JENOPTIK

High Precision Applications With Fast And Ultrafast Thin Disk Lasers

Ultrafast Laser Processing Forum, 16th September 2015
Korea Institute of Machinery & Materials (KIMM), Daejoen, Korea

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Head of Product Management

Megatrends are driving Micromachining

Mobility

→ growing wealth & globalization

Health

→ advance of medical technology

Sustainability & Efficiency

→ less energy, less CO_2

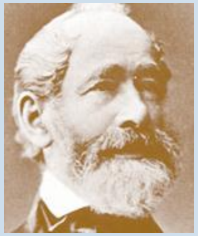
Micro / precision cutting & drilling solutions necessary for materials like **polymers, stainless steel, leather, diamond tools, ceramics, and others**

Problem: mechanical machining has limits
(e.g. small structures, tool life, process speed)

→ Demand for specialized laser machining

- Jenoptik at a glance
- Thin disk laser technology
- Fast & Ultrafast Material Processing
- High Precision Applications
- Summary

JENOPTIK Group
History



Carl Zeiss Jena GmbH gives rise to the creation of Jenoptik GmbH.

- 17,000 employees are dismissed
- Demolition, renovation and development of former Zeiss production sites

1846/1866 | **1945 - 1948** | **1991** | **1996/1998**

Carl Zeiss
University mechanic and entrepreneur; founded the workshop for precision mechanics and optics in Jena in **1846**

Ernst Abbe
Innovator and reformer; in 1867 scientific director of and in 1875 partner in the Zeiss workshop

1945/46: Transfer of patents and dismantling of parts of the company by the U.S. and Soviet armies.

1946: A new Zeiss Company is founded in Oberkochen.

The Zeiss plant in Jena, East Germany, is converted into state property.

In 1996
Jenoptik GmbH was converted into a joint stock corporation.

Going public: June 16, 1998

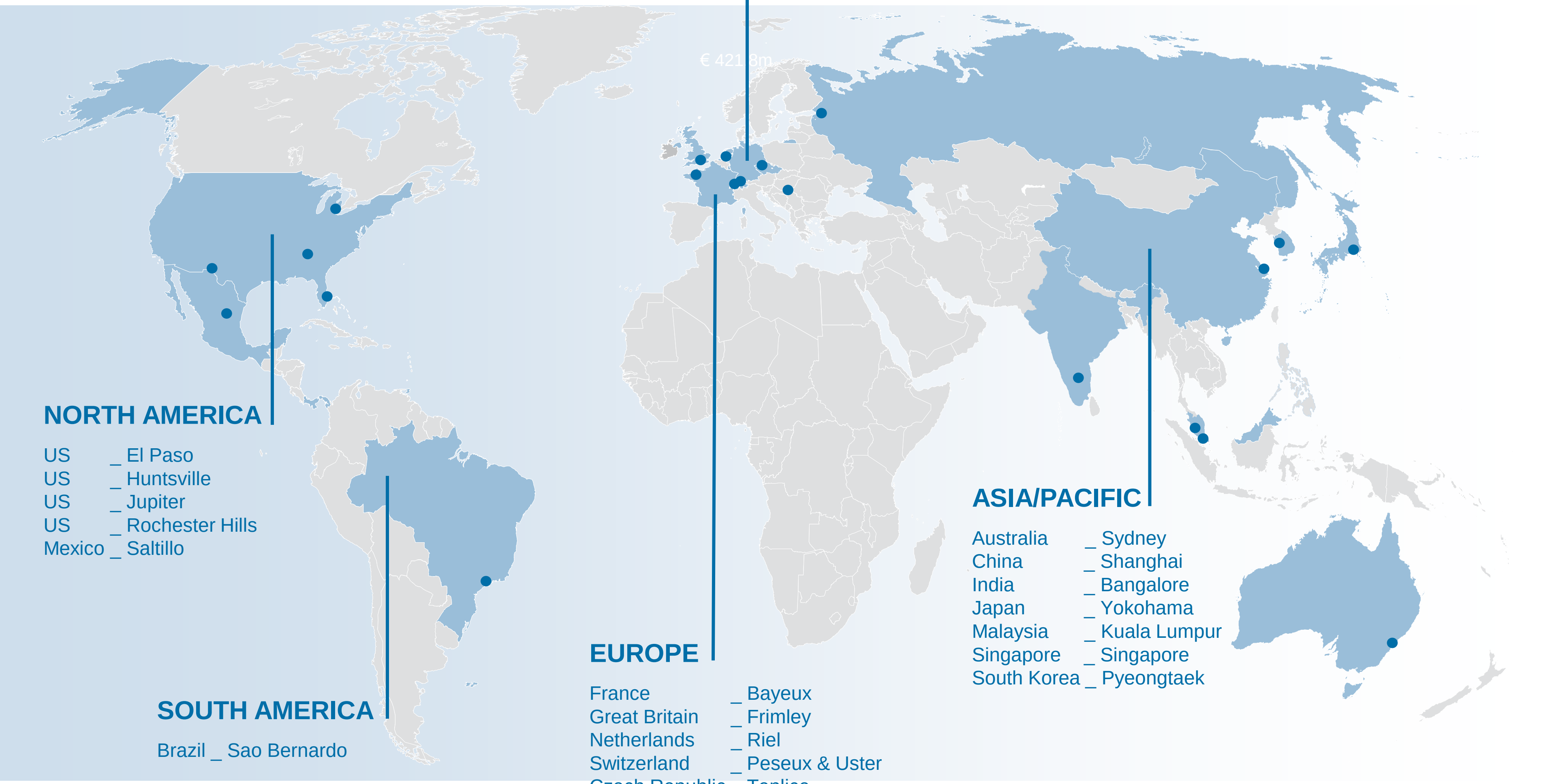
Jenoptik Group
Key Figures 2014 and 2013 (as at Dec. 31) Data in Million €

	2014	2013
■ Sales:	590.2	600.3
■ EBIT:	51.6	52.7
■ Order intake:	589.2	575.3
■ Order backlog:	422.5	441.4
■ Employees (incl. trainees):	3,553	3,433

Jenoptik Group
Locations

GERMANY

_ Altenstadt	_ Essen	_ Ratingen
_ Berlin	_ **Jena**	_ Triptis
_ Dresden	_ Hildesheim	_ Villingen-Schwenningen
_ Eisenach	_ Monheim	_ Wedel



NORTH AMERICA

US	_ El Paso
US	_ Huntsville
US	_ Jupiter
US	_ Rochester Hills
Mexico	_ Saltillo

SOUTH AMERICA

Brazil _ Sao Bernardo

EUROPE

France	_ Bayeux
Great Britain	_ Frimley
Netherlands	_ Riel
Switzerland	_ Peseux & Uster
Czech Republic	_ Teplice
Russia	_ St. Petersburg

ASIA/PACIFIC

Australia	_ Sydney
China	_ Shanghai
India	_ Bangalore
Japan	_ Yokohama
Malaysia	_ Kuala Lumpur
Singapore	_ Singapore
South Korea	_ Pyeongtaek

Jenoptik Group
Divisions and Business Units

Corporate Center

Lasers & Material Processing

- Lasers
- Laser Processing Systems

Optical Systems

- Optics
- Micro Optics
- Optoelectronic Systems

Industrial Metrology

- Roughness and Contour Measurement
- Form Measurement
- Dimensional Measurement

Traffic Solutions

- Equipment
- Service Providing

Defense & Civil Systems

- Mechatronics
- Sensor Systems

Business Unit Lasers
Companies in Germany

JENOPTIK Diode Lab GmbH, Berlin

- Semiconductor material
- In 2002 founded as a spin-off of the Ferdinand Braun Institute for High Frequency Technology
- 100% subsidiary of JENOPTIK Laser GmbH
- 42 Employees

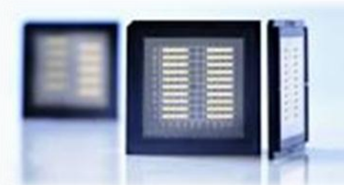
JENOPTIK Laser GmbH, Jena

- High-power diode lasers, solid-state & fiber lasers as well as diode laser systems (OEM)
- In 2010 JENOPTIK Laserdiode GmbH & Laser Technology Systems of JENOPTIK Laser, Optik, Systeme GmbH have merged
- 165 Employees

Business Unit Lasers
Product Portfolio

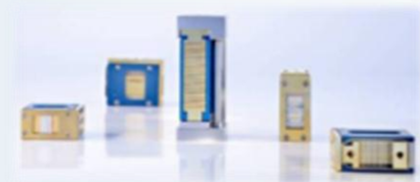
Semiconductors

- Epitaxial services
- Single emitters & bars (760-1070nm)

Diode Lasers

- Mounted diode lasers
- Stacks (cw & qcw)
- FC-modules




Thin Disk Lasers

- cw green lasers
- ns pulsed lasers
- fs pulsed lasers


Fiber Lasers

- ns pulsed lasers
- cw lasers (200W…3kW)


Finding the optimum laser for your specific applications

- Test your applications with our lasers on your materials
- Do individually adjusted tests, going beyond the standard certifications and find the best laser solution
- Compare different technologies
- Contact us and discuss with our experts

Newest Equipment on Board:

- Solid-state and fiber lasers
- Positioning equipment
- Equipment for parameter analysis
- Various focusing lenses
- Variable beam expander
- Optical microscope
- Digital camera and image analysis software

- Jenoptik at a glance
- **Thin disk laser technology**
- Fast & Ultrafast Material Processing
- High Precision Applications
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Thin Disk Laser Technology

for Fast- and Ultra-Fast Applications with highest Precision

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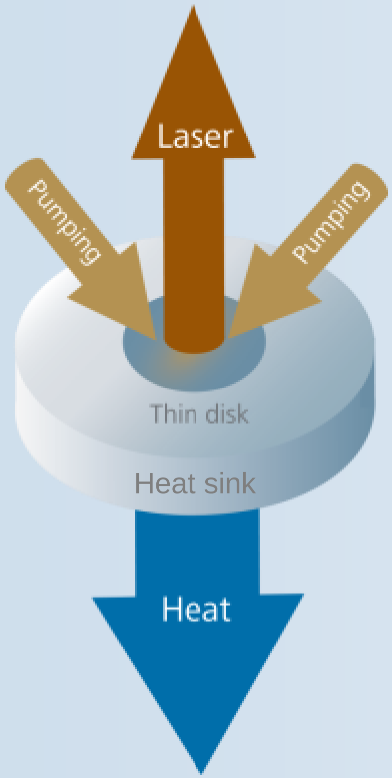
Specialized laser processing applications like

- High precision cutting (µm range accuracy)
- Micro hole drilling (< 500 µm)
- Machining of hard&brittle or transparent materials
- Thin film structuring

require…	calls for…
Focusability	Single mode beam quality ($M^2 \sim 1$)
Pointing & power stability Reproducibility	Efficient thermal management of the laser medium
Machining quality Process efficiency	Clean pulse shape, high pulse energy & peak power
Application flexibility	Fast change of repetition rate
Stable operation in 24/7 industrial environment	

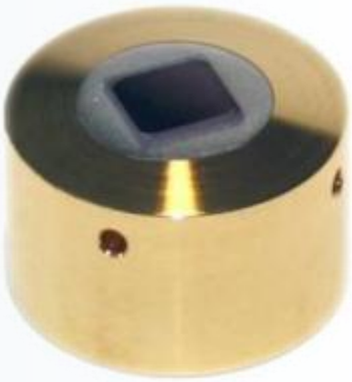
Thin disk lasers meet the requirements perfectly

More than 20,000 disk lasers sold!



