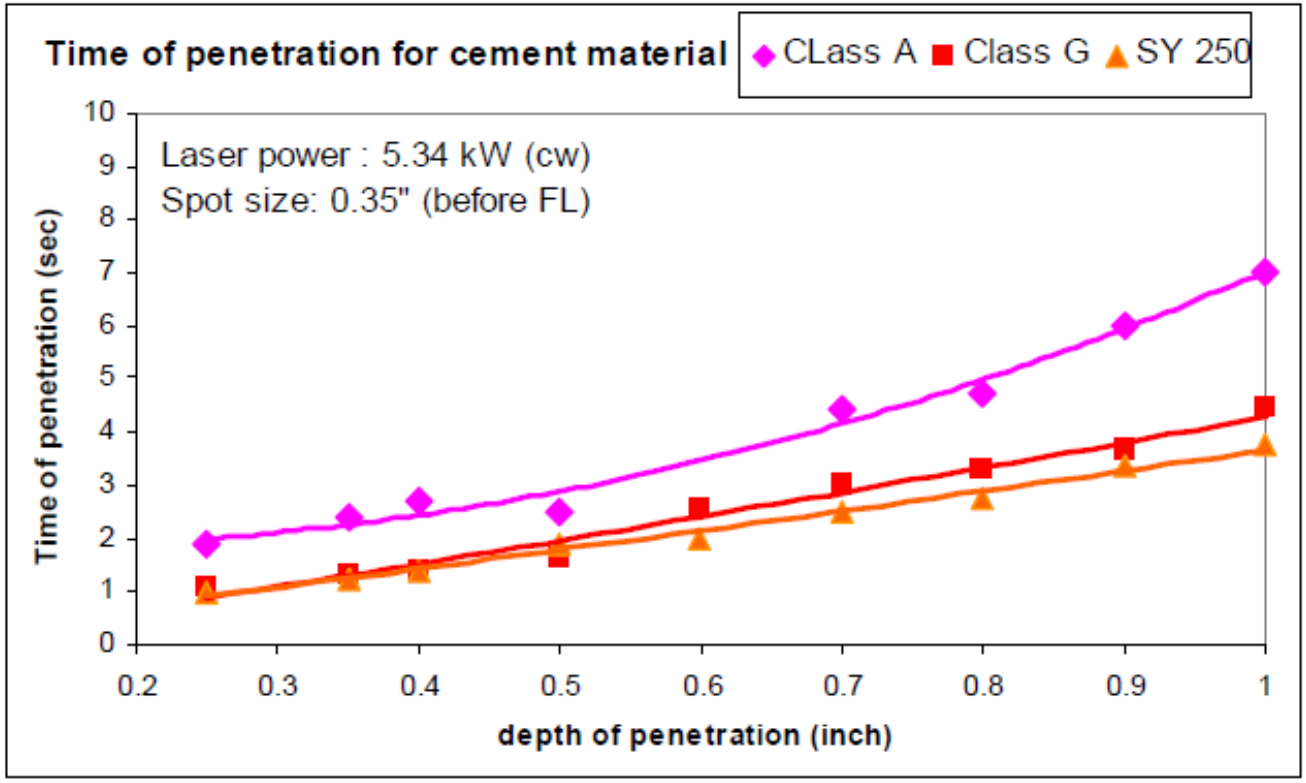
Source: Laser Drilling – Drilling with the Power of Light - Gas Technology Institute, 2007

Steel



Source: Laser Drilling – Drilling with the Power of Light - Gas Technology Institute, 2007

Cement



Source: Laser Drilling – Drilling with the Power of Light - Gas Technology Institute, 2007

And now I look forward to your questions!

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