Status of HiLASE project

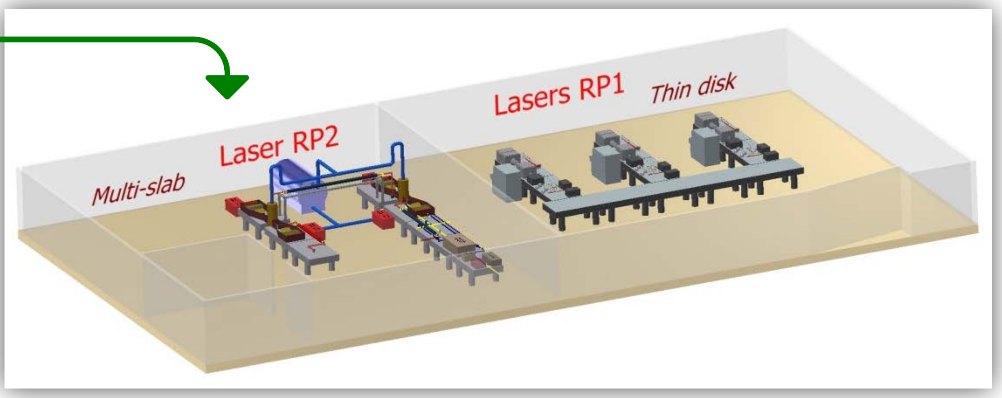
Tomáš Mocek
Chief Scientist & Project Manager

CZ.1.05/2.1.00/01.0027

Synopsis

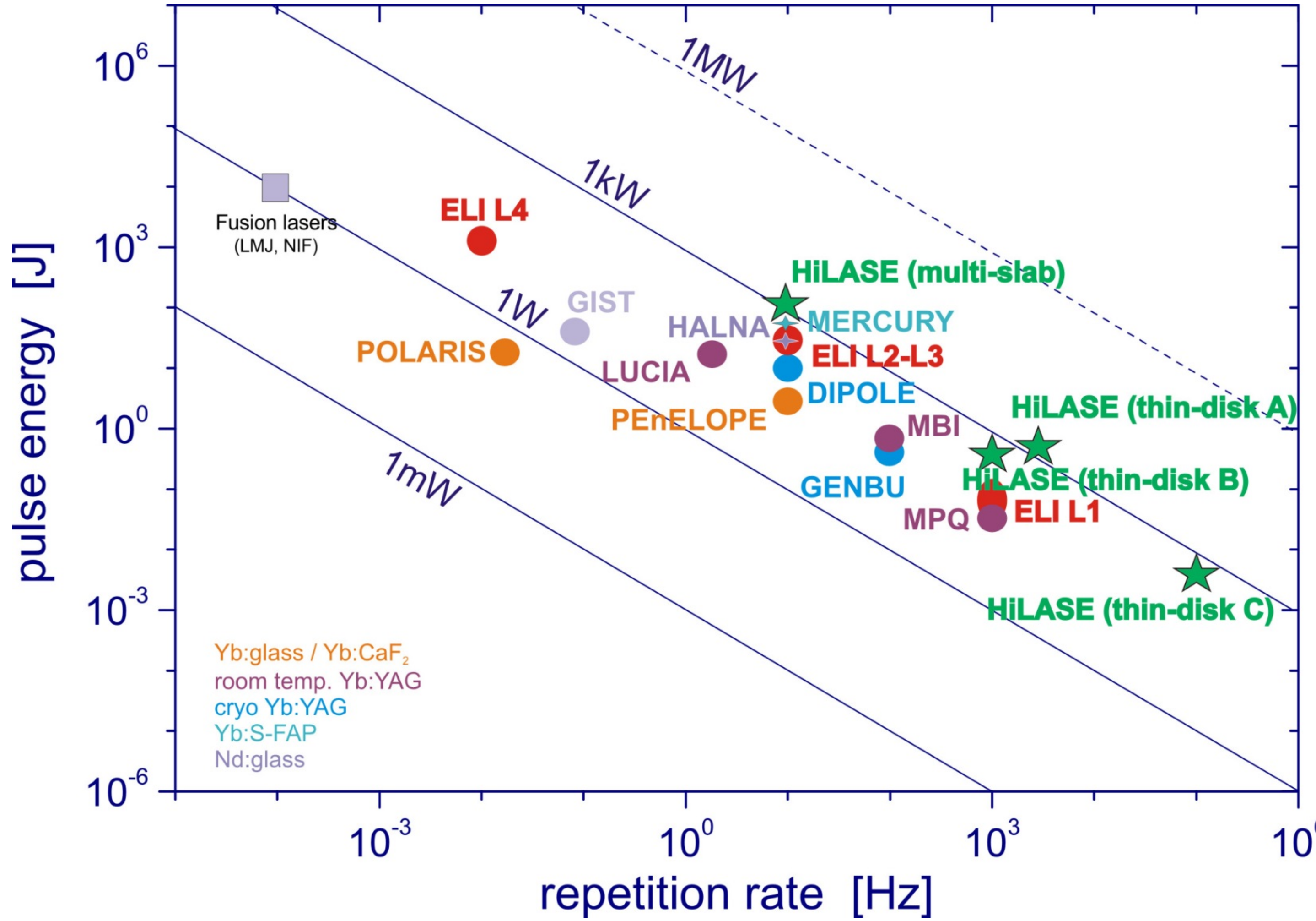
- Project led by the Institute of Physics
- Financed by the Research and Development for Innovation Operational Program (ERDF)
- Research center of international importance
- Applications of DPSSL in high-tech industry
- Lasers with breakthrough parameters
- Synergy with ELI Beamlines