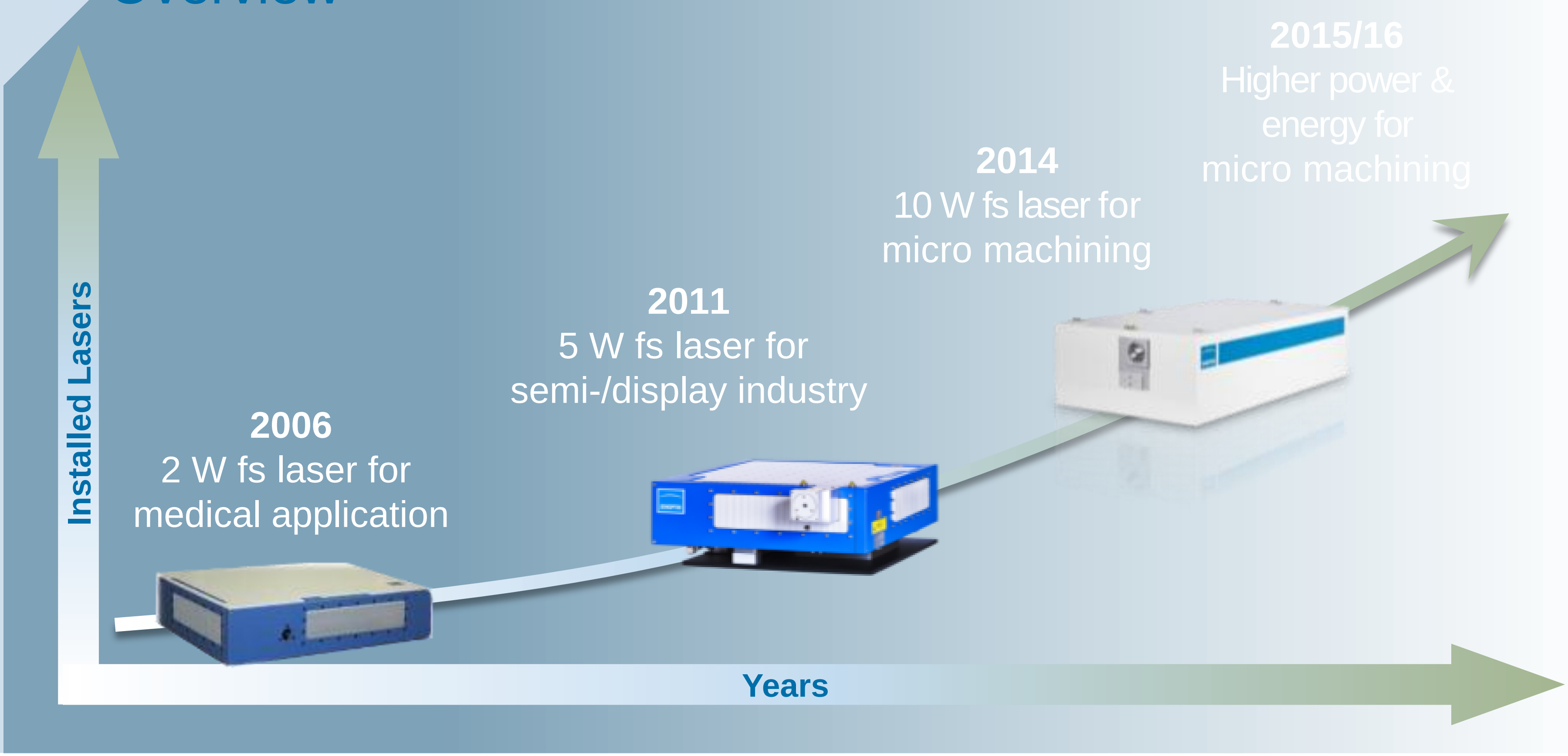
- Weak thermal lensing
- No problems with phase front distortions

- Effective thermal management easy to achieve
- Very stable focal position
- Clean pulse shapes (spatial, temporal)
- High peak power and energy can be achieved easily
- Proven stability in industry



Milestones of JenLas® femtosecond lasers

Overview



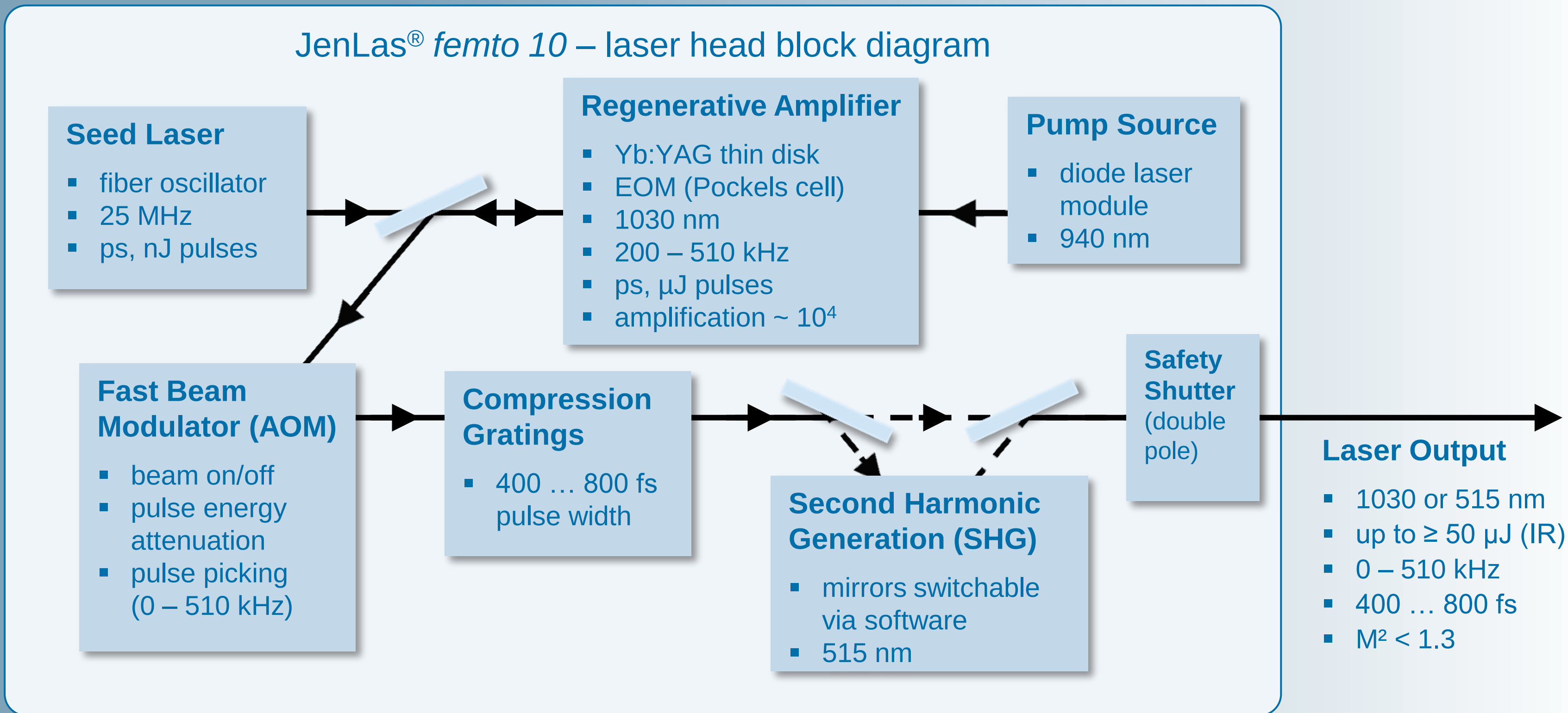
JenLas® *femto series*

Parameters	Femtosecond Laser	
	JenLas® *femto10*	JenLas® *femto10 HE*
Average Power	> 10 W	> 10 W
Pulse width	400 … 800 fs	
Repetition rate range	200* kHz – 510 kHz	**100* kHz** – 400 kHz
Pulse energy	50 µJ – 20 µJ	**100 µJ** – 25 µJ
M^2	< 1.3	
Wavelength	1030 nm, 515 nm	
Fast beam modulator	included, for pulse picking (single pulse) and attenuation	

