

HIGH POWER ULTRASHORT PULSE LASERS

Workshop „High Throughput and High Precision
Laser Micromachining with Ultra Short Pulses”

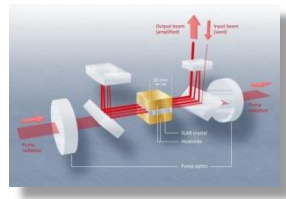
04. November 2015

Dr. Claus Schnitzler

Outline



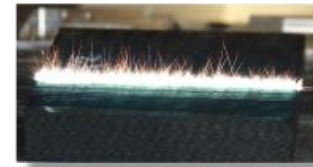
Introduction



Technology



Lasers



Applications

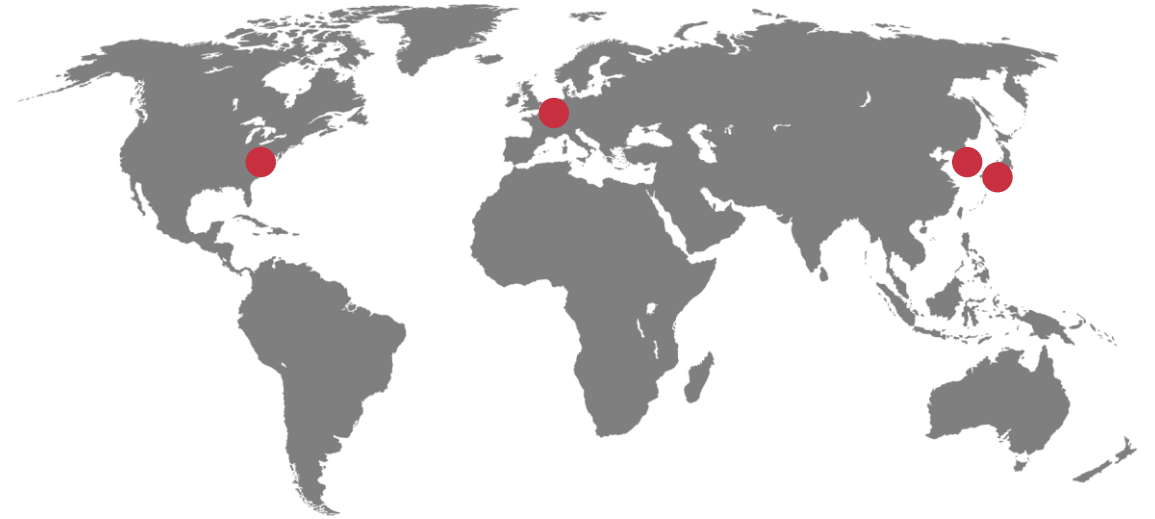


**Summary and
Outlook**

AMPHOS

Facts and Figures

- Founded in 2010 as a Spin-off of Fraunhofer ILT and RWTH University
- Headquarter located within Technology Park Herzogenrath, close to Aachen, Germany
- Office and laboratory space > 1000 m²
- Representatives in Asia: Japan and Korea
- US subsidiary: AMPHOS Inc. (Springfield, MA)



Headquarter in Germany

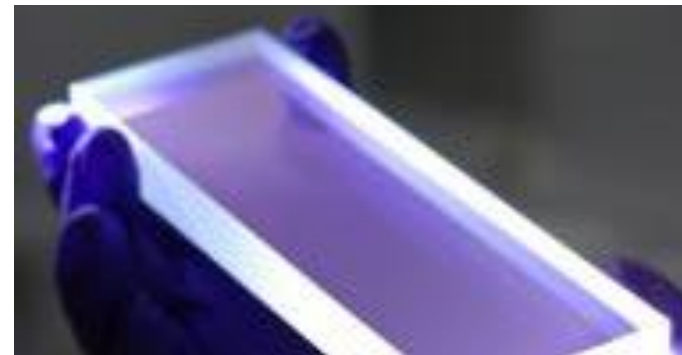
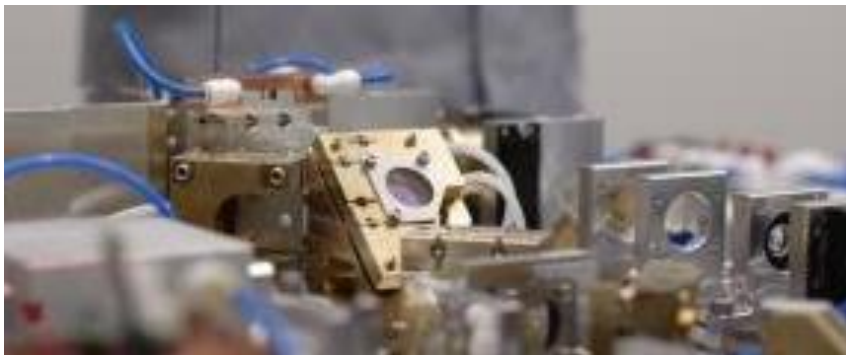


High Average Power Ultrafast Lasers

for Scientific and Industrial Applications



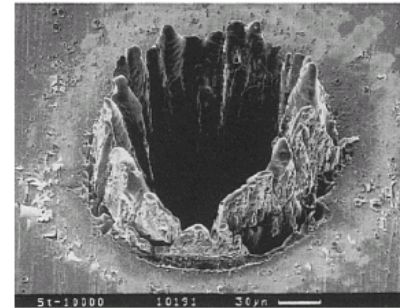
- AMplifying PHOtonicS - Amplifier Systems with focus on Ultrashort Pulse Lasers
- AMPHOS manufactures world record High Average Power Ultrafast Lasers:
 - Multi-100W average output power
 - Pulse duration from 500fs...10ps
 - Pulse energy up to mJ range
- AMPHOS Laser Systems are based on „Yb:InnoSlab“ Amplification Technology
- Management team with more than 15 years of experience in InnoSlab technology



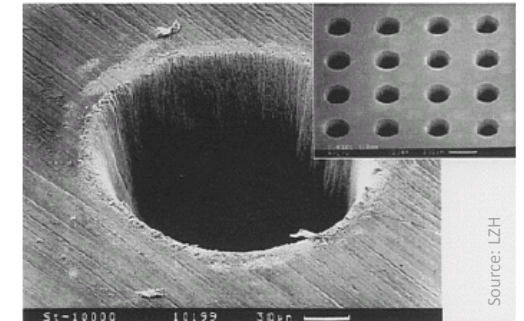
High Average Power Ultrafast Lasers

for high throughput processing

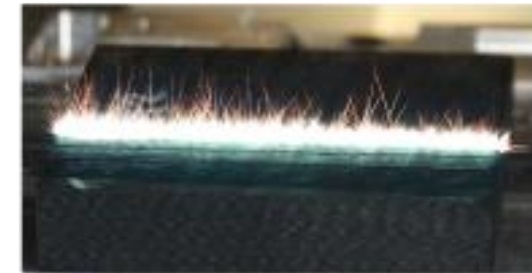
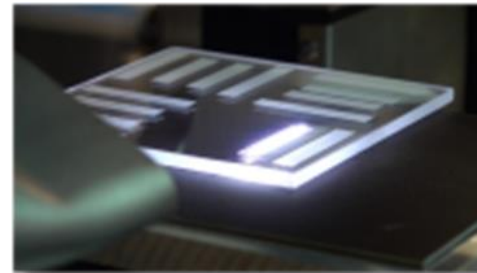
- Ultrashort Pulse Lasers:
 - extremely precise, „cold“ ablation
- Advantages:
 - Any material can be processed
 - No heat affected zone
 - Remote, contactless Process
- Application areas:
 - Ablation
 - Modification
 - Surface structuring
 - Drilling, Cutting



3.3 ns



200 fs



High output power of AMPHOS Lasers allows for high throughput in production

Industrial use and sectors

Almost every product can benefit from AMPHOS technology

- AMPHOS laser systems start a new era of laser materials processing
- Outstanding feature is the unique combination of highest output power and ultrashort pulses.
- All industrial sectors can benefit from AMPHOS laser technology.