Future HiLASE building



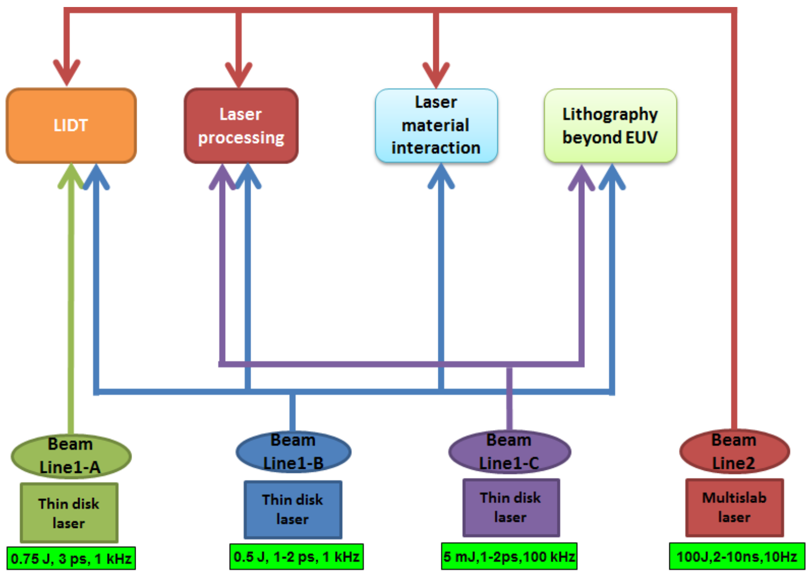
Laser technologies

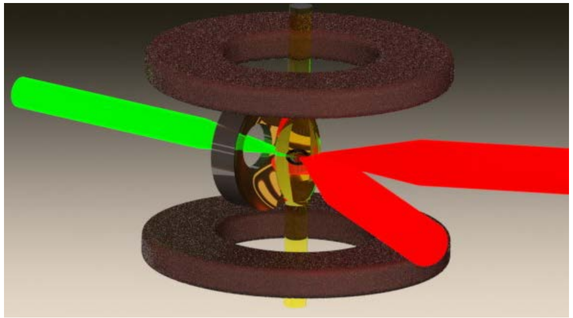
Aiming very high



High-tech industrial applications

- Laser induced damage threshold measurement of optical materials
- Laser shock peening
- Compact X-ray sources for lithography
- Precise cutting, drilling and welding of special materials for automotive and aerospace industry
- Technology of laser micromachining
- Laser paint stripping, surface cleaning





