High Average Power Ultrafast Lasers based on InnoSlab Technology

Ultrafast Laser Processing Forum

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KIMM Institute

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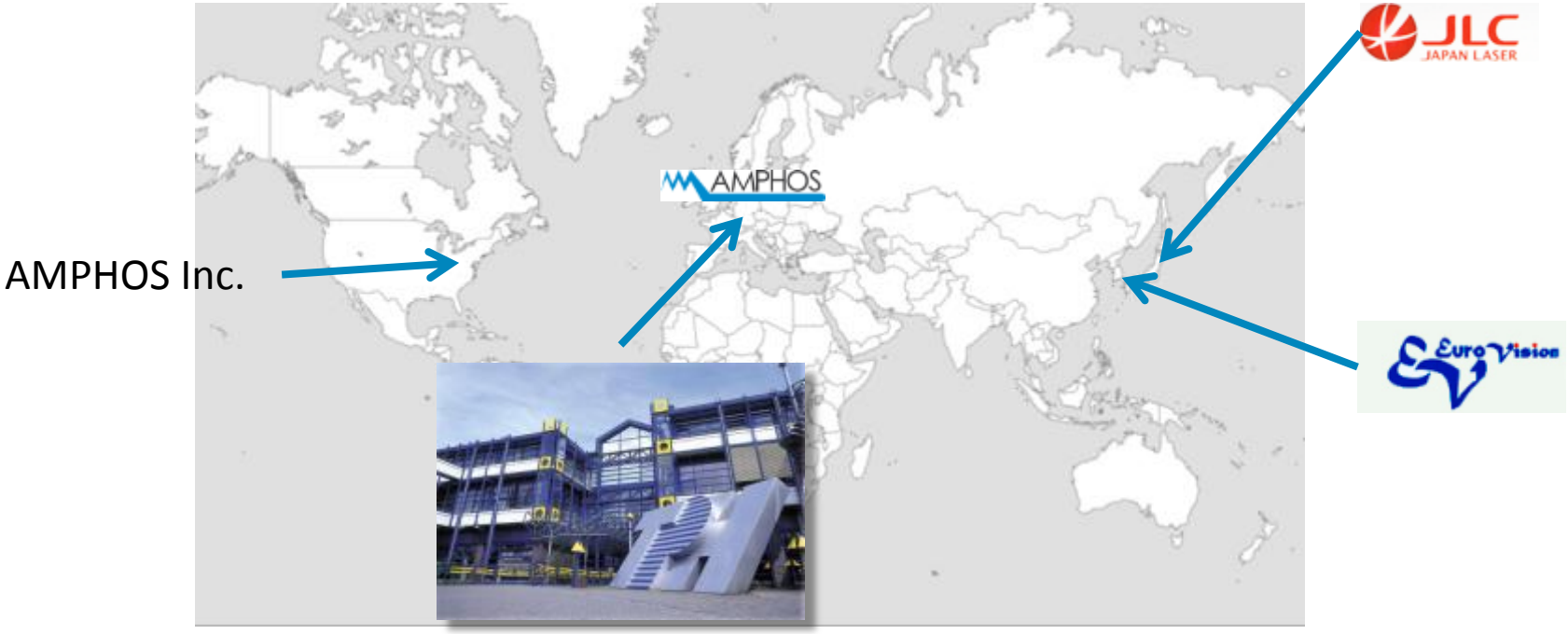
AMPHOS

Outline

- **Introduction**
- Technology
- Products
- Applications

AMPHOS – Facts and Figures

- Founded in Feb. 2010 (Spin-off of Fraunhofer ILT)
- Location: Technology Park Herzogenrath, close to Aachen, Germany
- Office and laboratory space > 1000 m²
- Representatives in Asia (Japan / Korea)
- AMPHOS Inc. (Springfield, MA)



High Average Power Ultrafast Lasrs

- AMplifying PHOtonicS - Amplifier Systems with focus on Ultrashort Pulse Lasers
- AMPHOS manufactures world record High Average Power Ultrafast Lasers:
  - Multi-100W average output power
  - Pulse duration from 500fs…10ps
  - Pulse energy up to mJ range
- AMPHOS Laser Systems are based on „Yb:InnoSlab“ Amplification Technology

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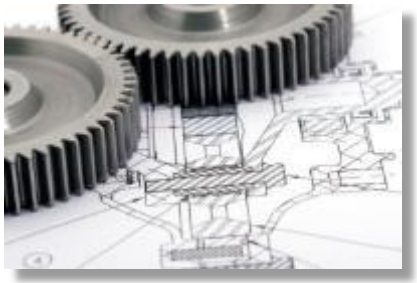
High Average Power Leads to High Throughput

- Ultrashort Pulse Lasers:
  - extremely precise, „cold“ ablation
- Advantages:
  - Any material can be processed
  - No heat affected zone
  - Remote, contactless Process
- Application areas:
  - Photovoltaics (thin film ablation)
  - Surface structuring
  - Drilling, Cutting (Turbo engines)
  - EDM (metals and dielectrics)
  - Composite Materials



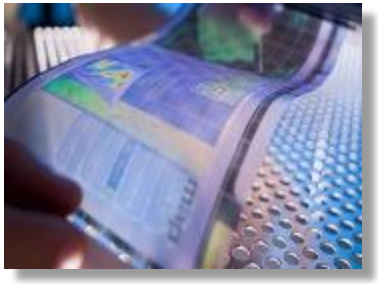



Photo: Flexible Display Center at Arizona State University

AMPHOS Laser systems allow for **higher throughput** due **to highest output power in ps and fs regime**

Key Driver for USPL Application is Power

Power = (Repetition Rate) x (Pulse Energy)

High Repetition Rate	Pulse Bursts	High Pulse Energy
5MHz, 40µJ, 200W	2…10s of pulses	200kHz, 1mJ, 200W
Polygon Scanners	Galvo Scanners	Galvo Scanner, DOE
Surface Structuring	Ablation, Cutting	Drilling, Cutting