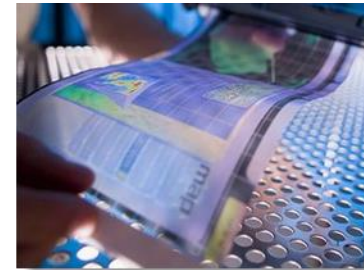
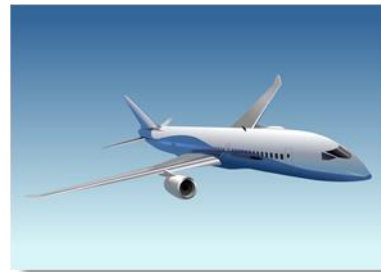
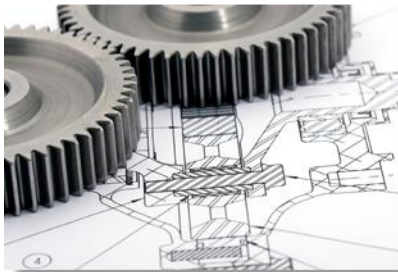


Photo: Flexible Display Center
at Arizona State University



Power is key driver for USPL applications

High laser power is the only way to increase productivity and reduce cost of ownership

$$\text{Power} = (\text{Repetition Rate}) \times (\text{Pulse Energy})$$

High Repetition Rate

5MHz, 40μJ, 200W

Polygon Scanners

Surface Structuring

Pulse Bursts

2...10s of pulses

Galvo Scanners

Ablation, Cutting

High Pulse Energy

200kHz, 1mJ, 200W

Galvo Scanner, DOE

Drilling, Cutting



One Solution for all Parameters

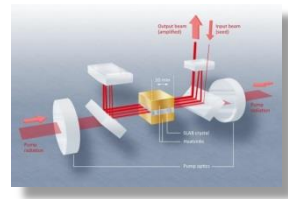
AMPHOS200



Outline



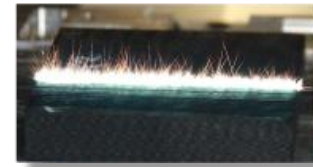
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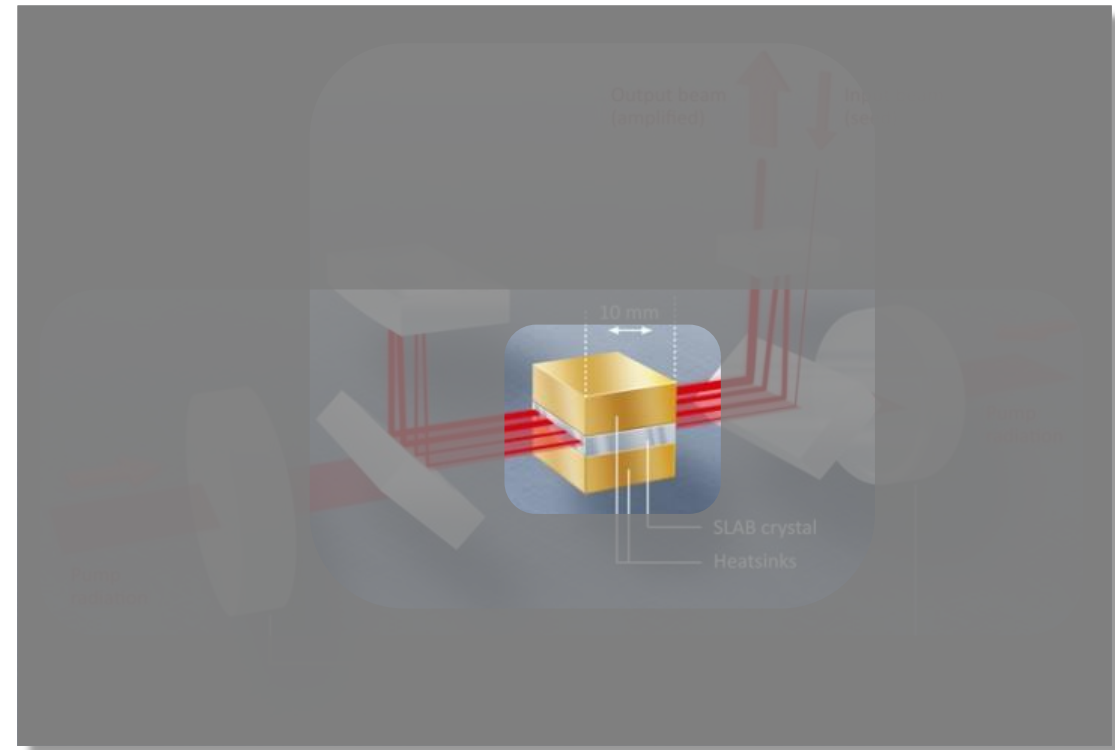


**Summary and
Outlook**

InnoSlab Amplification Scheme

3 core elements for efficient amplification

- slab shaped laser crystal
 - Yb:YAG as active medium
 - Highly efficient
- pumping with diode laser arrays
 - 938 nm pumping with highest lifetime
 - Efficient and low cost diode laser stacks
- smart beam path
 - Intensity is constant
 - High efficiency and high damage threshold
- Patented technology



Laser Crystal

Yb:YAG as the material of choice

Parameter	Nd:YAG / Nd:YVO	Yb:YAG
Type	4-level	3-level
Wavelength	1064	1030
Pumping	808	938
Transparency pumping	-	kW/cm ²
Minimum pulse duration	5ps	500fs
Heat generation [a.u.]	1	0,33

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

Modular System Architecture

for high flexibility and servicability



Seedlaser

Pulse duration (fs, ps)
Repetition Rate
Pulse Bursts

InnoSlab Amplifier

Yb doped Crystal
938nm pumped

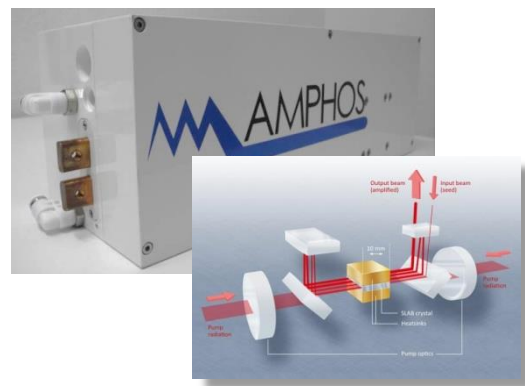
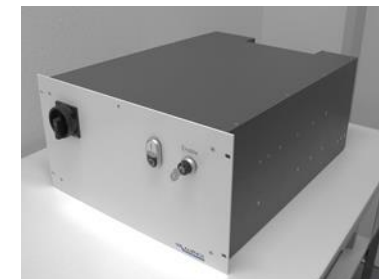
System Technology