In line with current trends in Europe

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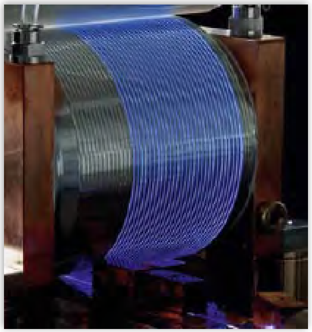
TOWARDS 2020 – PHOTONICS DRIVING ECONOMIC GROWTH IN EUROPE

Multiannual Strategic Roadmap 2014–2020

PHOTONICS21

Left: 3D laser cutting. © TRUMPF

Right: Thin-disk, laser-pumped, high-brightness fibre laser developed at the IFSW for material processing applications. © IFSW, University of Stuttgart



Therefore, more efficient lasers and new photonic components will be needed, including:

- high brilliance diode lasers (output power >20W per emitter) with improved energy efficiency and beam quality
- ultra high power (>1kW), ultra short pulse (fs-ps), visible and near IR lasers
- highly efficient and long term stable UV/EUV lasers (solid state)
- cw UV direct imaging (with 100W)
- 'fully tunable' laser (pulse width tailored to the application and variable in wavelength – UV to visible to MIR)
- efficient mid-infrared laser with output power up to 1kW (e.g. 1.5–1.9 µm / 2.6–4 µm for organic materials/polymers)
- industrial MIR systems
- coatings and components (e.g. gratings, isolators) for high power/high intensity beams
- non-linear transparent materials (crystals, ceramics) for high power/high intensities (and short/UV wavelengths)
- fast modulation capability provided in conjunction with high speed scanning devices (for synchronisation)

In the drive for higher product quality, further development and production implementation will be needed for beam delivery and control, process monitoring, adaptive control of the laser manufacturing process, and quality inspection of laser manufactured goods. Aspects of integrating laser sources within machine tools, in particular robotic manufacturing tools, will also require optimisation and standardisation. This will require that the following technological challenges be addressed for beam delivery, shaping and deflection systems:

- remote technologies
- connectors and integrated beam switches
- monitored high power connectors
- diffraction limited fibre delivery of output power >1kW over a distance of 100m
- laser arrays, multiple fibre arrays, and fibres for transport of ultra-short/energetic pulses
- precise beam deflection with a target speed of 1km/s (at the work piece)
- dynamically reconfigurable intensity distributions for advanced thermal management of laser processes e.g. for welding or soldering
- new electro optic materials, beam delivery systems, and fast electronics and data processing
- standardised modular systems