One Solution for all Parameters

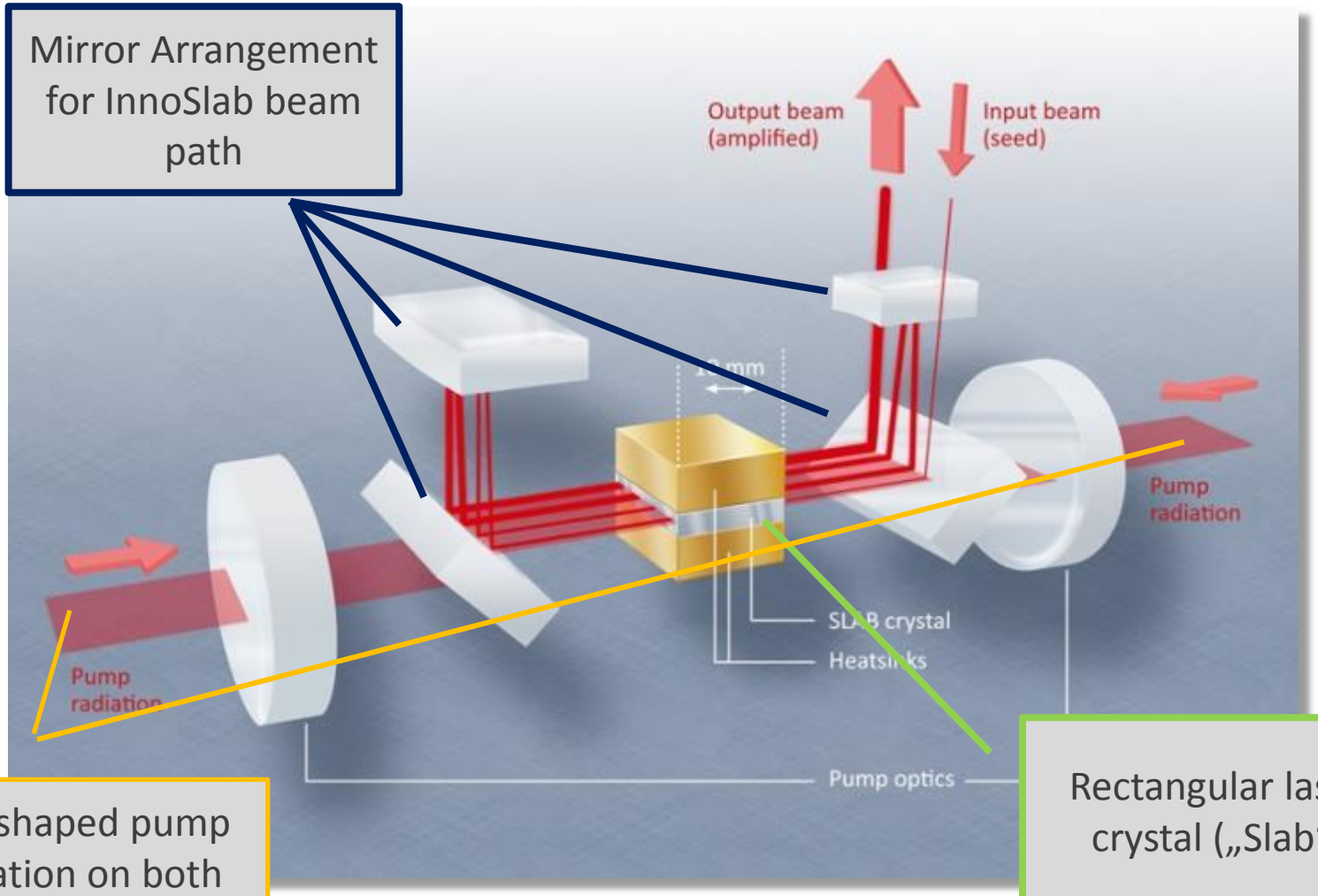
AMPHOS200

Outline

- Introduction
- **Technology**
- Products
- Applications

InnoSlab Amplification Scheme – 3 Core Elements

Mirror Arrangement for InnoSlab beam path



Line shaped pump radiation on both ends of the crystal

Rectangular laser crystal („Slab“)

AMPHOS Advantage of using Yb:YAG

Parameter	Nd:YAG / Nd:YVO	Yb:YAG
Type	4-level	3-level
Wavelength	1064	1030
Pumping	808	**938**
Transparency pumping	-	kW/cm²
Minimum pulse duration	5ps	**500fs**
Heat generation [a.u.]	1	**0,33**

Significant advantages of using Yb:YAG as a lasercrystal in InnoSlab amplifiers:

- **Pulse duration** down to **500fs** is possible
- **Higher average power** per crystal width is possible **due to lower thermal effects**

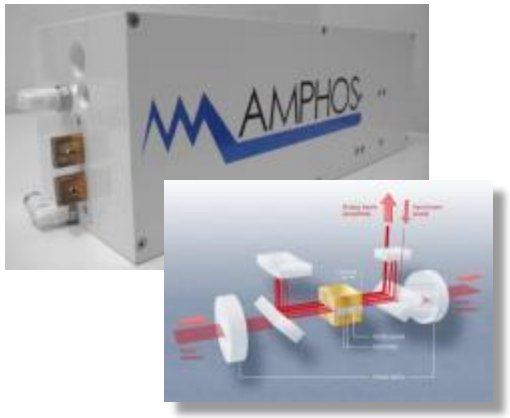
AMPHOS Lasers:
System Architecture based on One Amplifier Module

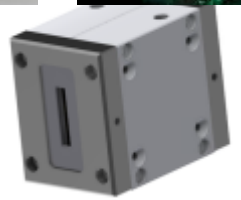
Laserhead

Seedlaser
Pulse duration (fs, ps)
Repetition Rate
Pulse Bursts

InnoSlab Amplifier
Yb doped Crystal
938nm pumped

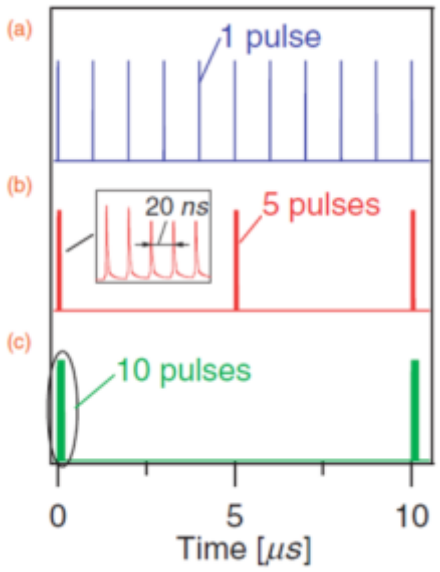
System Technology
Optical Isolator
Optical Modulator
Frequency Conversion



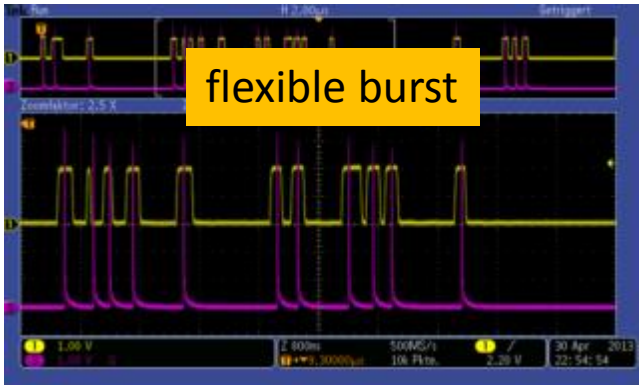


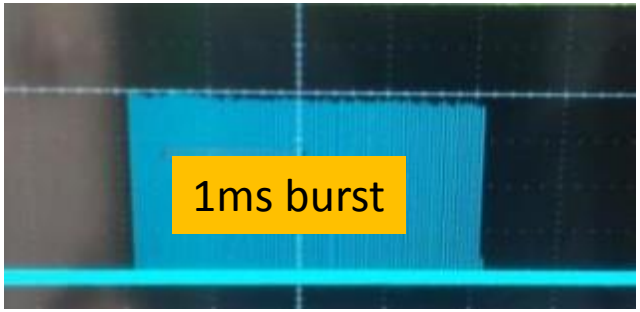
Burst Mode Operation

- Pulse-Bursts: optimized ablation process and increased ablation rate
- Quasi-single pass architecture of AMPHOS Lasersystems: very flexible burst-mode is possible