Optical Isolator
Optical Modulator
Frequency Conversion

Laserhead



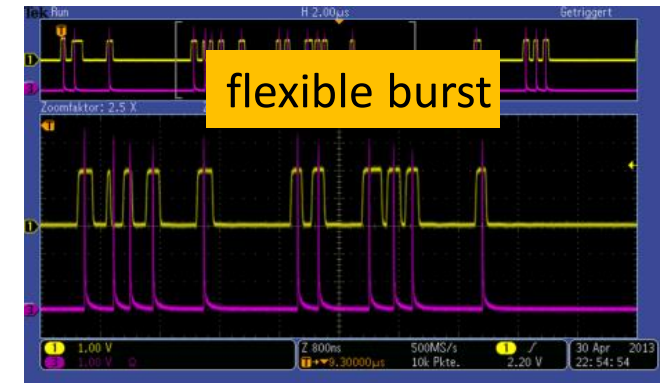
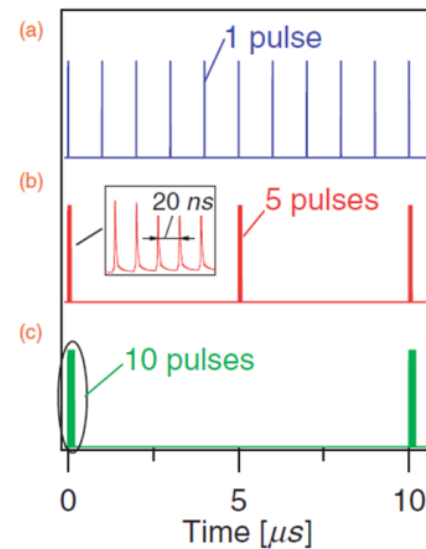
Control Unit



Flexible Pulse Bursts

for highly efficient materials processing

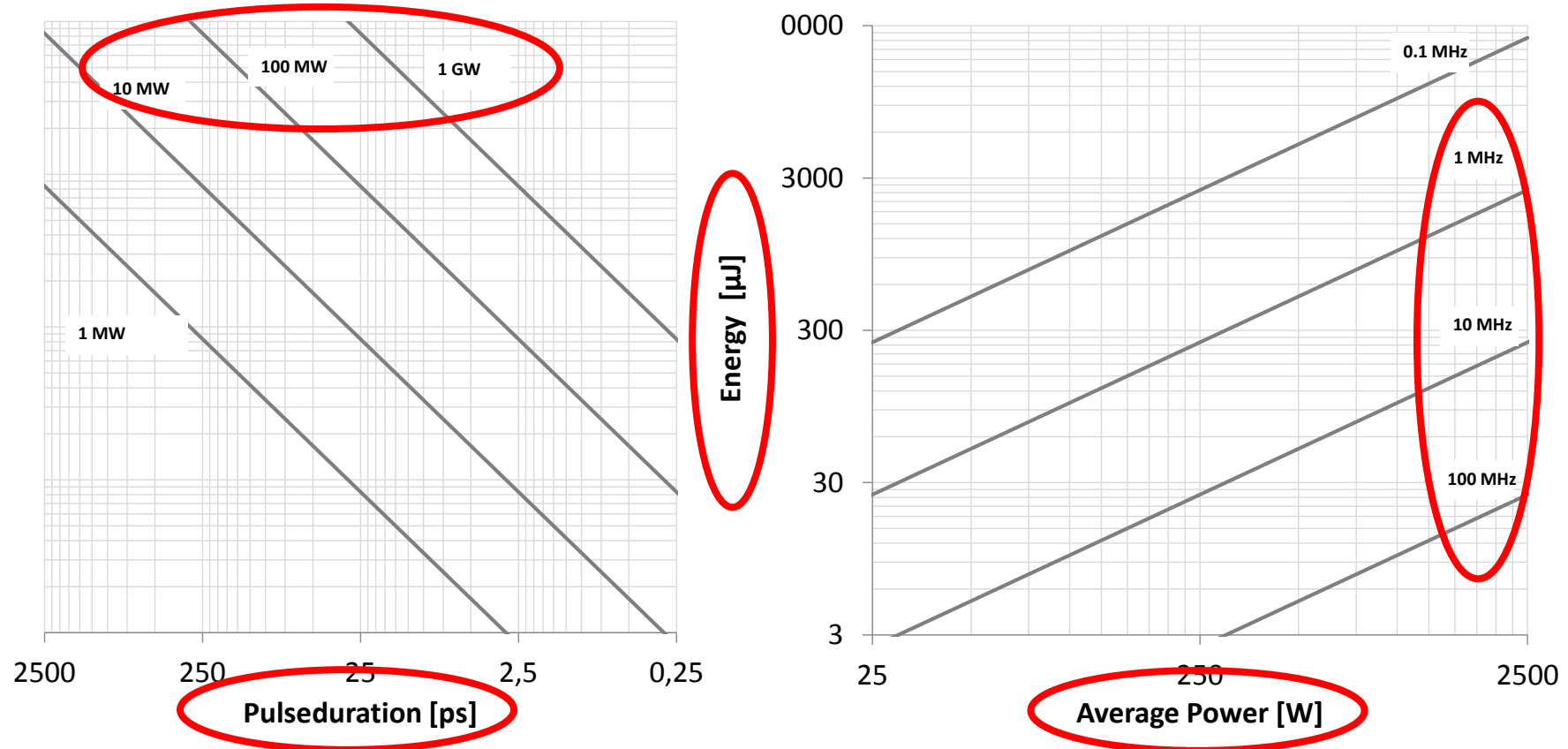
- Puls-Burst is „re-arranging“ pulses in pulse groups
- Pulse-Bursts are used for an optimized ablation process and increased ablation rate
- Quasi-single pass architecture of AMPHOS Lasersystems: very flexible burst-mode is possible