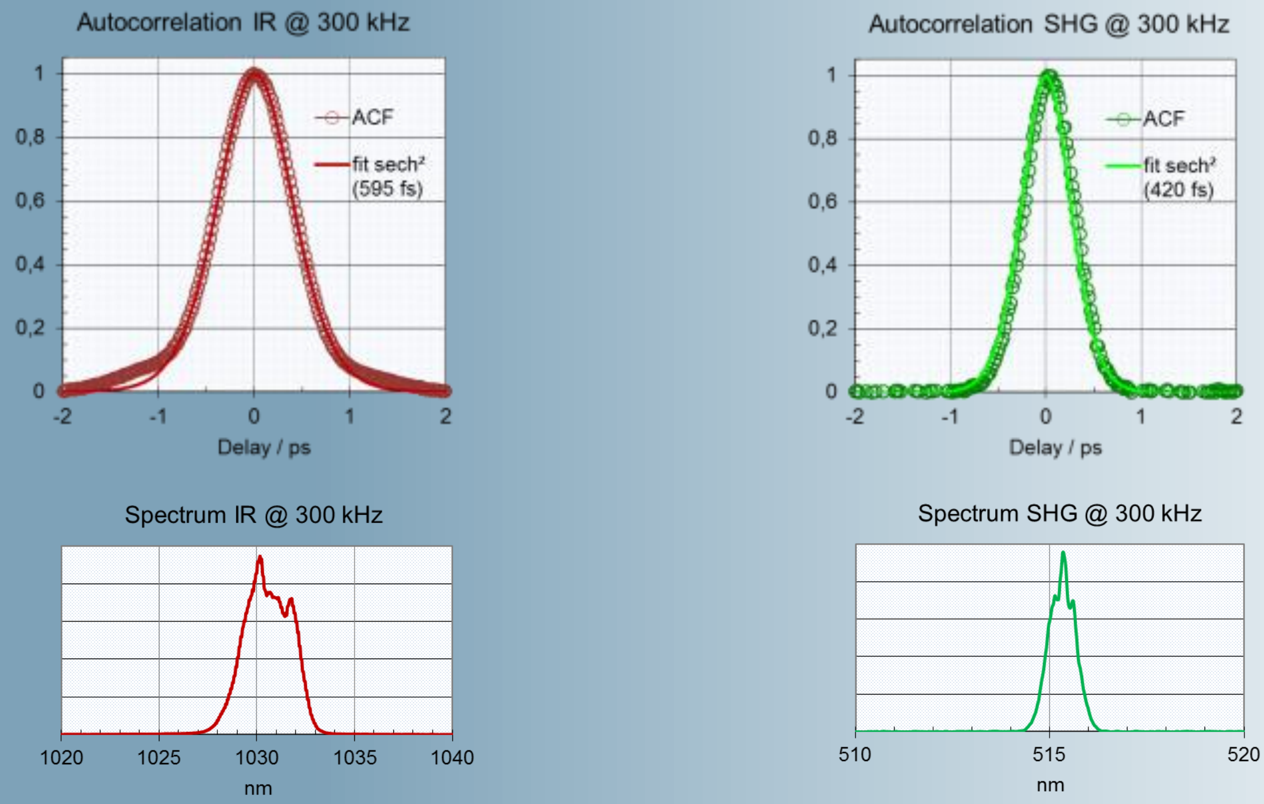
* single-shot by pulse-picking

JenLas® *femto 10*
Schematic

Setup of Laser Head



Autocorrelation & Spectrum



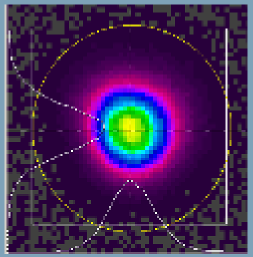
Beam Quality

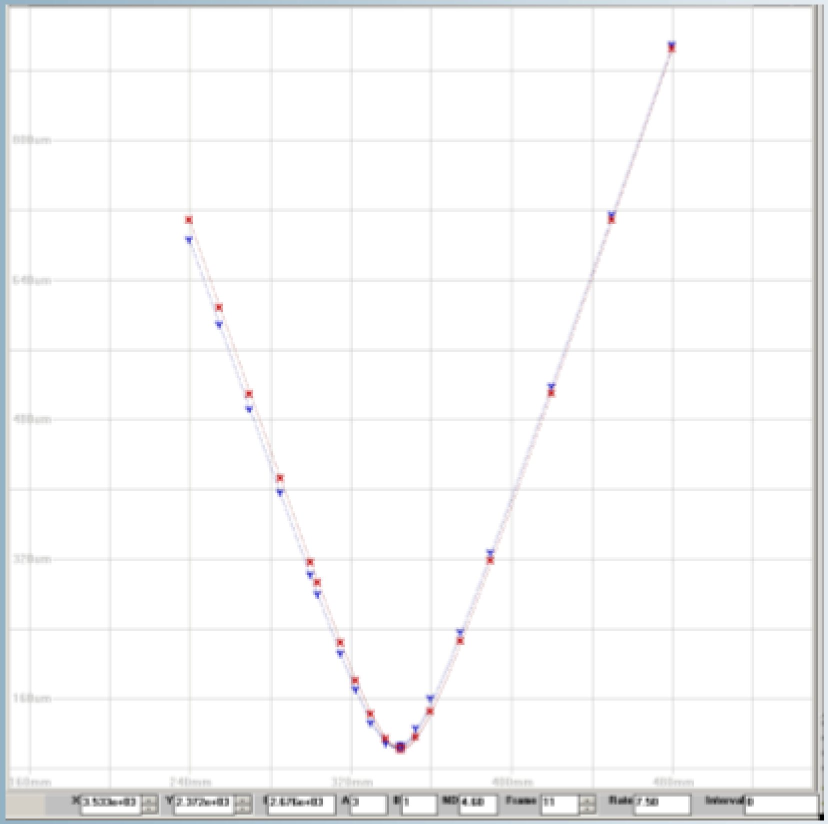
SHG @ 300 kHz:

M² X = 1.044

M² Y = 1.045

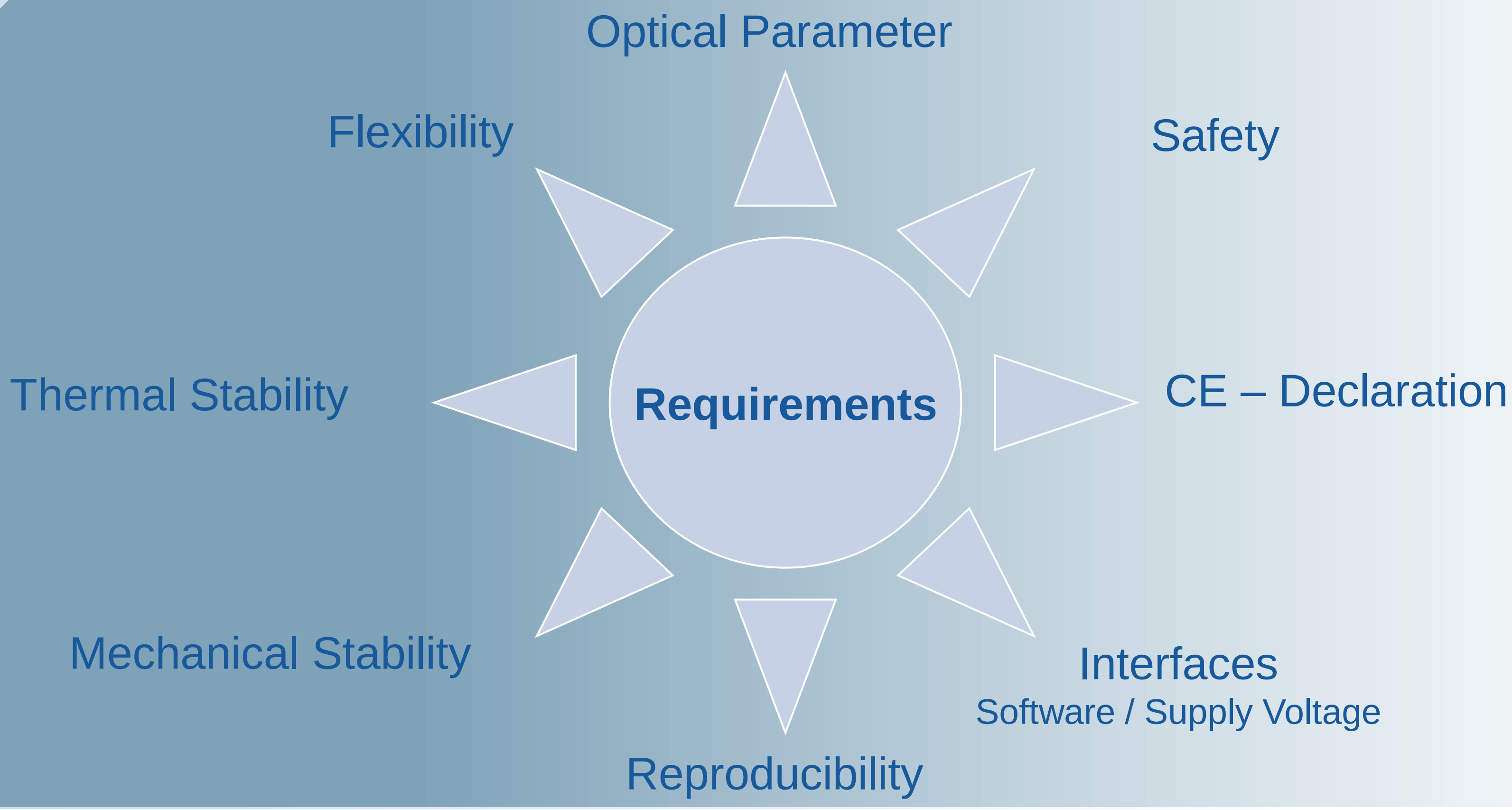
Specification: M² < 1.3





Requirements for Laser in Industrial/Medical Environments

Quality | Reliability



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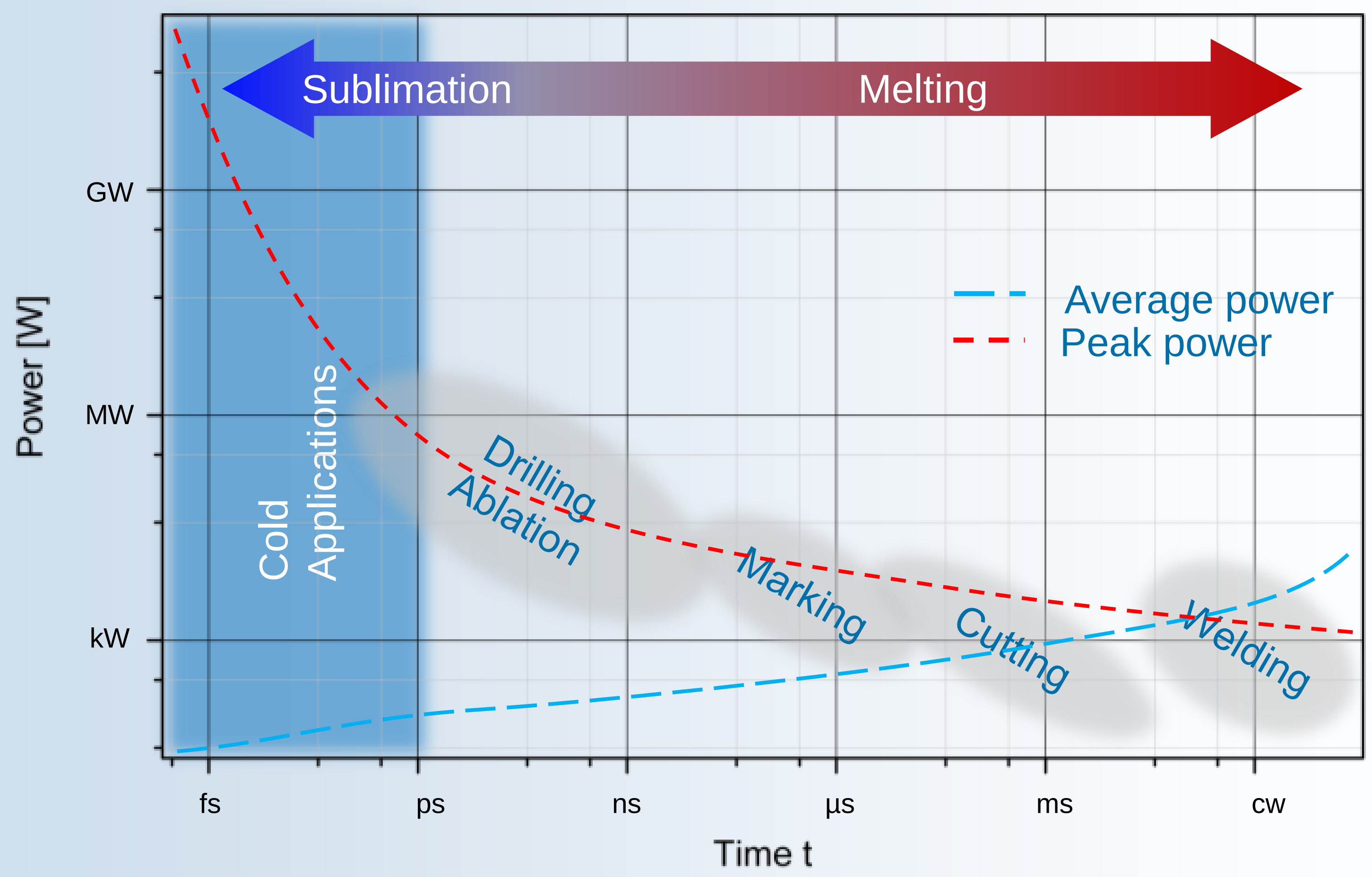
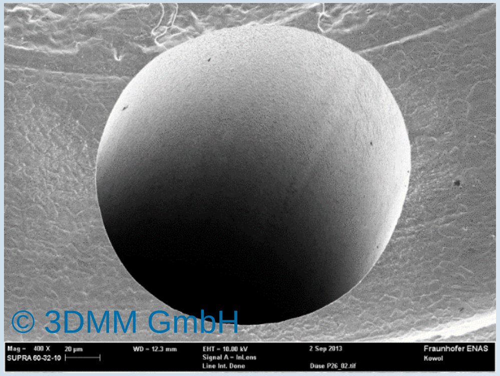
Material Processing
Application Map

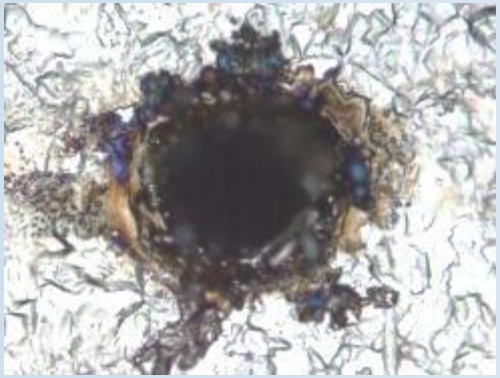


Material Processing Regimes

High precision cutting and drilling applications …



- in the **cold ablation regime** with femtosecond laser:
  - ⇒ lowest thermal damage to the bulk material
  - ⇒ highest precision down to a µm possible
  - ⇒ moderate ablation rates



- in the **thermal processing regime** with nanosecond laser:
  - ⇒ much higher ablation rates and throughput
  - ⇒ trade-off with regard to machining quality
    (larger heat affected zone than femtosecond laser)

“Cold” laser processing with femtosecond pulses

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fs pulses achieve best cutting quality and smallest Heat Affected Zone (HAZ)

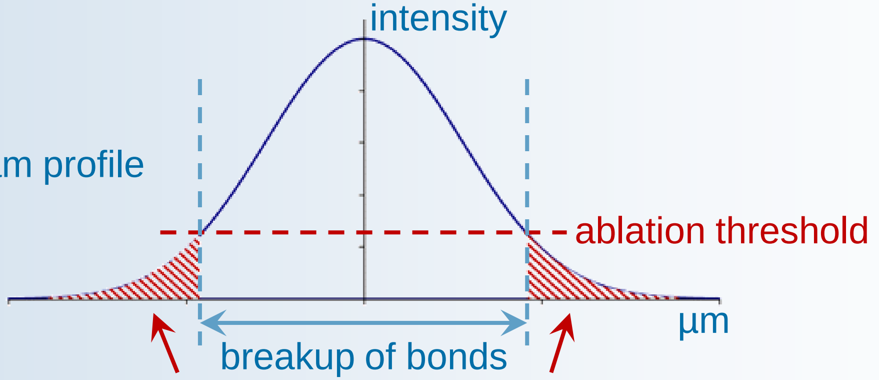
- Heat conduction in solids characterized by electron-phonon relaxation time

material	electron-phonon relaxation time [ps]
Au	4,7
Au film	0,71
Cu	1,1
Fe	0,5
Al	5
Al film	0,65
Polymers	0,3..0,7

- If pulse duration is shorter
  - no dissipation of absorbed energy from electrons to the lattice
  - direct destruction of bonds
  - no lattice heating – no HAZ

Importance of the process strategy

- Ablation threshold fluence > 0 J/cm² !
- Ablation threshold not reached at the edges of the beam



- Consequence:
  - dissipation of residual energy into the lattice
  - lattice heating by **heat accumulation** of successive pulses

⇒ **process strategy is important!**
(pulse energy, pulse overlap, feed speed, number of passes)

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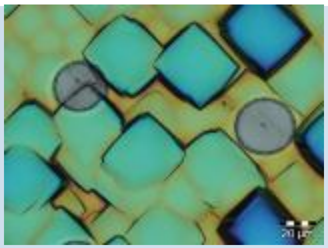
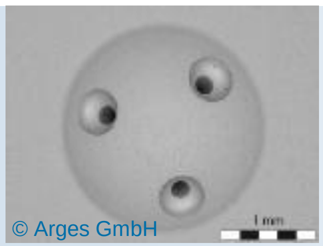
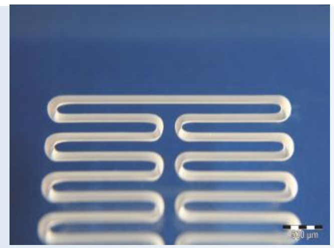
Application Samples
processed with fs-lasers



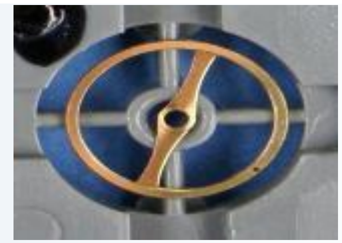
thin film ablation
semi / PV / display



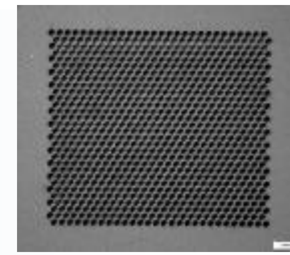
injection nozzles
automotive



microfluidic structures
biophotonics



weight trimming
watch industry



microfilters
automotive

flex PCB contacts
electronics

NiTi stents
medical

polymer stents
medical

microvalve springs
medical

glass structures
optical / security

Femtosecond laserprocessing is an enabling technology for "high quality" micro structures

- in thermal sensitive materials/materialsystems
- in transparent materials

High speed cutting of Polylactide for bio-resorbable stents

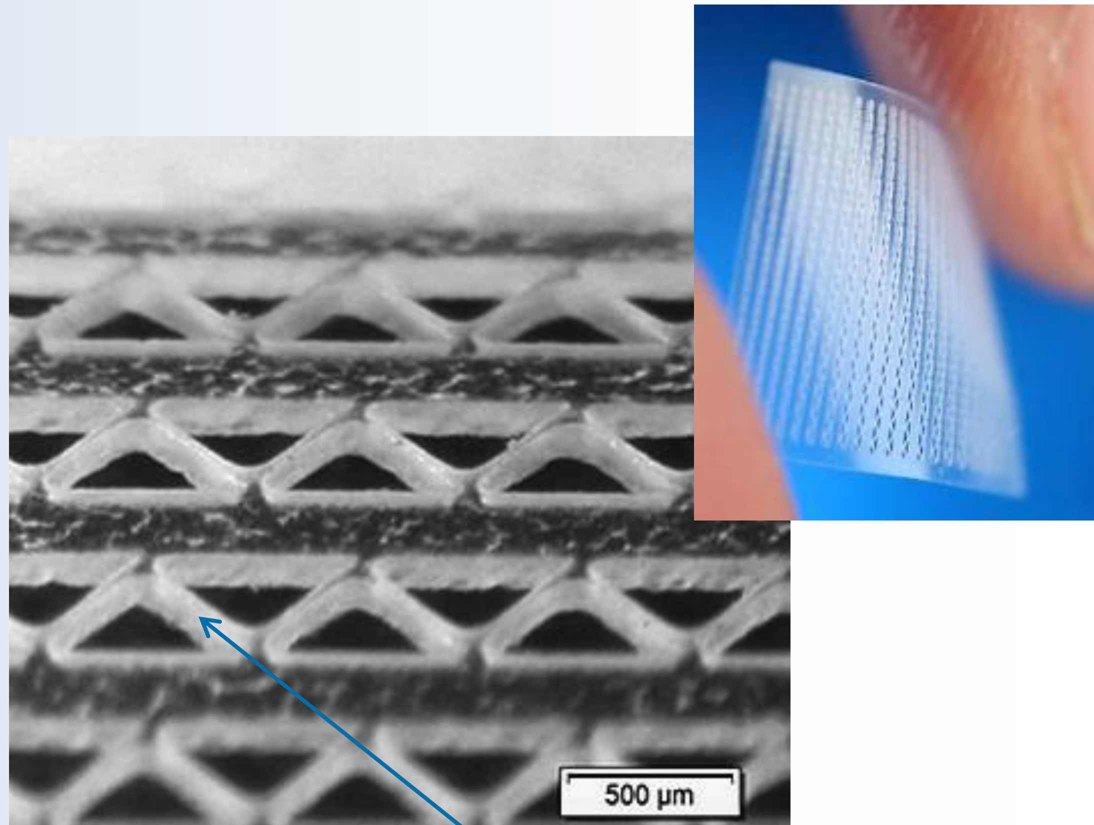
State of the art:

- today‘s stent cutting machines (rotating axis)
  with femtosecond lasers cut in single pass strategy
- Cut edge quality is optimized by fluence (J/cm²) and pulse overlap (= speed)

High speed cutting of Polylactide for bio-resorbable stents

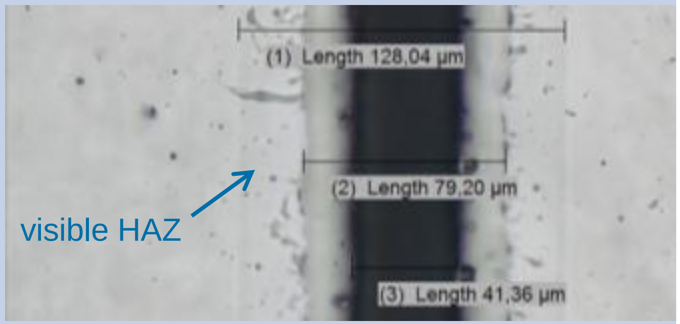
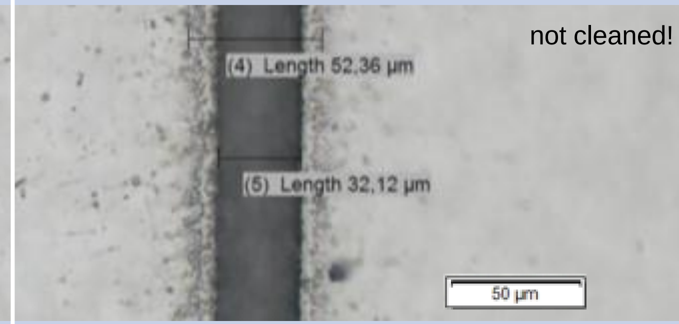
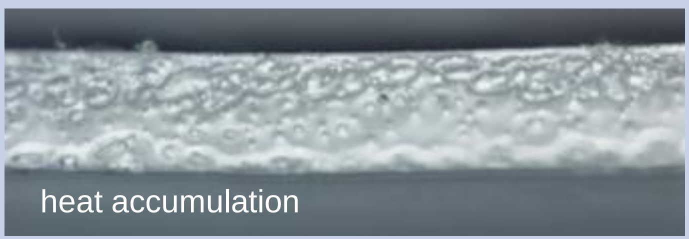
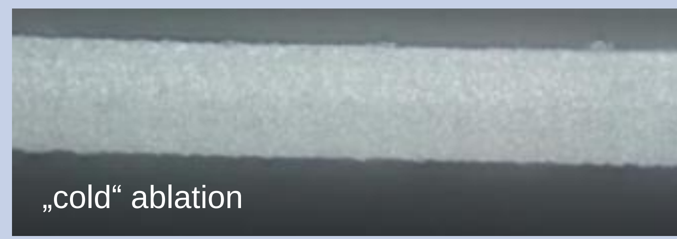
Optimizing the process

- Use of flat Polylactide sheets (PLLA, PDLLA) for cutting trials
- Sheet thickness ~ 120 µm
- Sample geometry with triangular cut-outs, 30µm wide bars
- Galvo scanner cutting
  - single-pass and multi-pass strategy
  - no process gas
- Results: multi-pass with an effective speed of 73 mm/s (fluence of 28 J/cm², 1030 nm)



bars = 30 µm wide, 120 µm high

High speed cutting of Polylactide for bio-resorbable stents

	Single-pass process	Multi-pass process
Cut kerf (top view)		
Cut edge (side view)		
	■ melting effects at the cut edge make the material macroscopically transparent ■ altered material properties	■ sharp cut edge ■ the „rough“, light-scattering cut edge indicates low HAZ ■ properties of the bulk material are unaltered

High speed cutting of Polylactide for bio-resorbable stents

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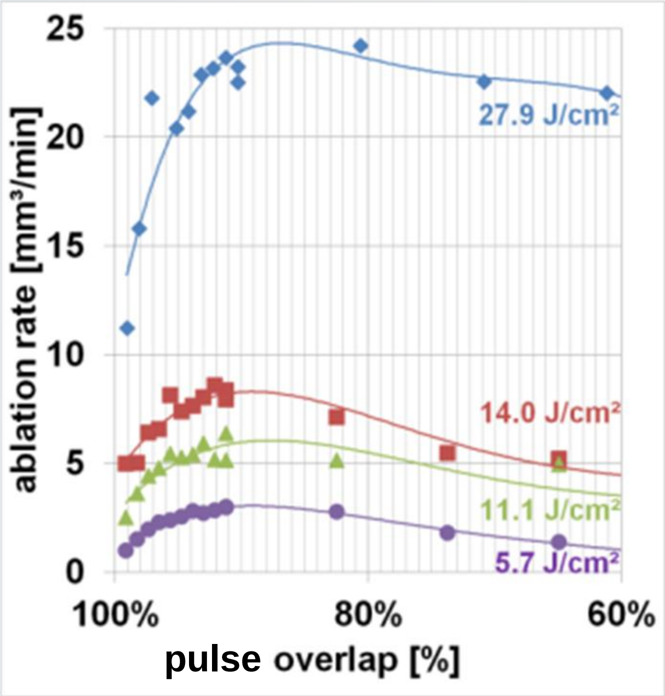
Application results in numbers

- Cutting with galvo scanner setup
- Material: PLLA
- Thickness: 120 µm flat-sheet

Wavelength	1030 nm		515 nm	
Pulse width	~550 fs			
Process strategy	single-pass	multi-pass[a)]	single-pass	multi-pass[a)]
Fluence	27,9 J/cm²		10 J/cm²	
Cut speed	160 mm/s	73 mm/s	b)	50 mm/s



Process parameter: 1030nm, single-pass

a) multi-pass: effective speed, low overlap (down to 0%)
b) cut quality not acceptable

Cutting of Polycarbonate with fs laser

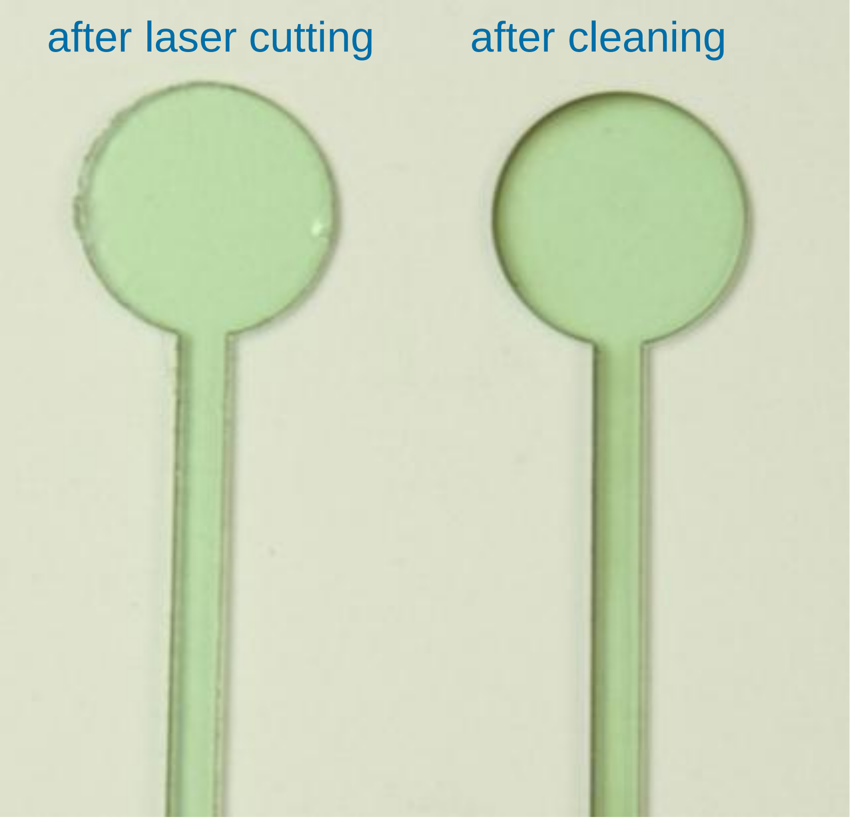
Demonstration of cut-outs in polycarbonate sheet material

Material

- Polycarbonate sheet, thickness 350µm

Results

- Eff. cutting speed > 1.2 m/min (multi-pass)
- Power: 4 W@200 kHz
- High quality cut
- No carbonization



Predetermined break lines in airbag leather covers

State of the art:

- Cutting of break lines at the underside (rearside) of leather with knives
- Cycle time and cutting accuracy need optimization

⇒ **laser cutting as an alternative!**

Requirements for laser cutting:

- Break lines invisible from the viewing side over the lifetime of the car
  - ⇒ no thermal damage from laser processing
- Defined break load
  - ⇒ precise end point control of the laser cutting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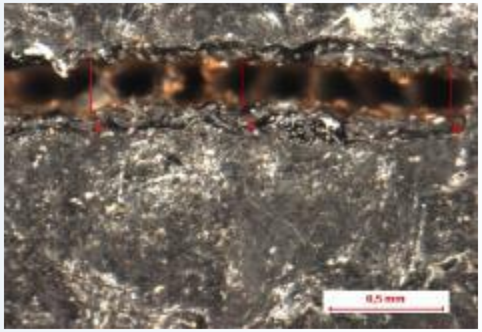
Predetermined break lines in airbag leather covers