Schematic of pulse bursts



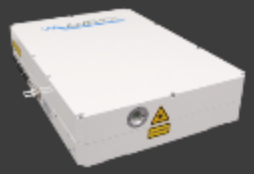


Examples of pulse bursts

Outline

- Company
- Technology
- **Products**
- Applications

AMPHOS Products –
One System Architecture for Wide Parameter Range



AMPHOS 10

- > 10 W output power
- 800fs … 10ps
- > 100µJ
- $M^2 < 1.5$
- compact size (40 x 30 x 15 cm^3)

AMPHOS 200

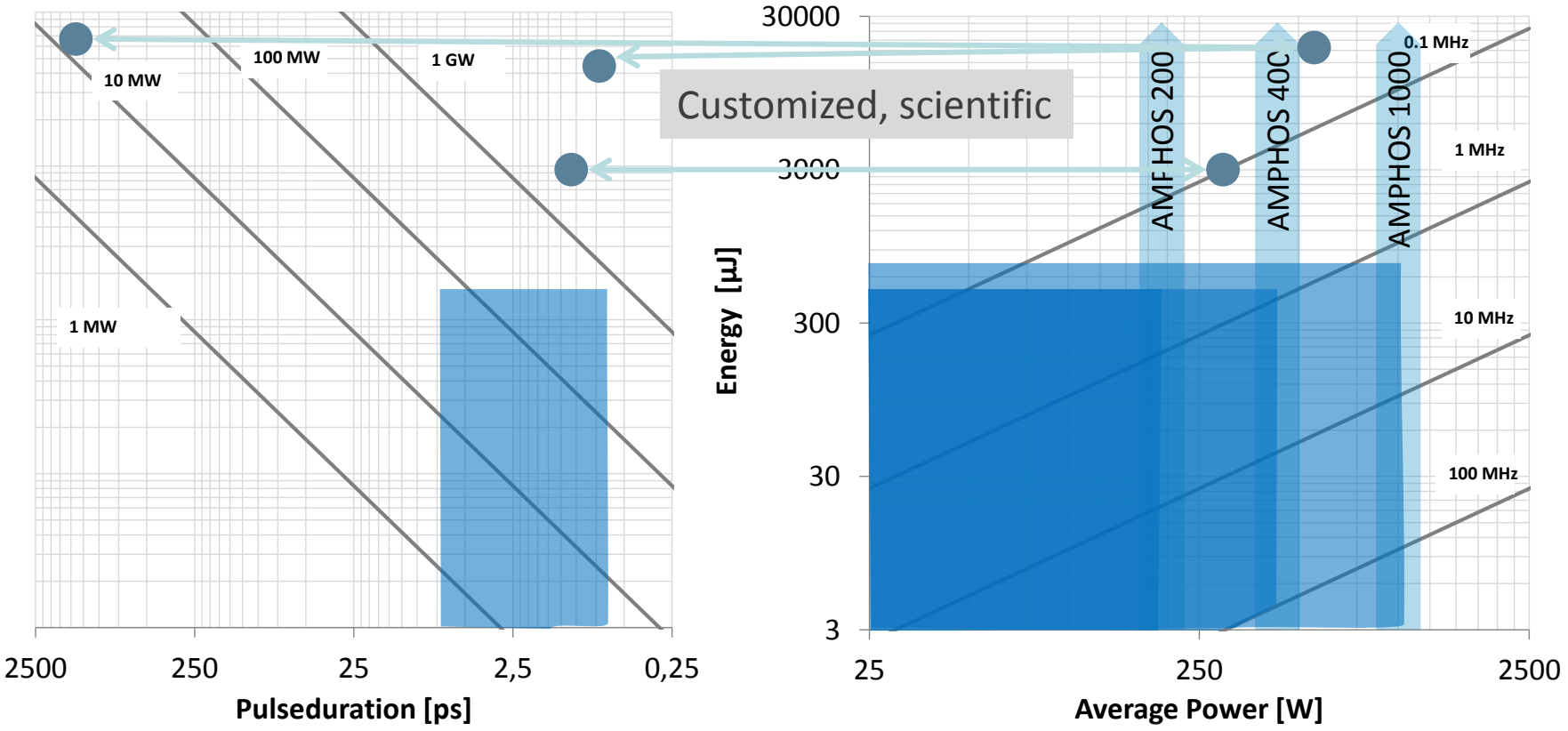
- > 200 W output power
- 800fs … 10 ps
- > 500µJ
- $M^2 < 1.5$
- 100 W version
- robust system design (60 x 60 x 16 cm^3)

AMPHOS 400

- > 400 W output power
- 800fs … 10ps
- Up to 10mJ and higher
- $M^2 < 1.5$
- scalable to >1000 W
- scientific applications (110 x 60 x 15 cm^3)

- Optical parameters: up to 40MHz / up to 10mJ
- System architecture: one interface / all parameters by software
- Control Unit: 19“ wide and 3-4 HU

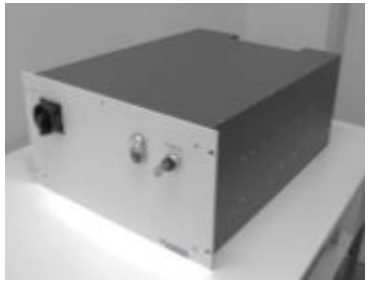
AMPHOS Laser Systems



Extremely wide parameter space can be covered with just one basic amplification module

AMPHOS 200 for Industrial Applications

- Modular System architecture
  - High flexibility
  - Simple serviceability
- Very compact laserhead:
  - 60 x 60 x 16 cm³
- Technical parameters:
  - Output power > 200 W
  - Max. Pulse energy > 400 µJ (opt. 1mJ)
  - Pulse duration 800fs…15ps
  - Repetition rate: 500kHz…40MHz
  - Pulse bursts, Puls on demand (PLL)
- Control unit:
  - 19“ wide, 7HU
  - Control PC included



Applications:

- Micromaching
- Glass cutting
- SLE process
- Surface structuring

High Power Ultrafast Fiber Coupling

- Kagomé type fibers for transportation of ultrashort pulses with high average power
- First experimental results in cooperation with Photonic Tools GmbH