Examples of pulse bursts

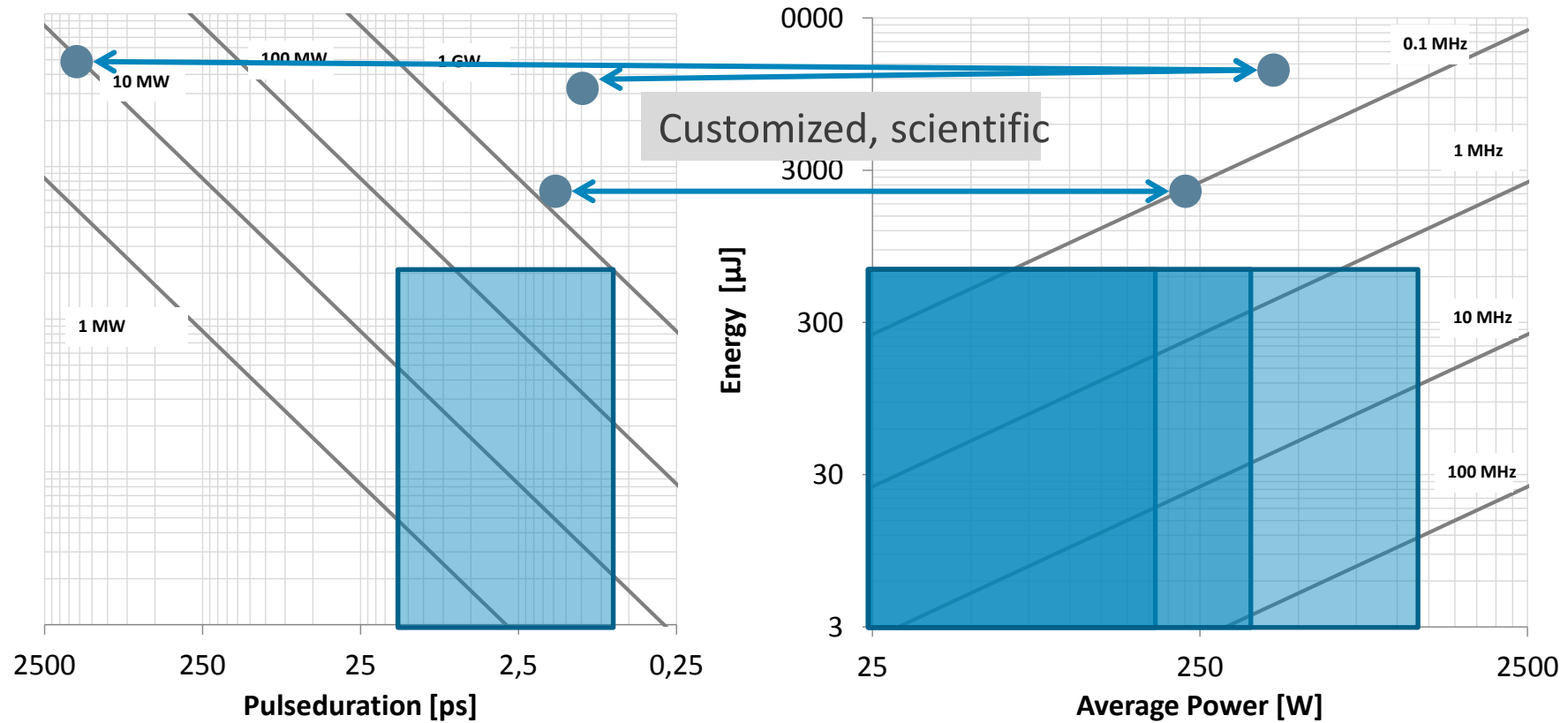
Parameter Space

Ultrashort-Pulse Lasers can be characterized by 5 parameters



Parameter Space

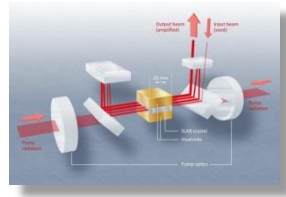
Wide range of pulse parameters can be addressed with just one amplification module



Outline



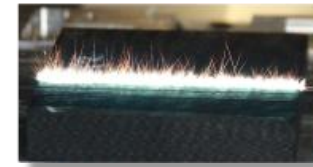
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**Summary and
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AMPHOS PRODUCT RANGE

Main product platforms



Product	AMPHOS 10	AMPHOS 200	AMPHOS 400
Specific features	10 W > 100 μ J	200 W > 500 μ J	400 W > 1 mJ
Standard features	up to 40MHz replate, pulse bursts, pulse on demand, 800fs ...15ps		
Options	SHG 515 nm	pulse energy > 1mJ SHG 515 nm 100 W version	pulse energy > 50 mJ output power > 1 kW

OPCPA Pumping

Amphos technology allows for sub 10fs pulses at high average 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 (-> $\tau_{\text{BWL}}=878\text{fs}$)
 - minimal pulse duration 936fs (=1.07* τ_{BWL})

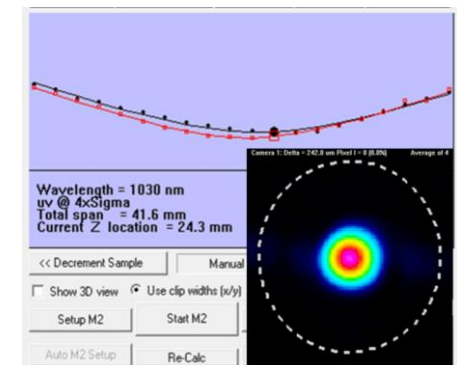
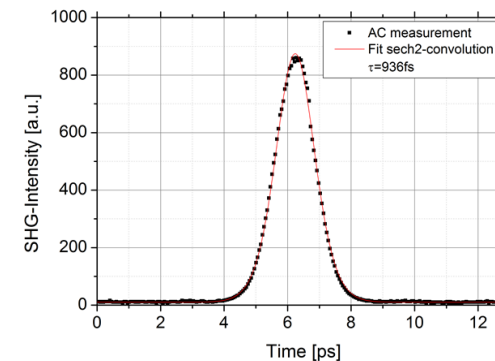
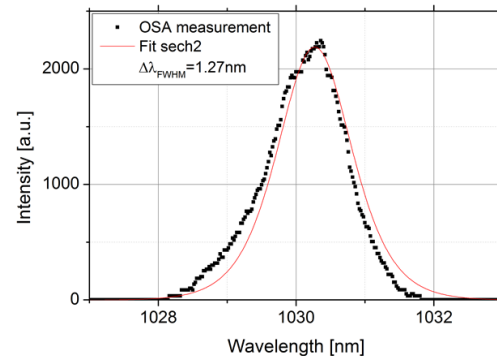
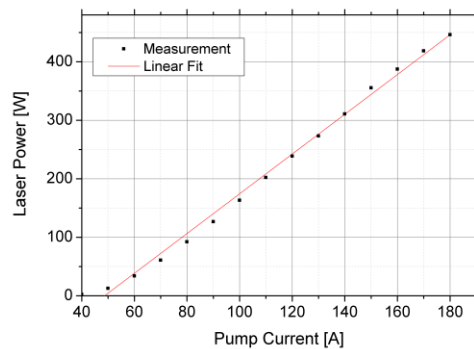


Output parameters

Average Power 300 W

Pulse energy 3 mJ

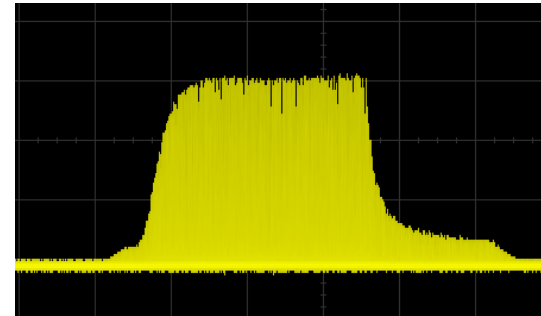
Pulse power 3 GW



20kW Burst-Mode Amplifier

for XFEL – Research facility

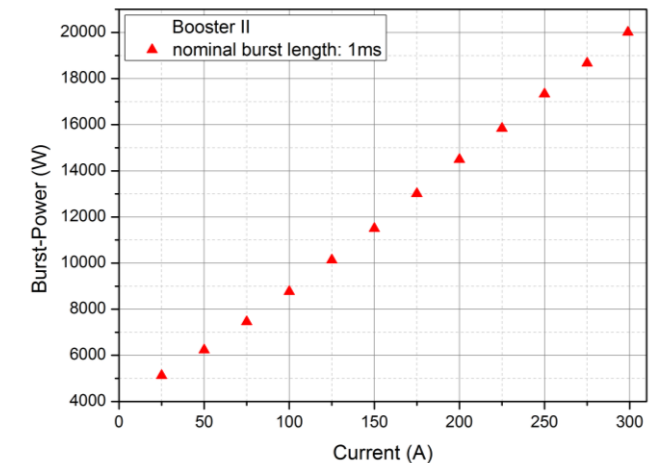
- 3 InnoSlab-Type Amplifiers
- Technical Parameters
 - $P_{\text{IntraBurst}} = 20.000 \text{ W}$
 - $\nu_{\text{IntraBurst}} = 100 \text{ kHz} - 4.5 \text{ MHz}$
 - $T_{\text{Burst}} = 600 \mu\text{s} - 3 \text{ ms}$
 - $\nu_{\text{RepBurst}} = 10 \text{ Hz}$
 - $E_{\text{Pulse}} = 50 \text{ mJ}$
- 24/7 operation
- 4 amplifier chains will be realized until 2016