Patent Application: - DE102013104138B3
- EP0827802B1

Boundary conditions:

- Uneven leather (1 … 1.6 mm thickness)
- Varying absorption (also depending on color)
- Remaining material thickness in the groove for the defined break load: ~ 0.1 mm

CO_2 laser cut:
- thermal damage, burned leather
- swelling of the break line



Solution:

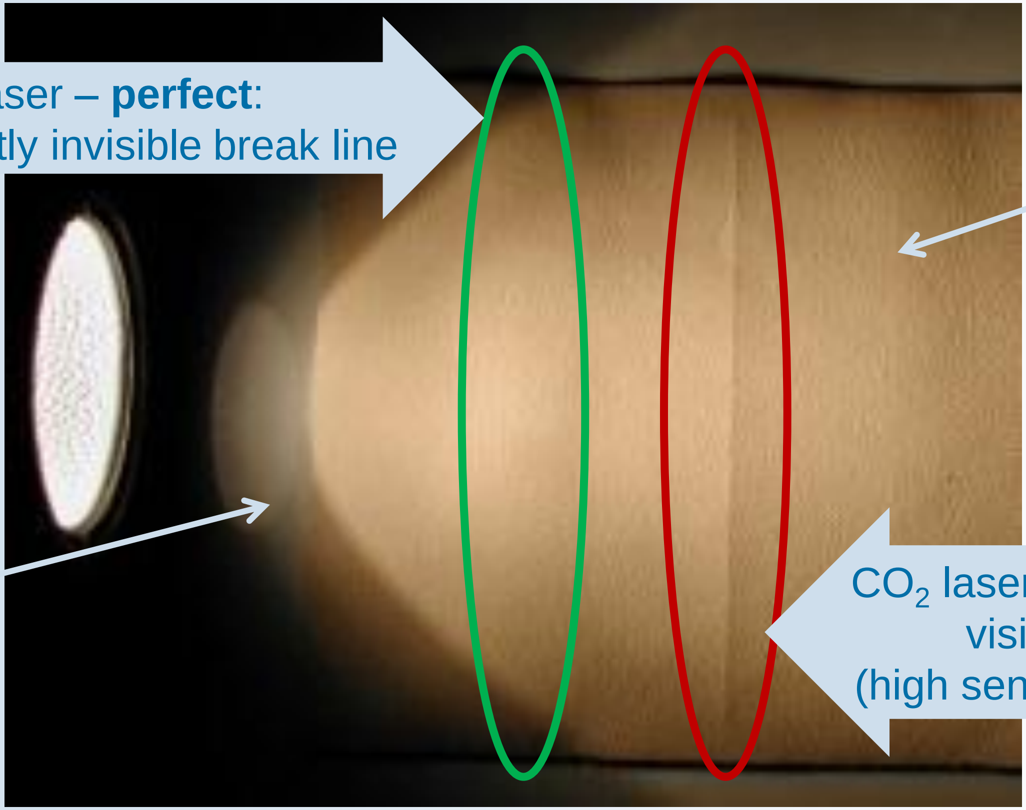
- 10W femtosecond laser with galvo scanner, 15 to 20 passes, feed rate 500 to 1.000 mm/s
- End point control by light transmission sensor under the leather and sophisticated software (requires pulse-on-demand)

fs laser cut – non-thermal process

Predetermined break lines in airbag leather covers

Patent Application: - DE102013104138B3
- EP0827802B1

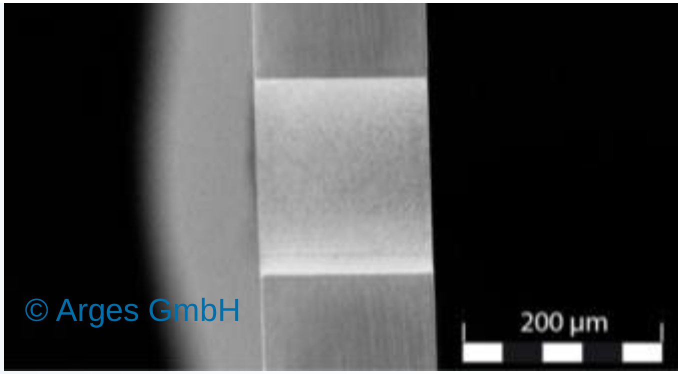
Comparison of femtosecond and CO_2 laser cutting in genuine leather



Drilling and cutting with defined taper angle

Functional parts need:

- Defined edge-angles (like gears, contacts, etc.)
- Defined holes (like filters, injection nozzles, etc.)
- Other free-form bores/cuts, used for various purposes

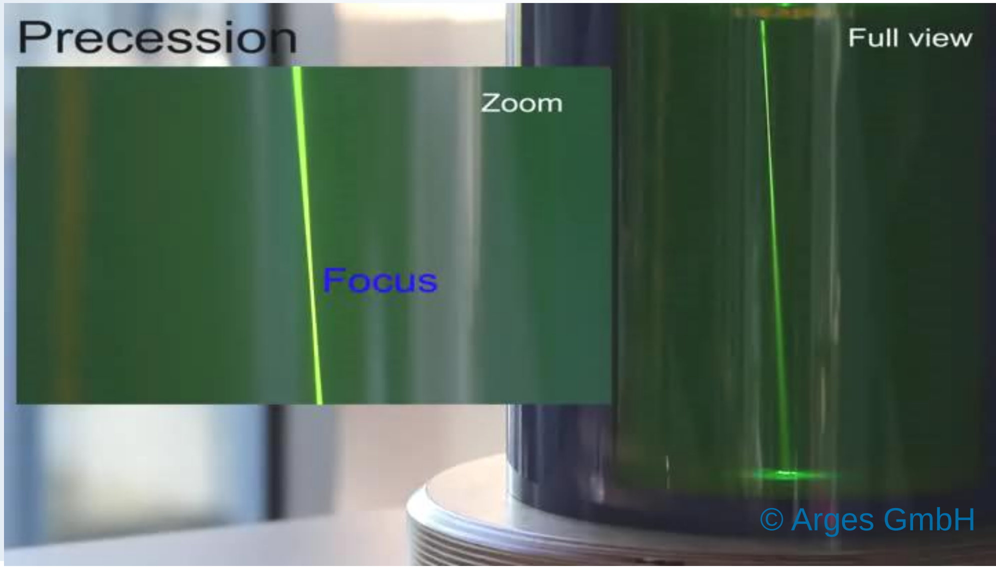


Technical requirements:

- defined edge-/wall-angle
  - best contact for interaction
  - optimized flow characteristics
- high drilling/cutting-rates

Results with precession-scanner:

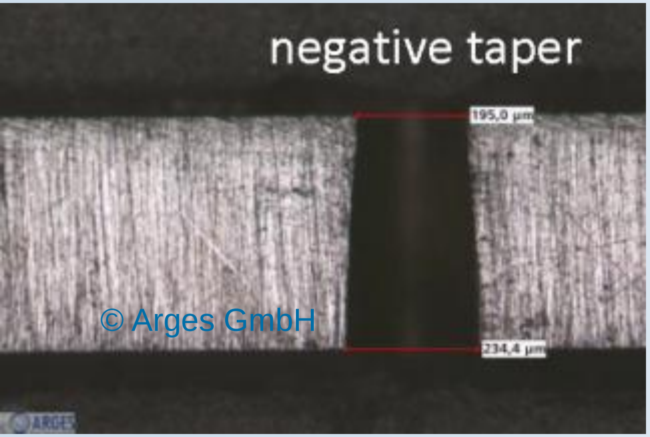
- ± 20° taper angle possible
- low roughness of wall surface
- burr-free edges

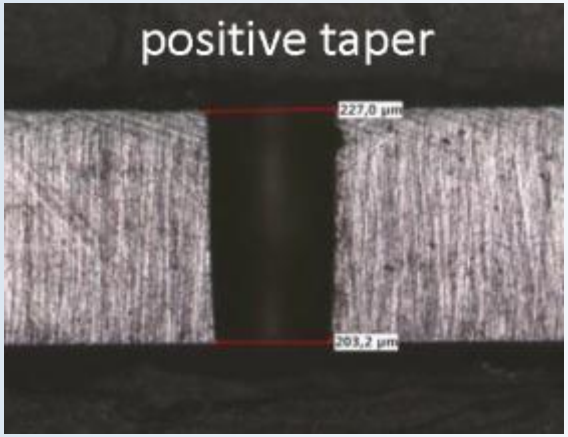


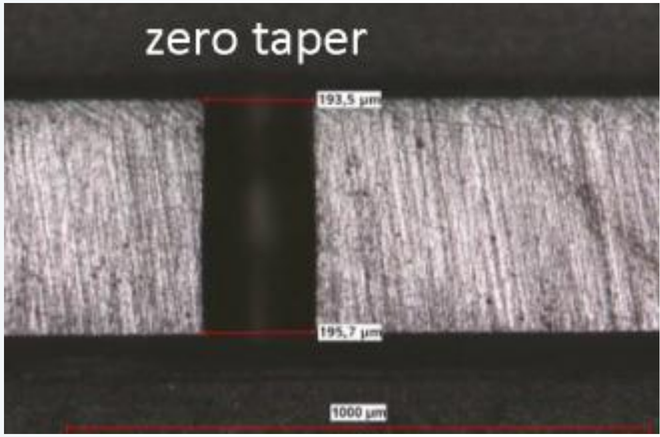
Drilling and cutting with defined taper angle

Demonstration of different taper angles by use of femtosecond laser + precession scanner

- Process — Drilling
- Material — Steel sheet, 350 µm thickness
- fs laser parameters — 1030 nm, 100 kHz, 5…10 W