AMPHOS 200 Laser System

Photonic Tools Fiber Connector

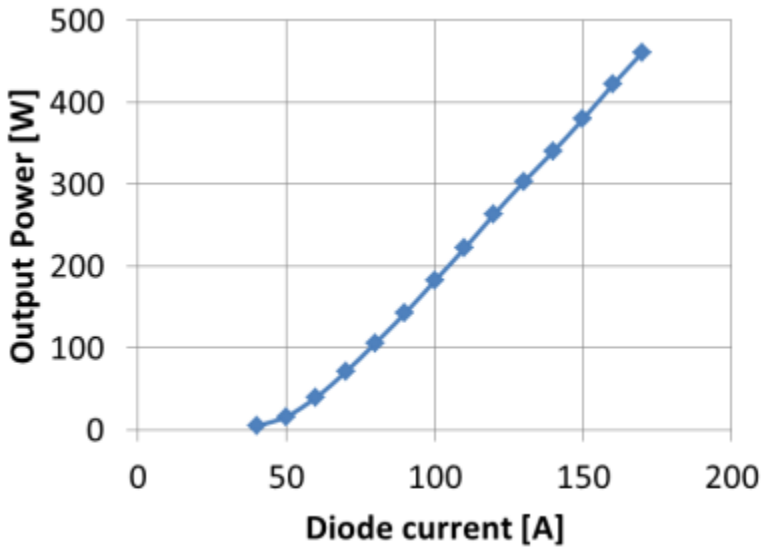
Output power after fiber
185 W 1.4 MHz and 7 ps pulse duration

AMPHOS 400 – Covering Large Parameter Space

- Output power > 400W
- Max. Pulse Energy >500µJ
- Pulse duration from <1ps to 10ps
- Repetition Rate from 800kHz…40MHz
- Wavelength: 1030nm (opt. 515nm)
- Beam Quality: $M^2 < 1.5$

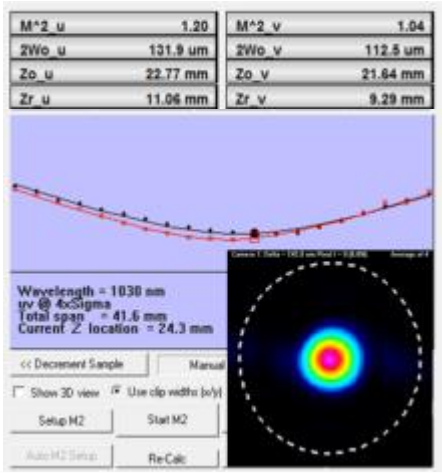
- Options:
  - 100MHz
  - 1 GW pulse power

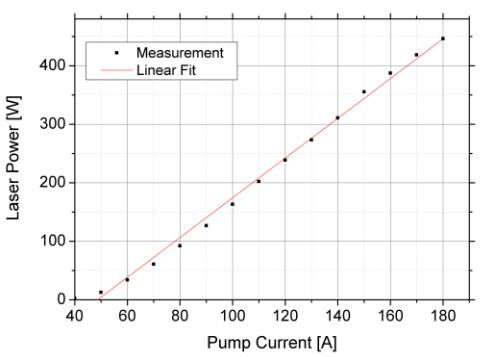
- Control unit: 19“ rack
- Integrated EOM / Pulsepicker
- Control by TCP/IP or sim.
- Fast modulation up to 3MHz by TTL

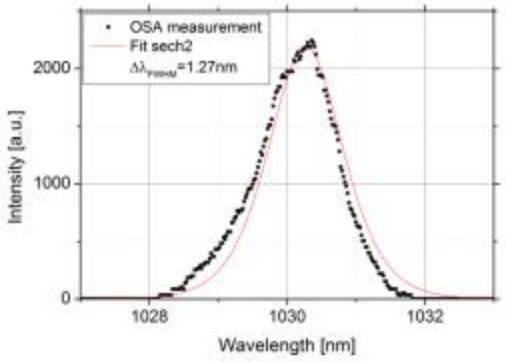


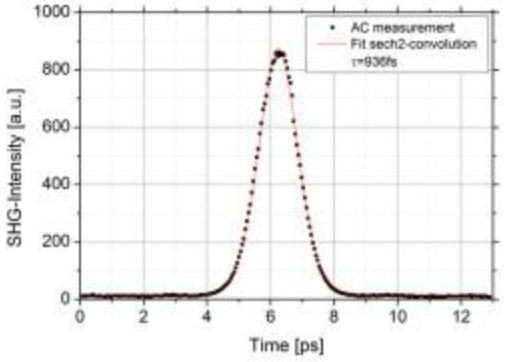
Scientific application – OPCPA Pumping: 300 W Average Power, 3mJ, 3 GW Pulse Power

- Seedlaser: 1030nm, 100kHz, 100nJ (=10mW), t=100ps
- Amplifier based on a 10mm wide slab crystal (AMPHOS 400)
- Compressor:
  - transmission grating 1740 lines/mm
  - transmission efficiency ~80%
  - FWHM-spectrum 1.27nm (-> τ_{BWL}=878fs)
  - minimal pulse duration 936fs (=1.07*τ_{BWL})









Output pulses with 3GW pulse power

Overview of Laser Systems

Output Power	Pulse Energy	Repetition Rate	Pulse Duration	Pulse Power
10 W	100 µJ	100 kHz	1 ps	100 MW
150 W	1.5 µJ	100 MHz	600 fs	2.5 MW
200 W	500 µJ	400 kHz	1 ps	500 MW
300 W	3 mJ	100 kHz	900 fs	3 GW
400 W	800 µJ	500 kHz	800 fs	1 GW
500 W	12.5 µJ	40 MHz	700 fs	17 MW
1.500 W	15 mJ	100 kHz(10 Hz)	900 fs	16.5 GW
5.000 W	50 mJ (5 J)	100 kHz (10Hz)	500 ps	100 MW
20.000 W	4 mJ (20 J)	4.5 MHz (10 Hz)	500 ps	8.9 MW