typical pulsed burst



XFEL facility in Hamburg
Germany



AMPHOS 200

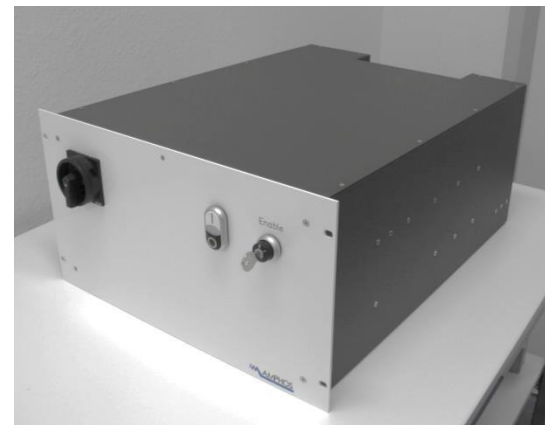
The choice for industrial applications



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



60 x 60 x 16 cm³



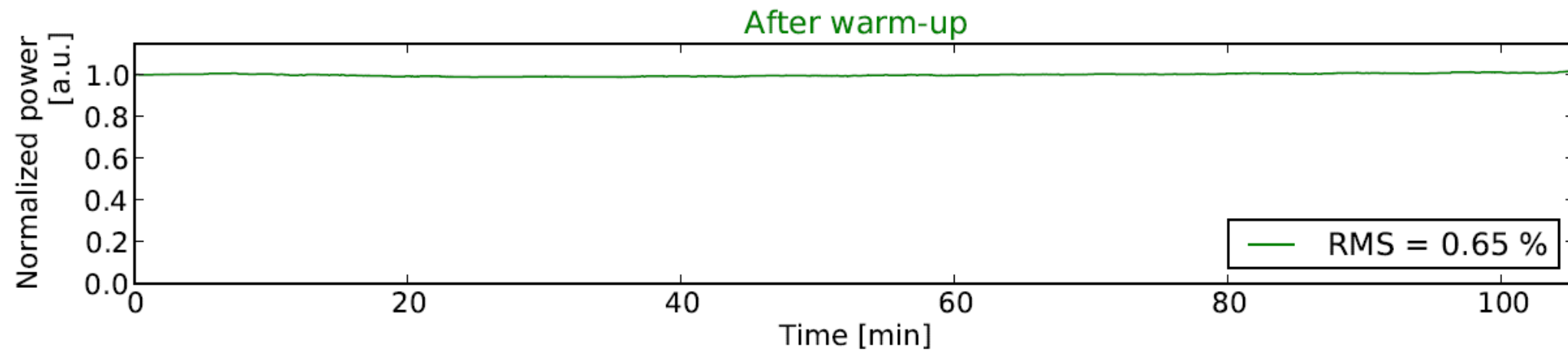
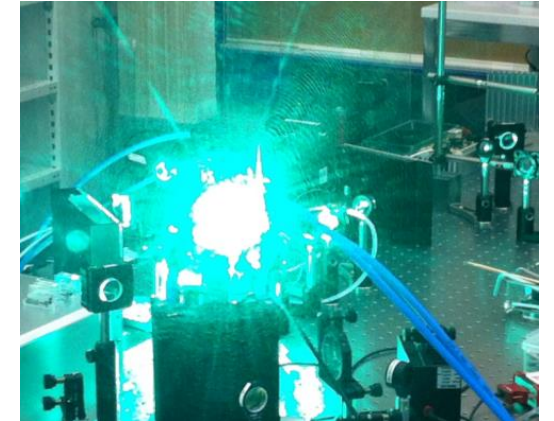
Applications:

- Micromachining
- Glass cutting
- CFRP machining
- Surface structuring

Nonlinear Frequency Conversion

100 W of output power at 515nm

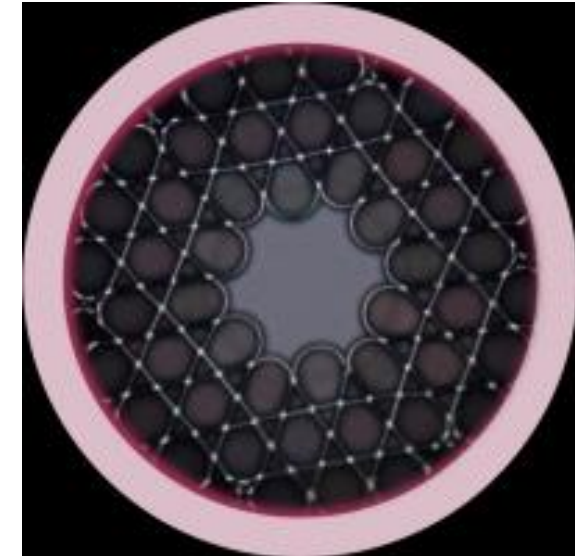
- Frequency conversion of AMPHOS 200 System
 - Output power >100W @ 515nm
 - Repetition rate 400kHz
 - Pulse Energy 250μJ
 - $M^2 < 1.2$
- 2w stage is integrated into laser head



FIBER COUPLING AMPHOS 200

New transportation of ultrashort pulses can drastically improve the flexibility

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



Kagomé type fiber

**Output power after fiber
>200 W at 1 MHz and 1 ps pulse duration**

AMPHOS – Laser Systems

Technical parameters of realized laser systems

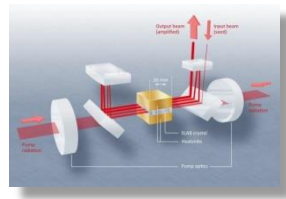


Output Power	Pulse Energy	Repetition Rate	Pulse Duration	Pulse Power	Operation
20.000 W	4 mJ (20 J)	4.5 MHz (10 Hz)	500 ps	8.9 MW	Burst- Mode 10Hz, app. 2ms
5.000 W	50 mJ (5 J)	100 kHz (10Hz)	500 ps	100 MW	
1.500 W	15 mJ	100 kHz(10 Hz)	900 fs	16.5 GW	continuous and burst mode
300 W	3 mJ	100 kHz	900 fs	3 GW	continuous mode
200 W	400 μ J	500 kHz	1.25 ps	320 MW	continuous mode
80 W	8 mJ	10 kHz	1.6 ps	5 GW	continuous mode
10 W	100 μ J	100 kHz	800 fs	120 MW	continuous mode