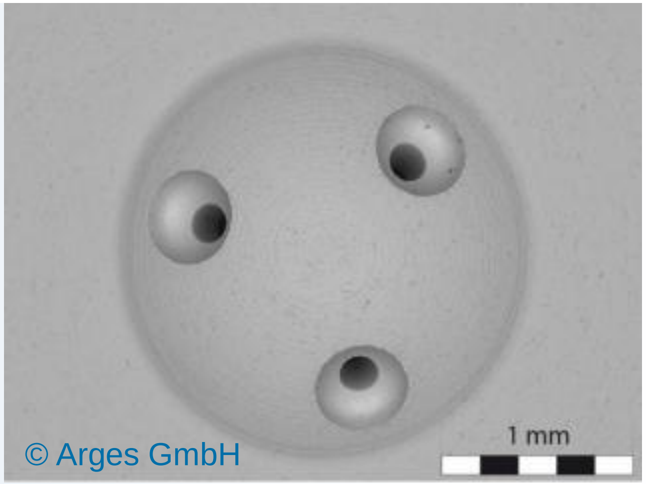


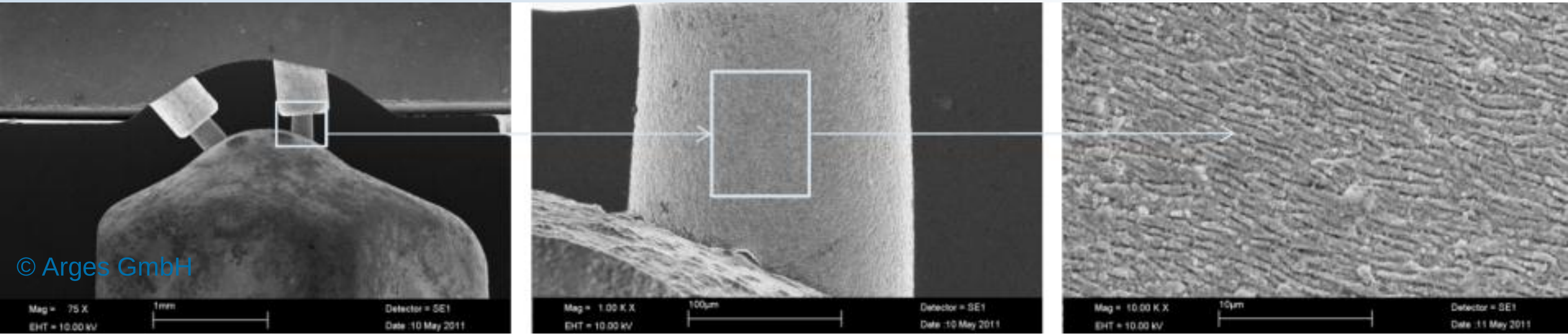


Drilling and cutting with defined taper angle

Demonstration of injection nozzle drilling

Material	stainless steel
Negative taper	16° (full angle)
Wall surface roughness	$R_a < 0.1\ \mu m$
Diameter	~ 200 µm
Diameter repeatability	< 0.4 % variation
Diameter accuracy	< 1 µm
Typical hole drilling time	1.5 s



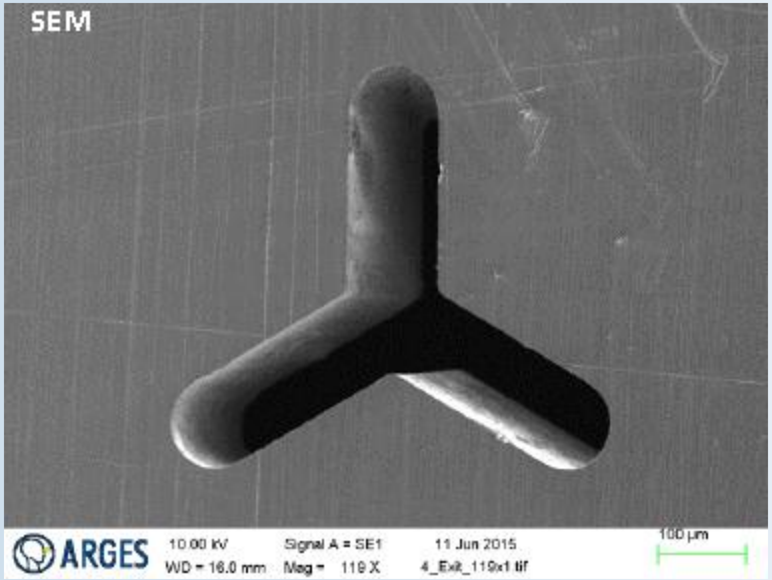


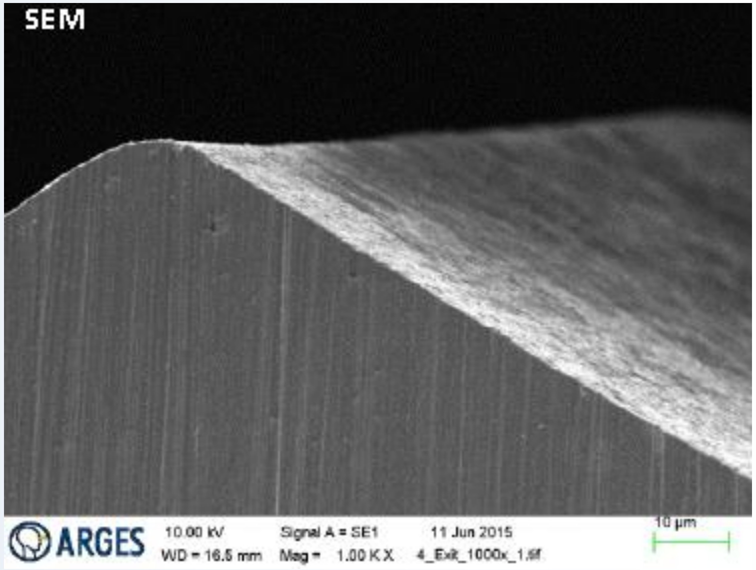
Photos © and by courtesy of Arges GmbH

Drilling and cutting with defined taper angle

Demonstration of free-form cutting with 0° taper

■ Material	stainless steel, 300 µm thickness
■ Circumference	1.8 mm
■ fs laser parameters	1030 nm, 100 kHz, 5 W
■ Processing time	< 5 s





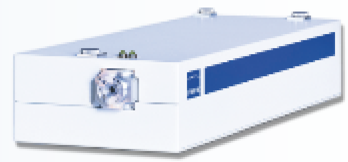
Comparison of fs and ns metal cutting
Cutting metal stent implants

- Cutting of NiTi alloy (Nitinol) with minimal heat affect
- NiTi tubes, wall thickness 200µm

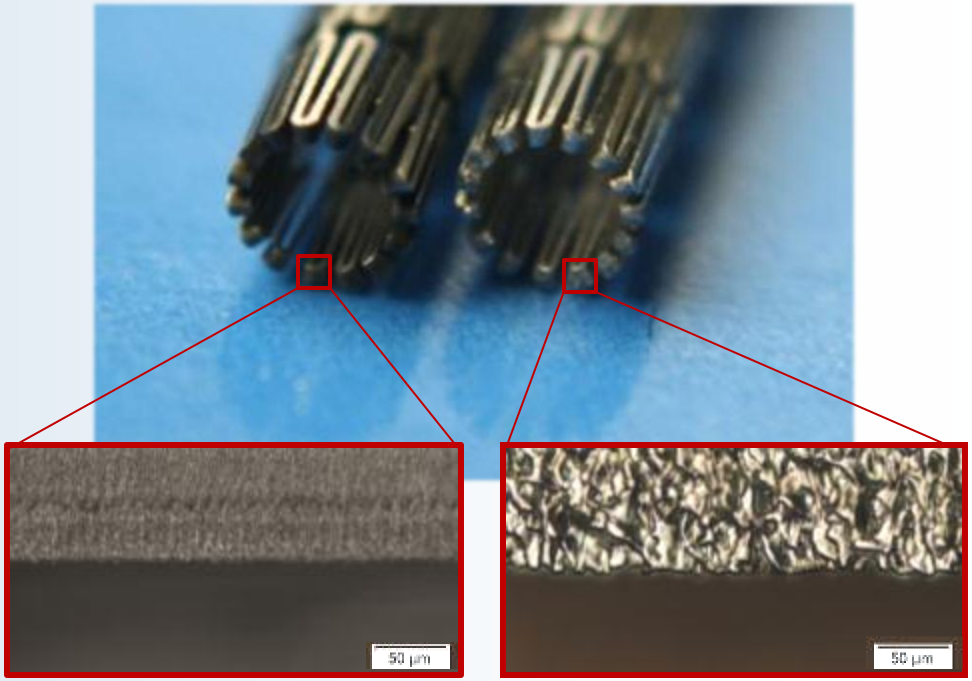
Results:

Parameter	femto 10	IR 70E
Pulse duration	< 800 fs	~ 700 ns
cutting speed	> 4 mm/s	> 10 mm/s
taper	< 2°	< 4°
cutting slit	~ 5 µm	~ 17 µm
burr	none	< 5 µm, post-processing required
wall surface roughness	< 1 µm	< 4 µm, visible melt