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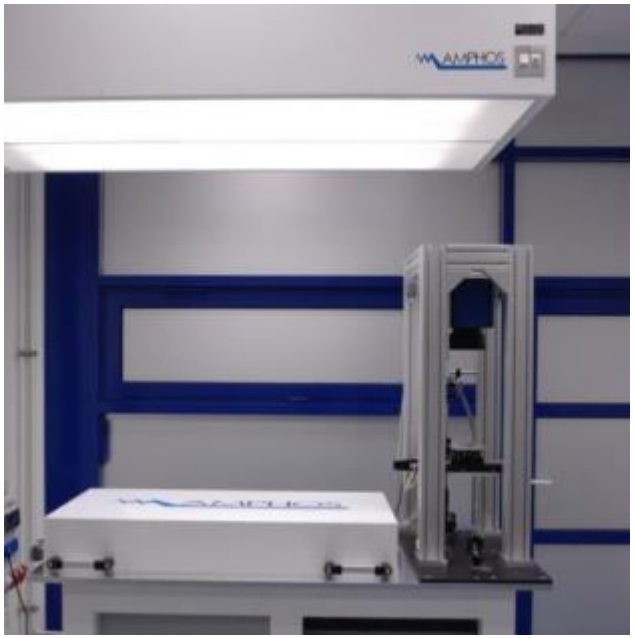
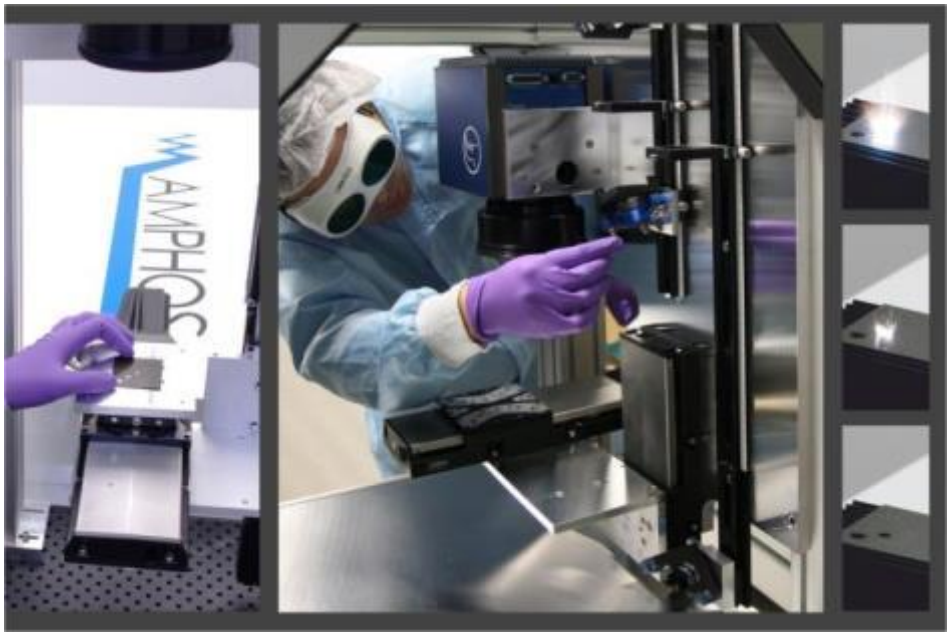
AMPHOS Application Lab

- Currently installed:
  - 400W Laser System, 1030nm, <1ps…10ps
  - Galvo scanner (f=80mm / 163mm / 254mm) lenses (SILL TZ)
  - 3-axes moving stage

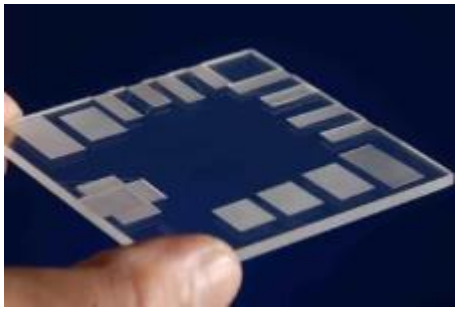




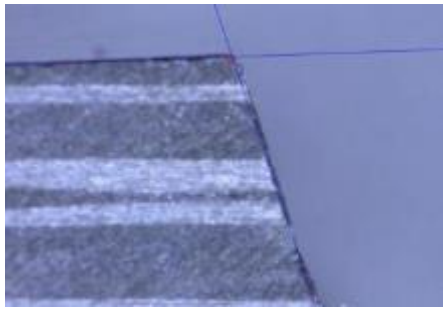
AMPHOS offers feasibility studies for processing different materials

Results of Materials Processing: High Average Power Translates Into Processing Speed

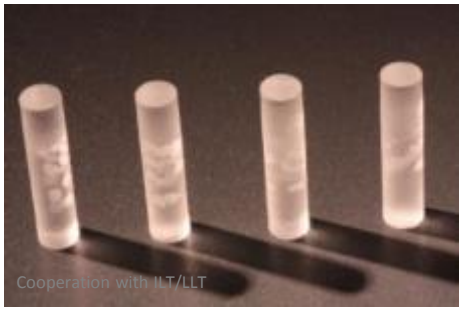
Fused Silica



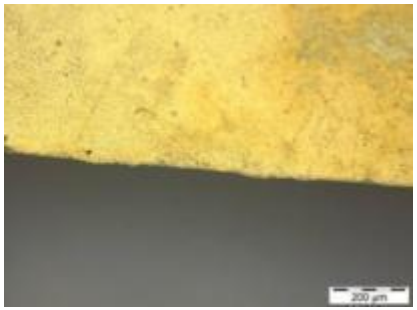
CFRP



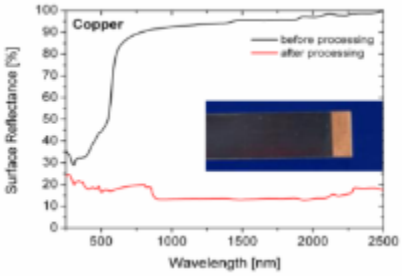
In Volume Selective Laser Etching (ISLE)