Outline



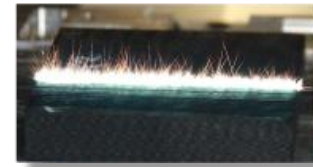
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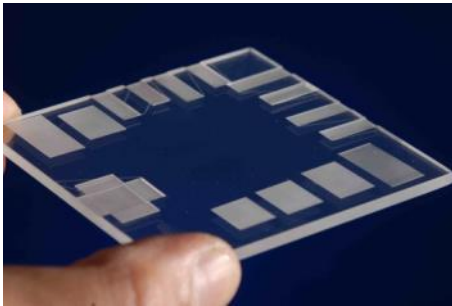


**Summary and
Outlook**

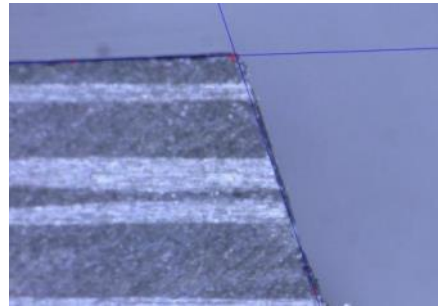
Application Examples

High ablation rate for any material

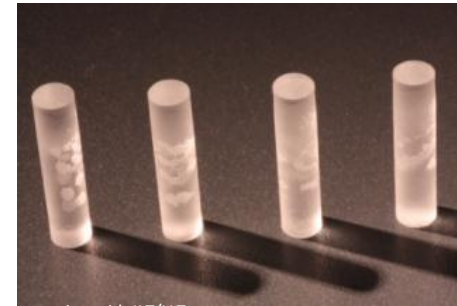
Fused Silica



CFRP Material



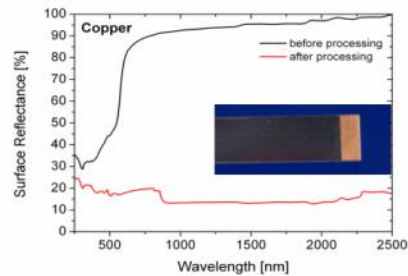
SLE process



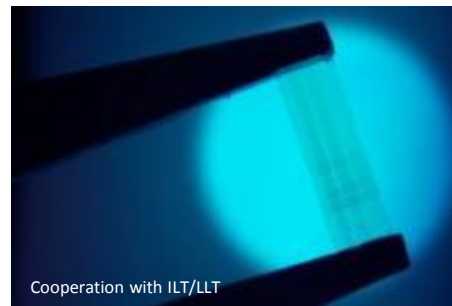
Compound Wafer



Blackening of Metals



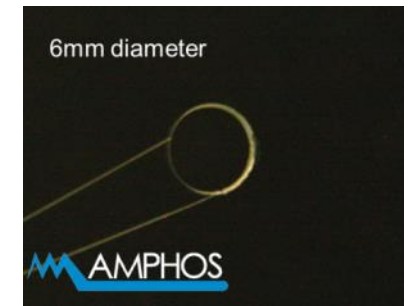
Waveguide



Processing of Metal



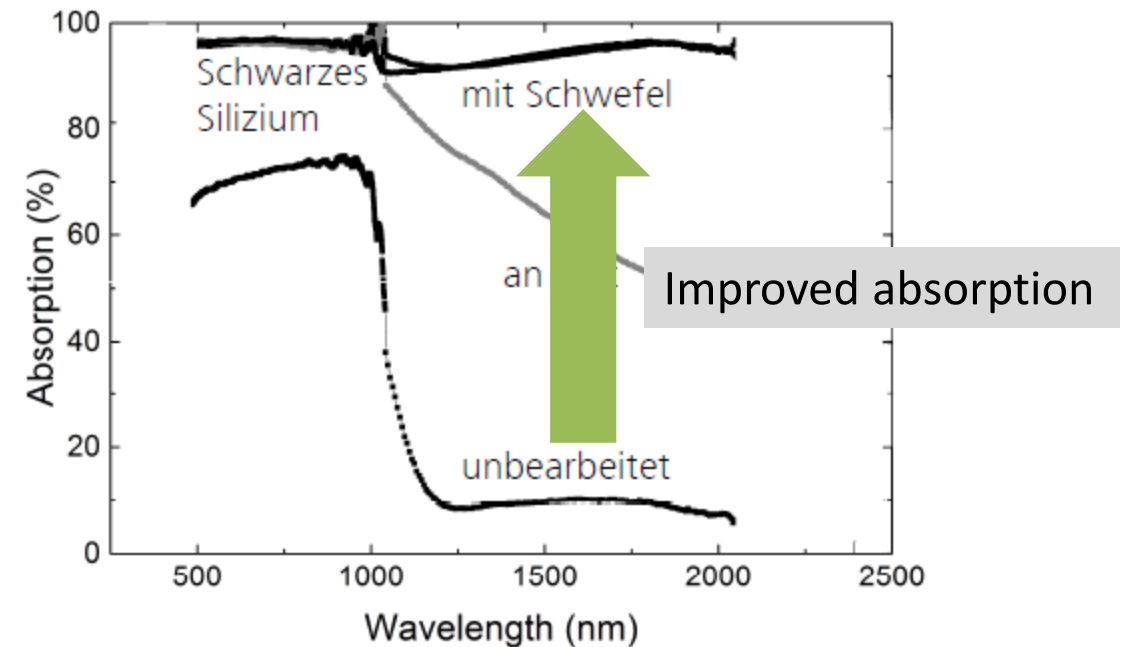
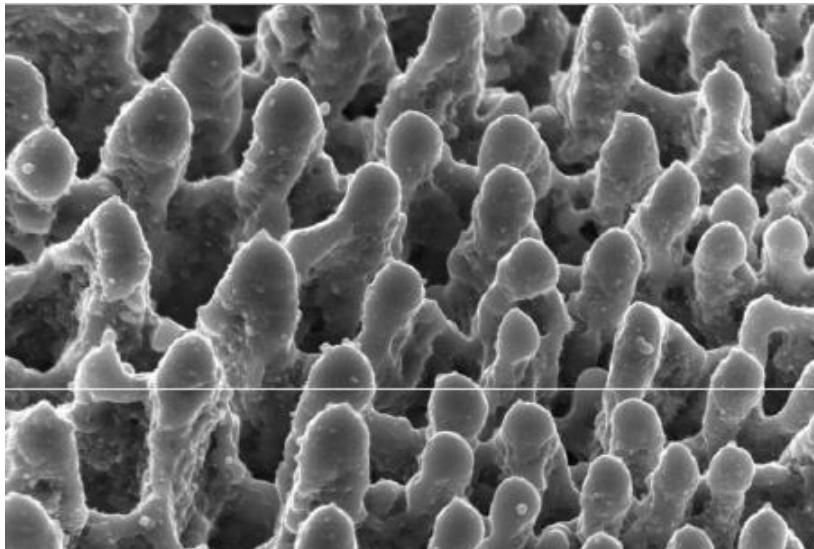
Strengthened glass