JenLas® *femto 10*

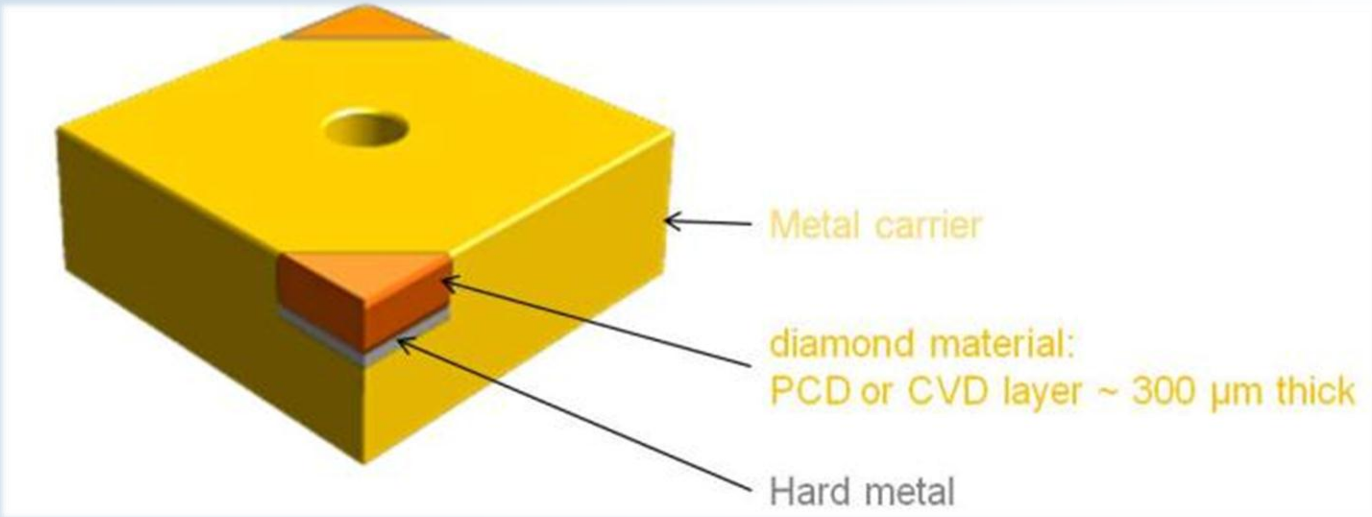


JenLas® *disk IR70E*



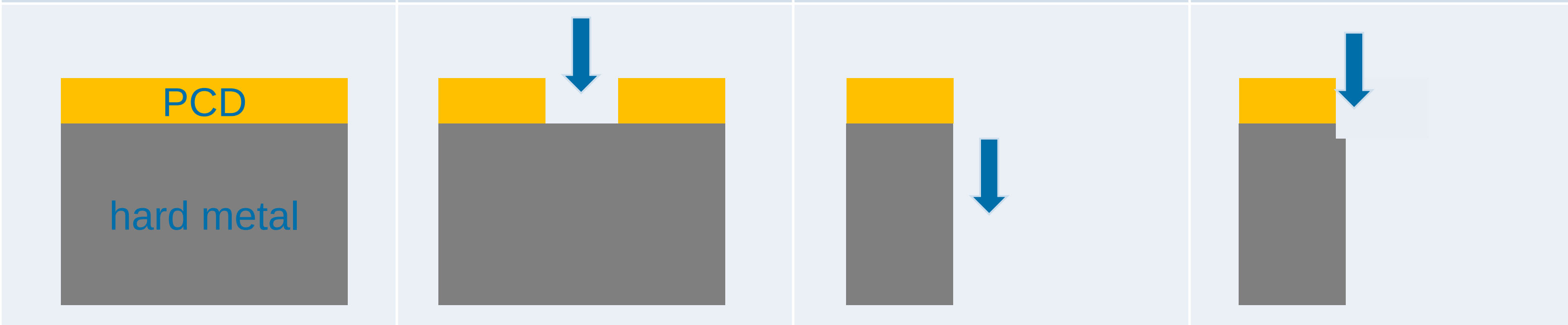
Diamond tool finishing with ns-lasers

- Indexable inserts for tipped tools
- “Indexable” means: the insert has multiple blades which can be used by turning it
- The insert is mounted to a tool holder by brazing, welding or clamping
- Finishing: shaping of diamond layer (knife edge) and hard metal to the final geometry
- State of the art: mechanical grinding (slow)



Diamond tool finishing with ns-lasers

	1st step	2nd step	3rd step
PCD on hard metal before mounting on metal carrier	Fast ablation of PCD	Fast ablation of hard metal	Optimization of PCD edge quality



Requirements:

- Edge sharpness with radius < 10 µm
- Wall taper with angle ≤ 1°

⇒ Engraving process for enhanced edge quality and minimized thermal input

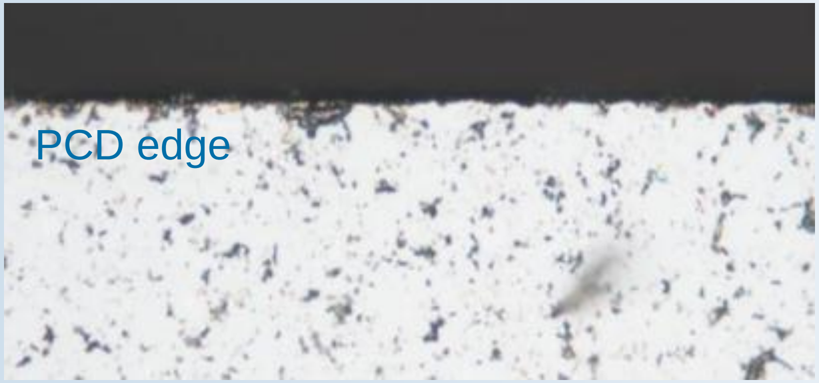
Diamond tool finishing with ns-lasers

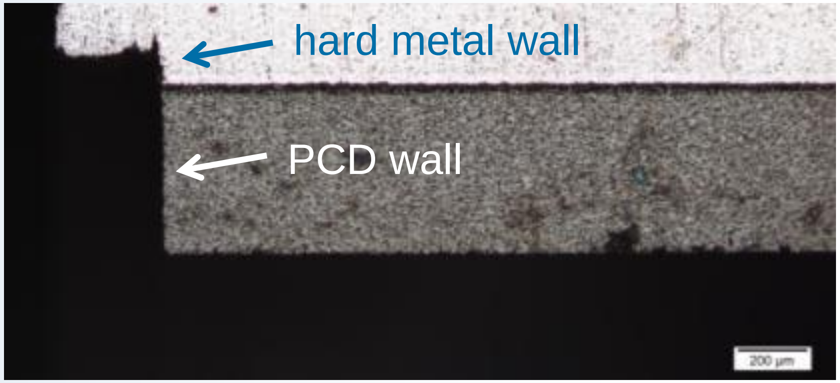
Chipping at PCD edge:

- r < 10µm. Best value shown: r = 1.4 µm
- Limited by mechanical accuracy of beam motion system (not laser)

Taper angles:

- PCD wall: 0.4° taper at perpendicular beam incident angle
- Hard metal wall: 1° taper





PCD and hard metal require very different laser parameters

- PCD: 30 ns pulses at medium pulse energy
- Hard metal: 300 ns pulses at > 5 mJ pulse energy

⇒ JenLas® disk IR70E addresses both parameter ranges!

- Jenoptik at a glance
- Thin disk laser technology
- Fast & Ultrafast Material Processing
- High Precision Applications
- **Summary**

Summary

Successful application results are depending on:

Properties of the laser

- Pulse duration, pulse energy and beam quality
- Stability, reliability and repeatability

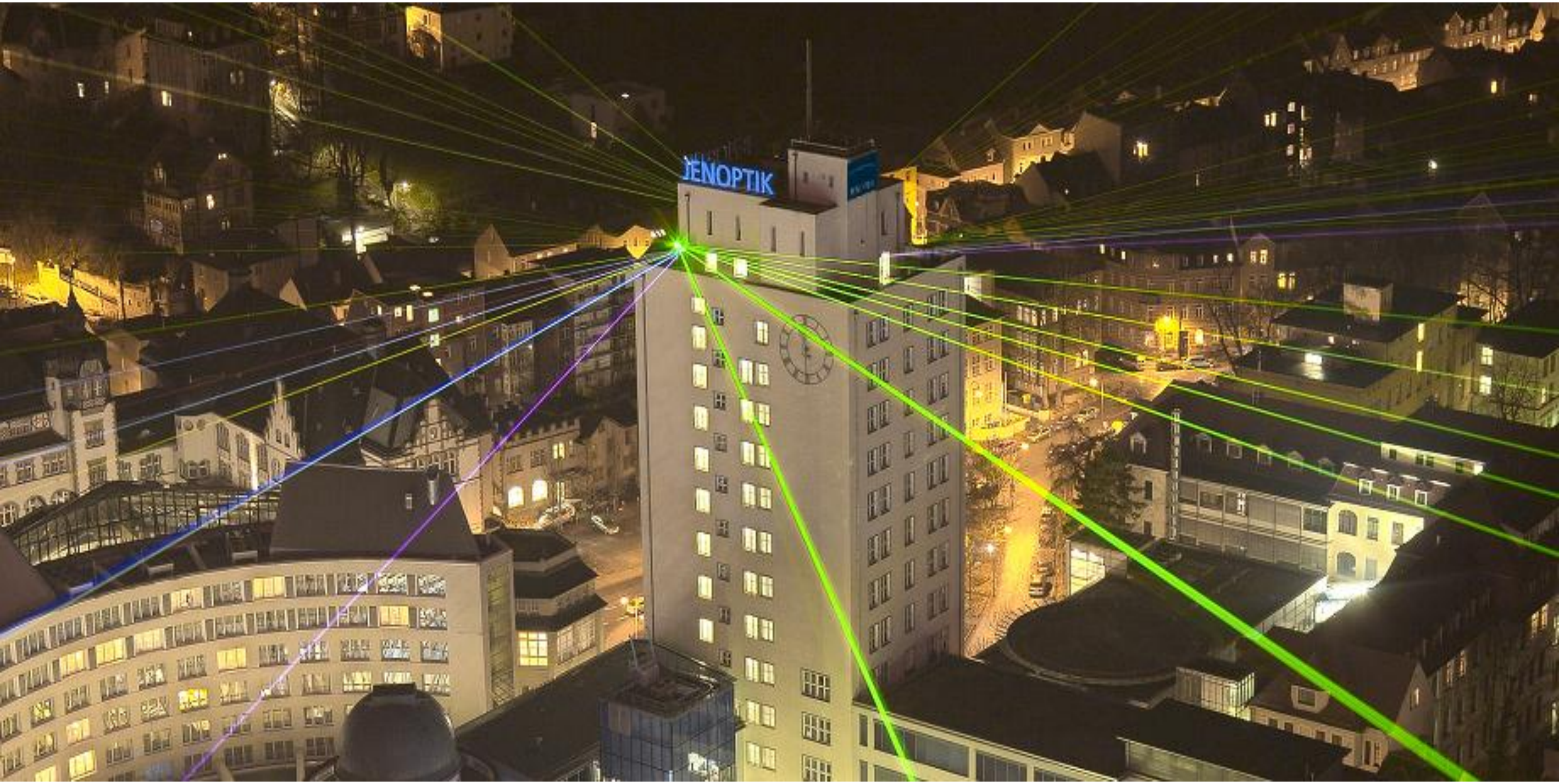
Process strategy

- Focus-size, pulse energy, wavelength
- pulse overlap, motion speed, number of passes

Additional value by

- Transport fibers for fs-lasers
- Deflection-/motion-systems
  (like 3D-scanner or trepanning-head)
- Advanced Optics (e.g. tophat distribution)
- Monitoring systems

Thank you very much for your attention!



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