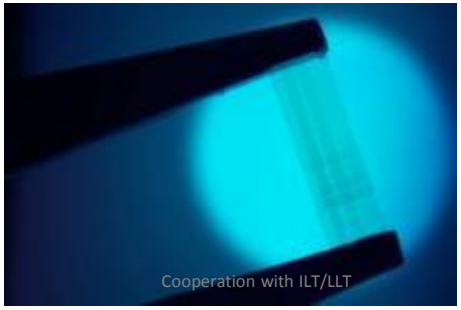
Compound Wafer



Blackening of Metals

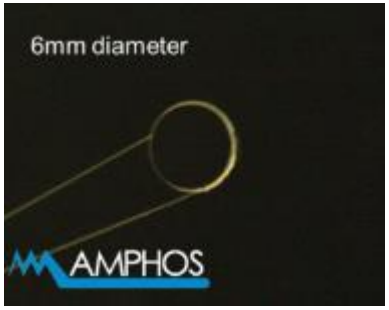


Waveguide Structures



Processing of Metal

Strengthened glass

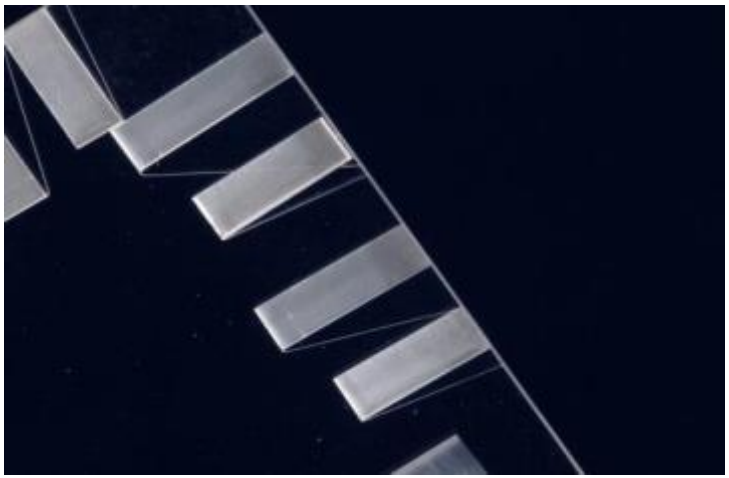


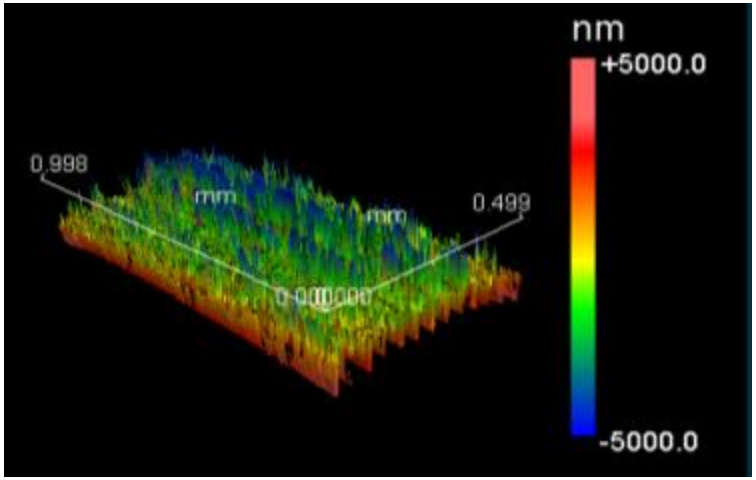
Output Power of 150 W (@500fs & 6MHz):
Ablation rate in the range of 1-2 mm³/s

AMPHOS for Industrial Applications – Machining of Glass

Laser Parameter
P = 150 W
τ = 510 fs
ν_{Rep} = 5.9 MHz

Result for Fused Silica
Removal Rate: up to 2 mm^3/s
Ra = 1.4 µm



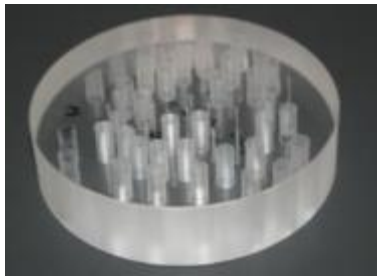


Standard Galvo Scanner is sufficient for this process

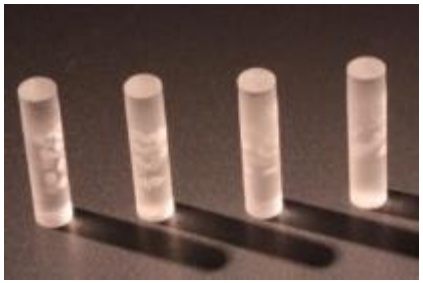
Another example: Cutting of thin glass

AMPHOS for Industrial Applications – Machining of Glass

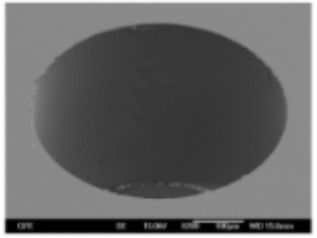
- Two-step process „**S**elective-**L**aser-**E**tching“*:
  - Modification by fs-laser radiation
  - Selective etching of selected area

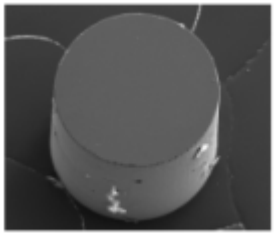


Fused silica
(H ca. 10mm)

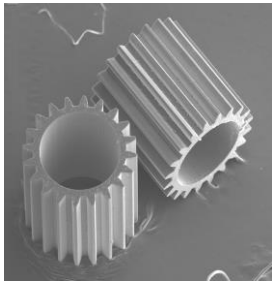


cylinders

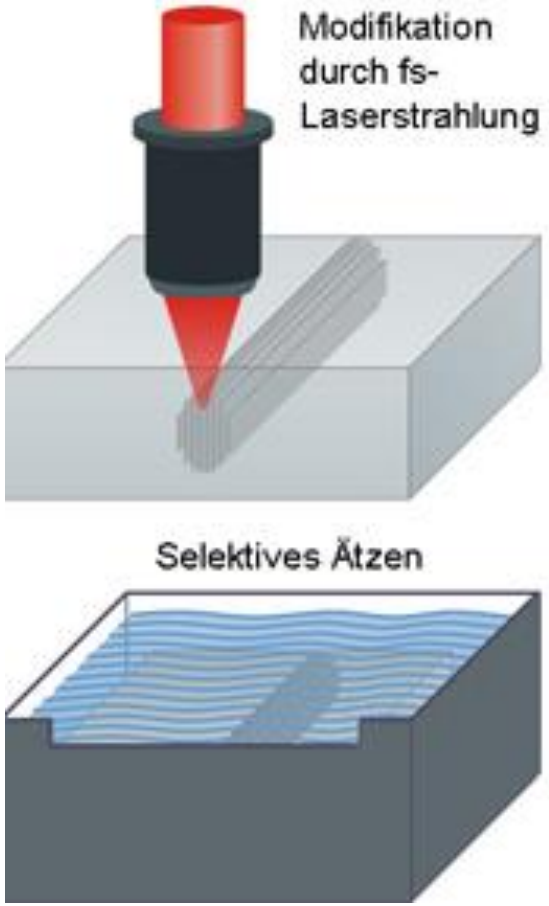




cylinder from sapphire (d=400um)