Nanostructuring

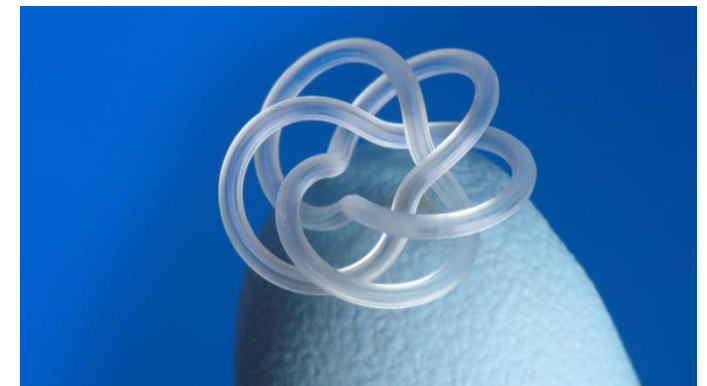
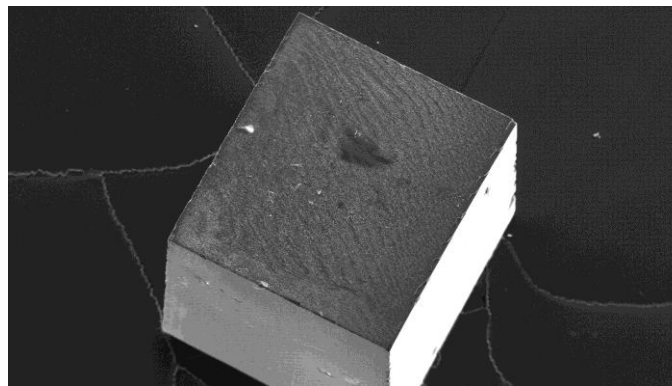
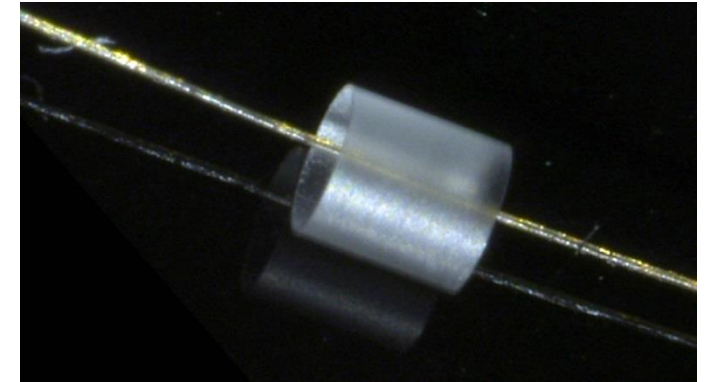
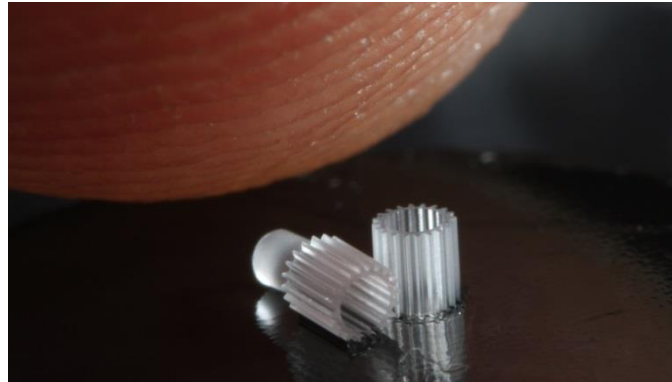
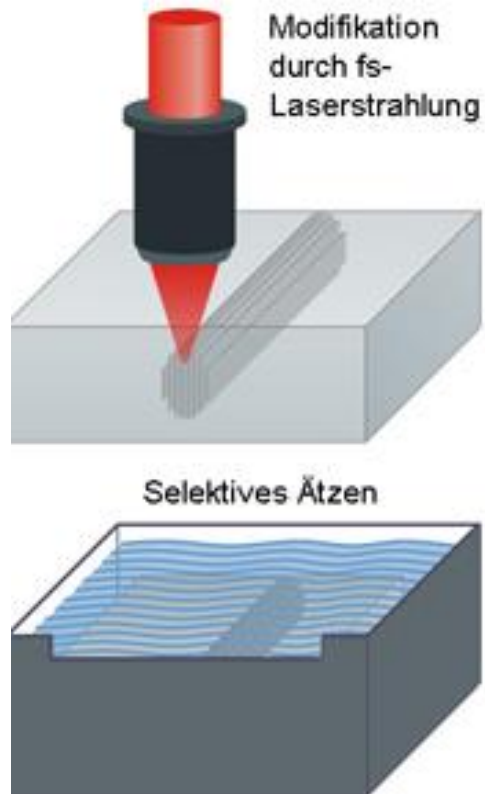
Metal surfaces with tailored properties

- Treatment of Silicon with high average power laser for increasing the absorption („black silicon“)
- Also possible for metals (e.g. Aluminum, Titanium, Steel)
- Further application: changing the wetting property of surfaces (hydrophobic, hydrophilic)
- Process speed: 100's mm² per second



SLE Process

3D printing in glass

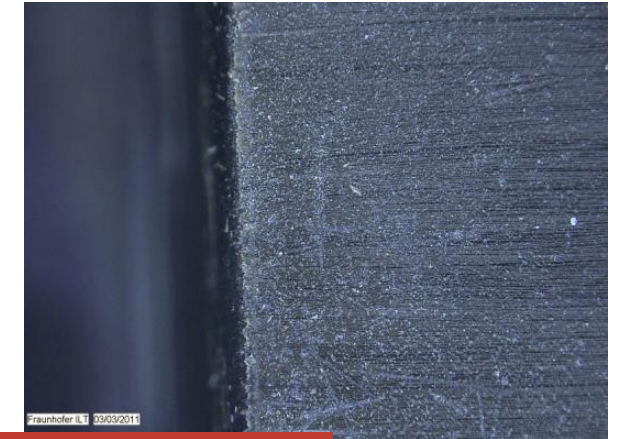
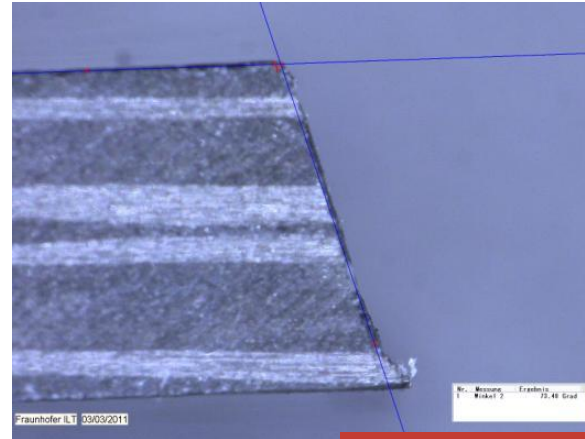
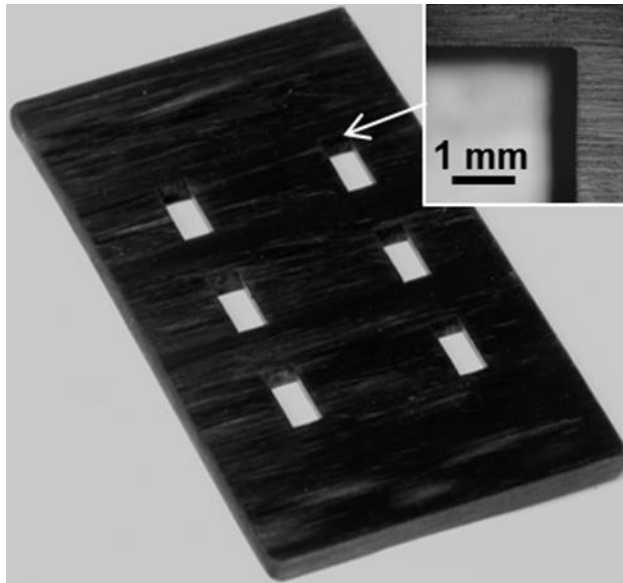