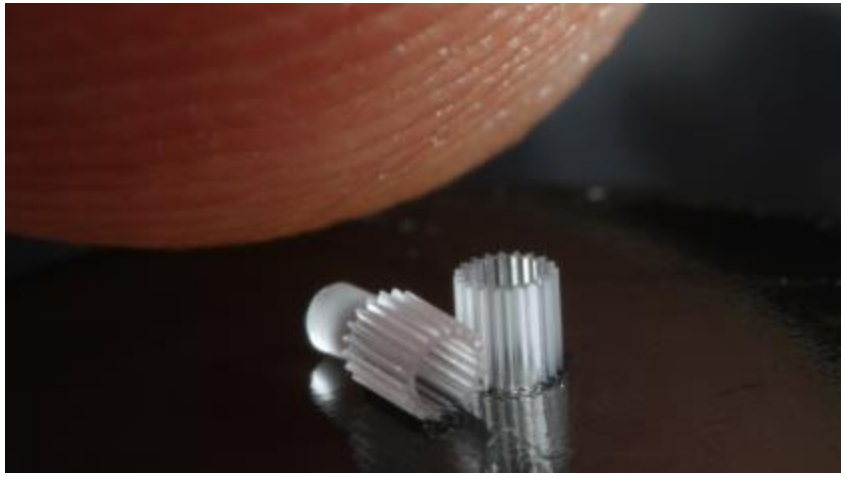


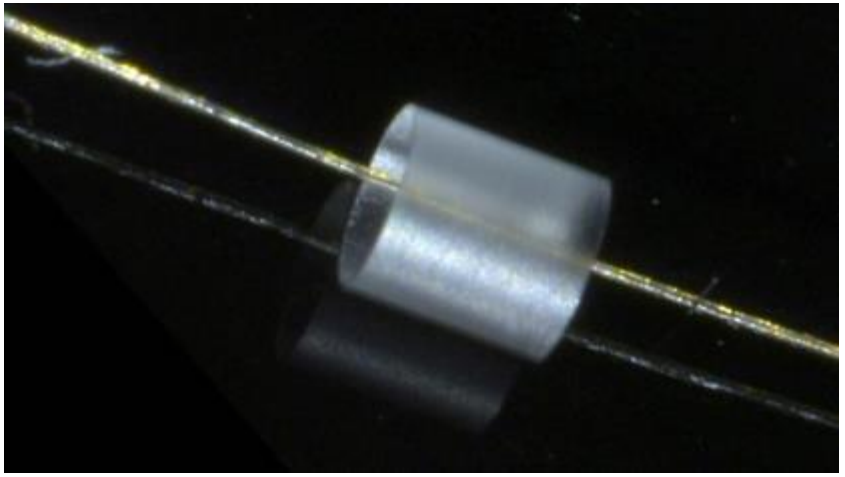
Tooth wheel
(L=1mm)

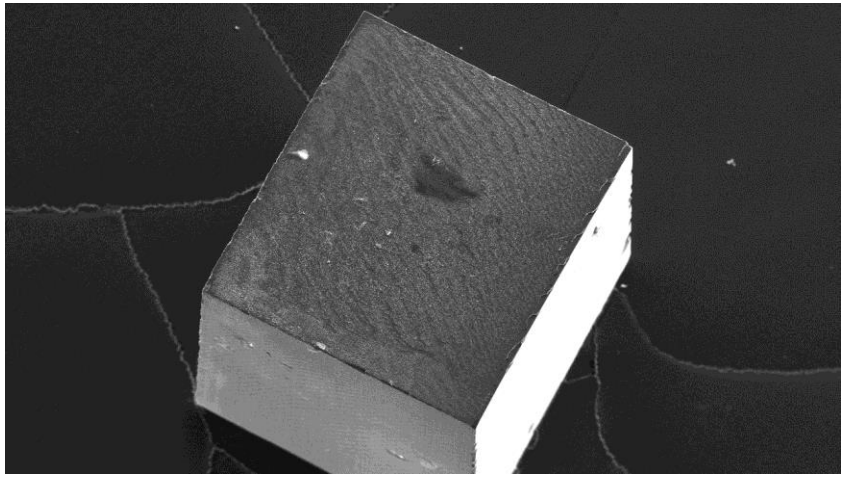


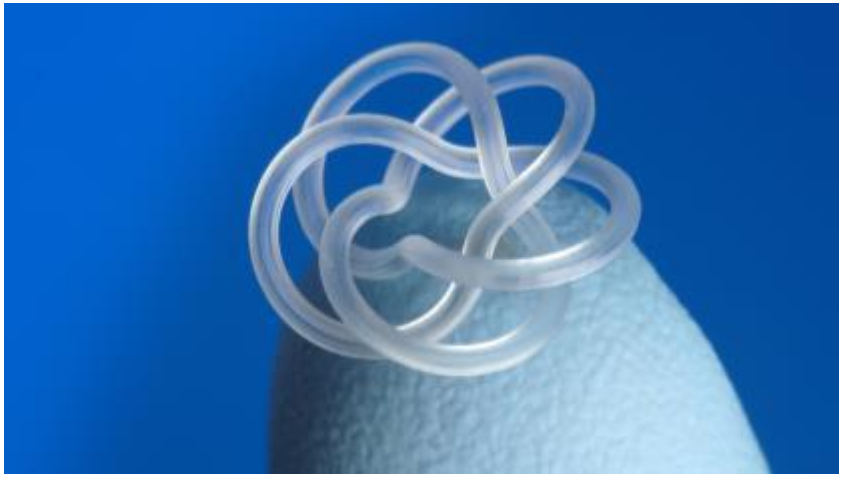
*Source LLT, RWTH-Aachen

Selective Laser Etching – Results



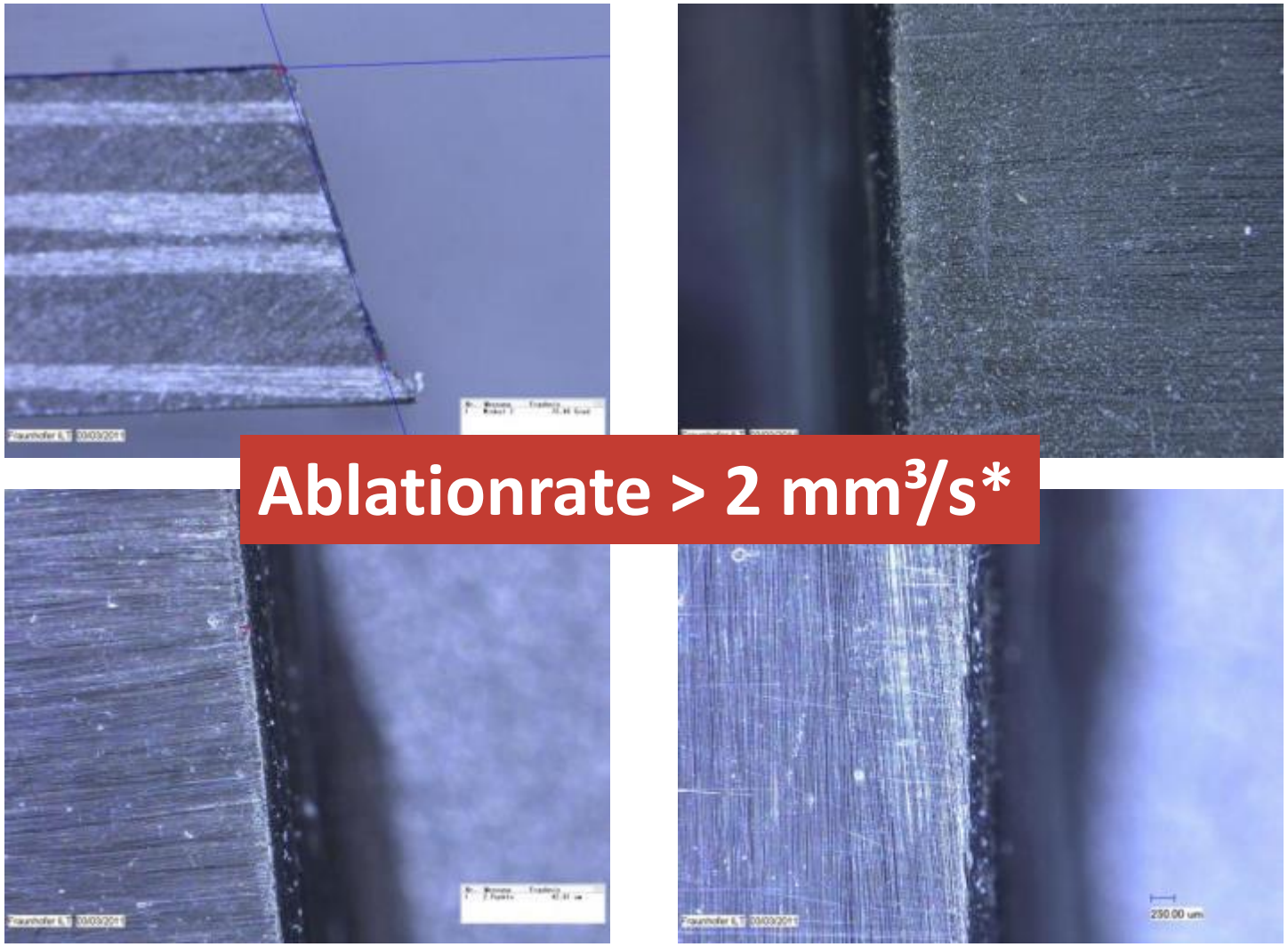






Source: Fraunhofer ILT, Lightfab

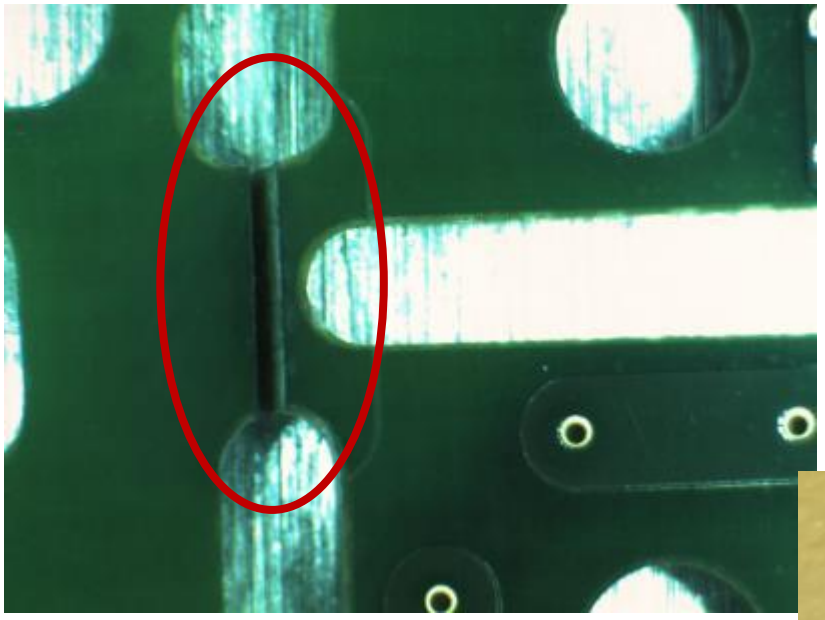
CFRP Machining with AMPHOS Lasers
Cut Through 1.8mm Thick Material

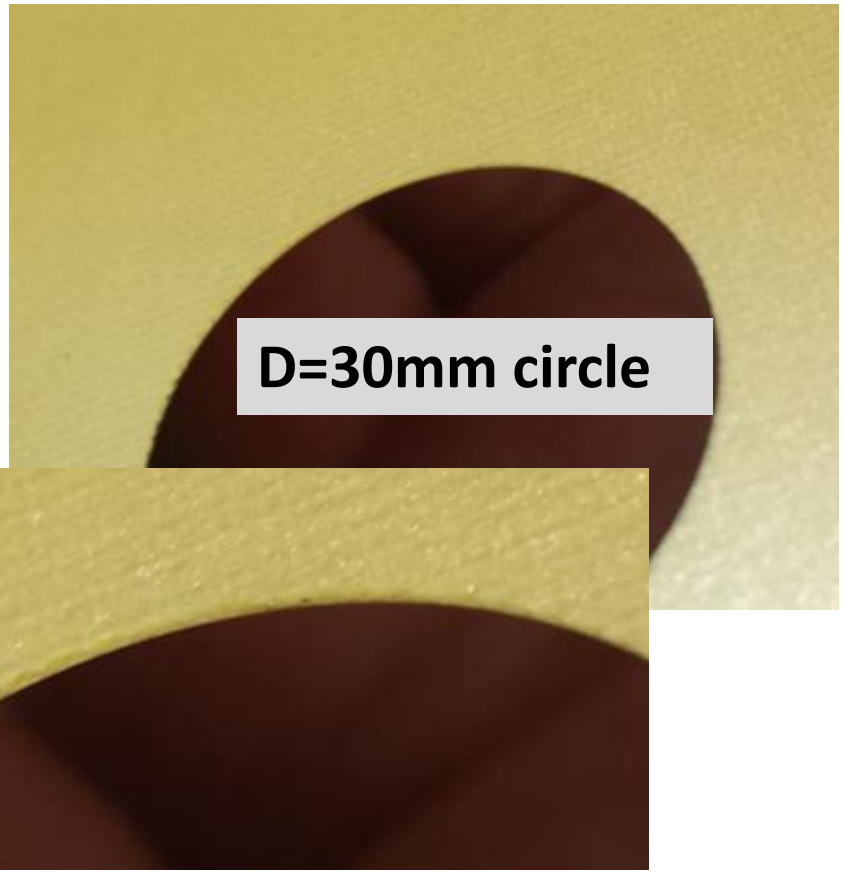


*150W output power, optional 400W / 1000W

Cutting of Printed Circuit Boards (PCB)

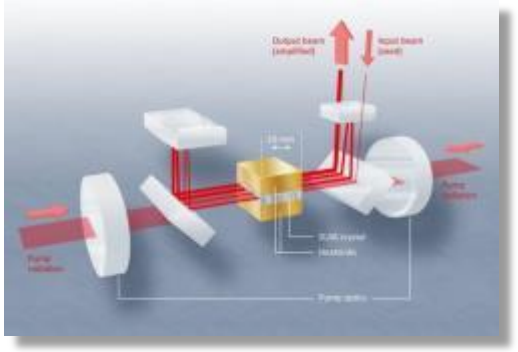
- Glass fiber based materials as PCB can be cut with AMPHOS laser
- No carbonization also at high power level (200-400W)





Summary

- AMPHOS is technology leader in High Average Power Ultrafast Lasers
- InnoSlab amplification technology using a Yb:YAG laser crystal allows for highest output power in the Ultrafast regime
  - up to mJ pulse energy, multi 100W output power
  - GW pulse power,
  - diffraction limited beam quality
- The simple setup and high output power result in an optimum process efficiency and low cost of ownership



From industry to science – a lot of applications and products benefit from those outstanding properties

Thank you very much

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