Source: Fraunhofer ILT, Lightfab

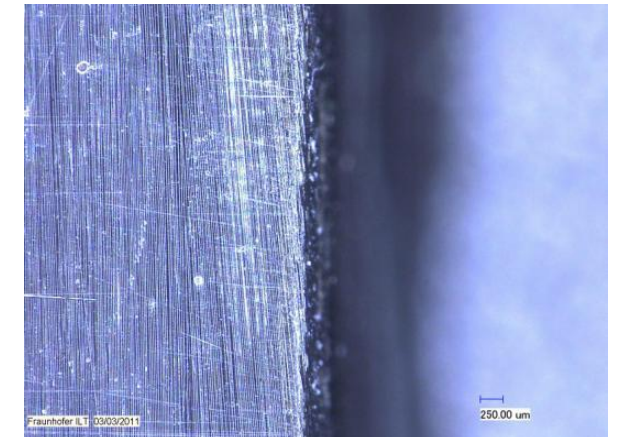
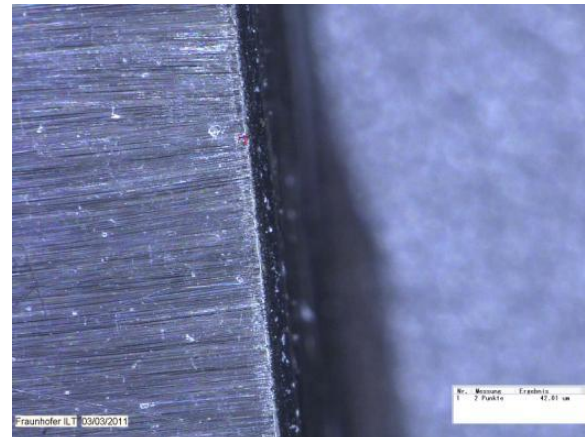
Processing of CFRP Material

Highest quality at highest ablation rate

- ablation of fibres and plastic
- no heat-affected-zone (HAZ)
- highest precision
- high ablation rate



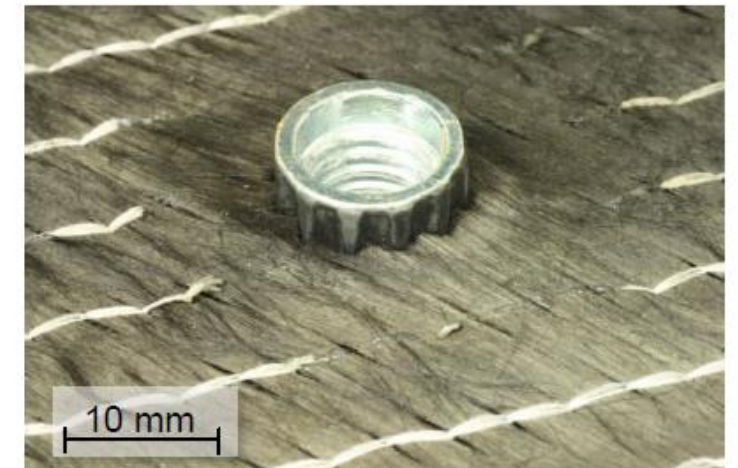
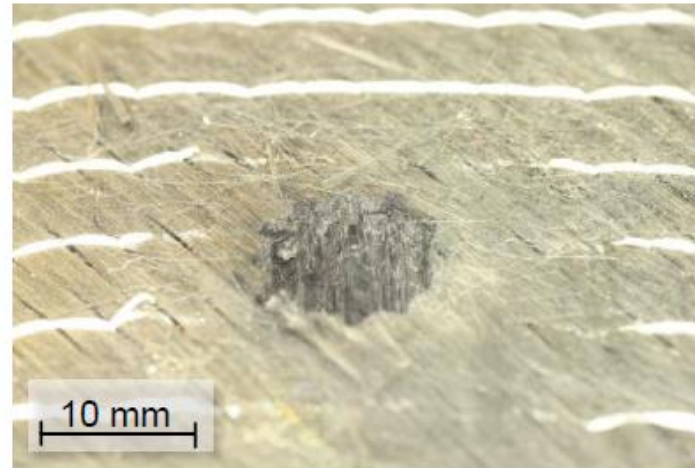
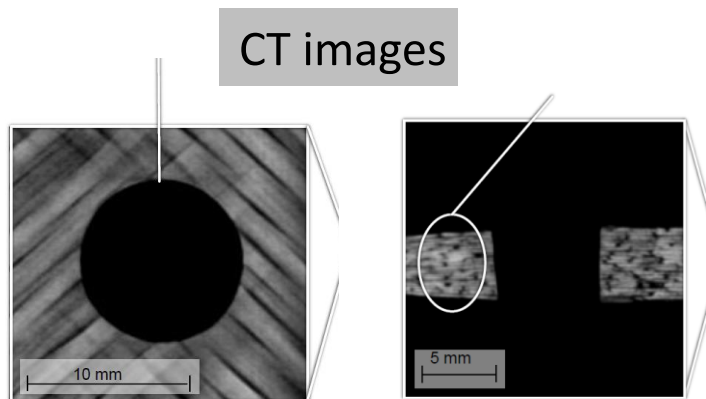
Ablationrate > 2 mm³/s



Processing of CFRP Material

Cutting of Carbon fiber fabric

- Before intrusion of plastic material, the bare carbon fibre fabric can be cut using AMPHOS Ultrafast Laser
- Process is ablation of the material without melting the fiber ends



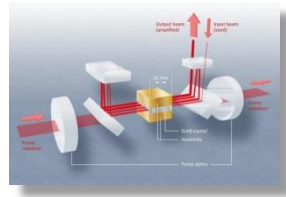
Application:

Force transmission inserts with higher pull-out force (+73% improvement)

Outline



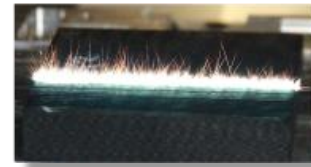
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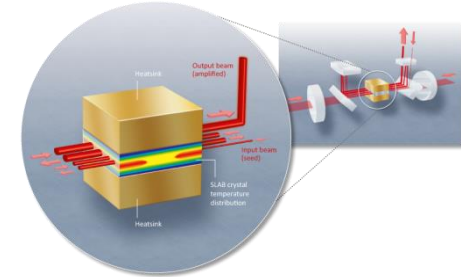
Applications



**Summary and
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Summary and Outlook

- AMPHOS is technology leader in High Average Power Ultrafast Lasers
- InnoSlab amplification technology using a Yb:YAG allows for highest output power in the Ultrafast regime
 - multi 100W output power
 - up to mJ pulse energy
 - 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 – all applications and products benefit from those outstanding properties

THANK YOU



Lasers are ready for applications!

... how much can we improve your process?

... 5x ? ... 10x ? ... 100x ?