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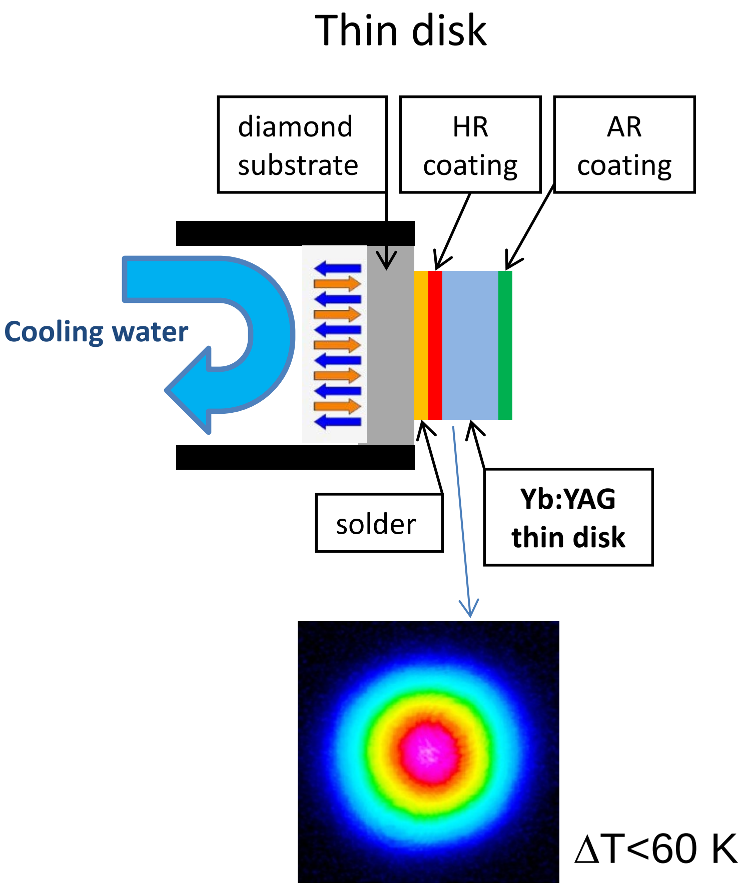
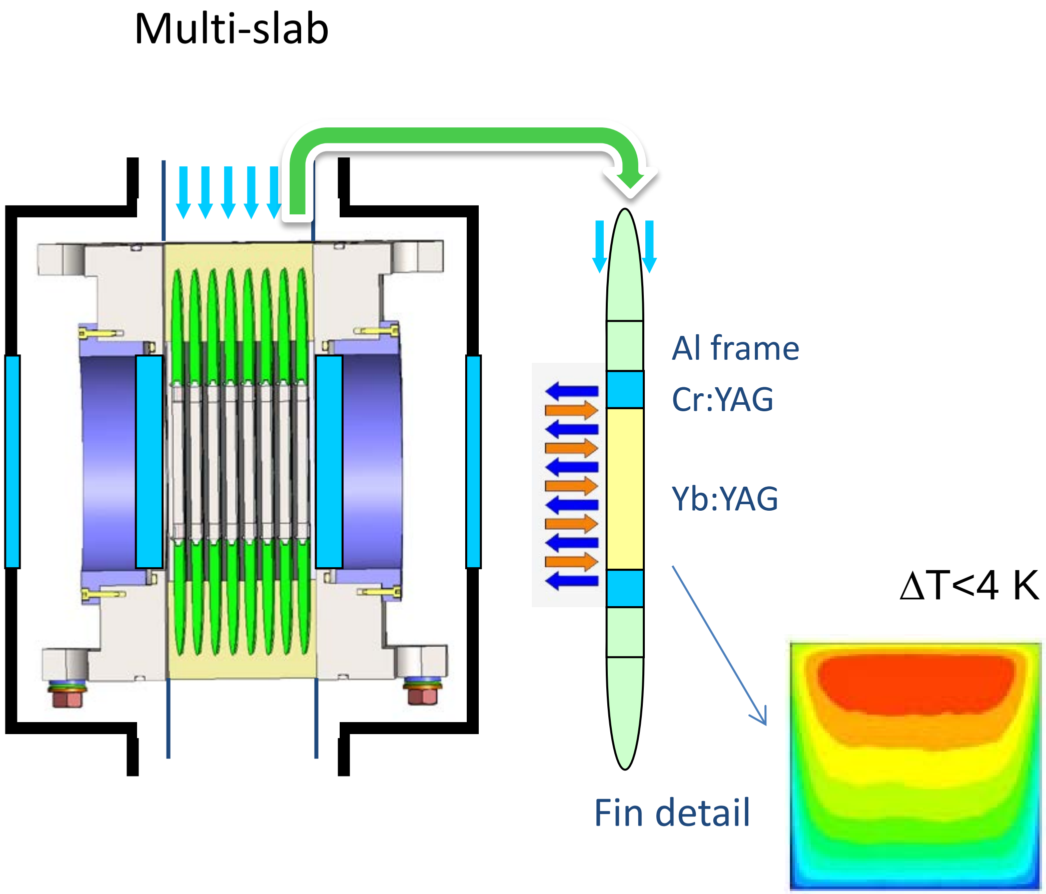
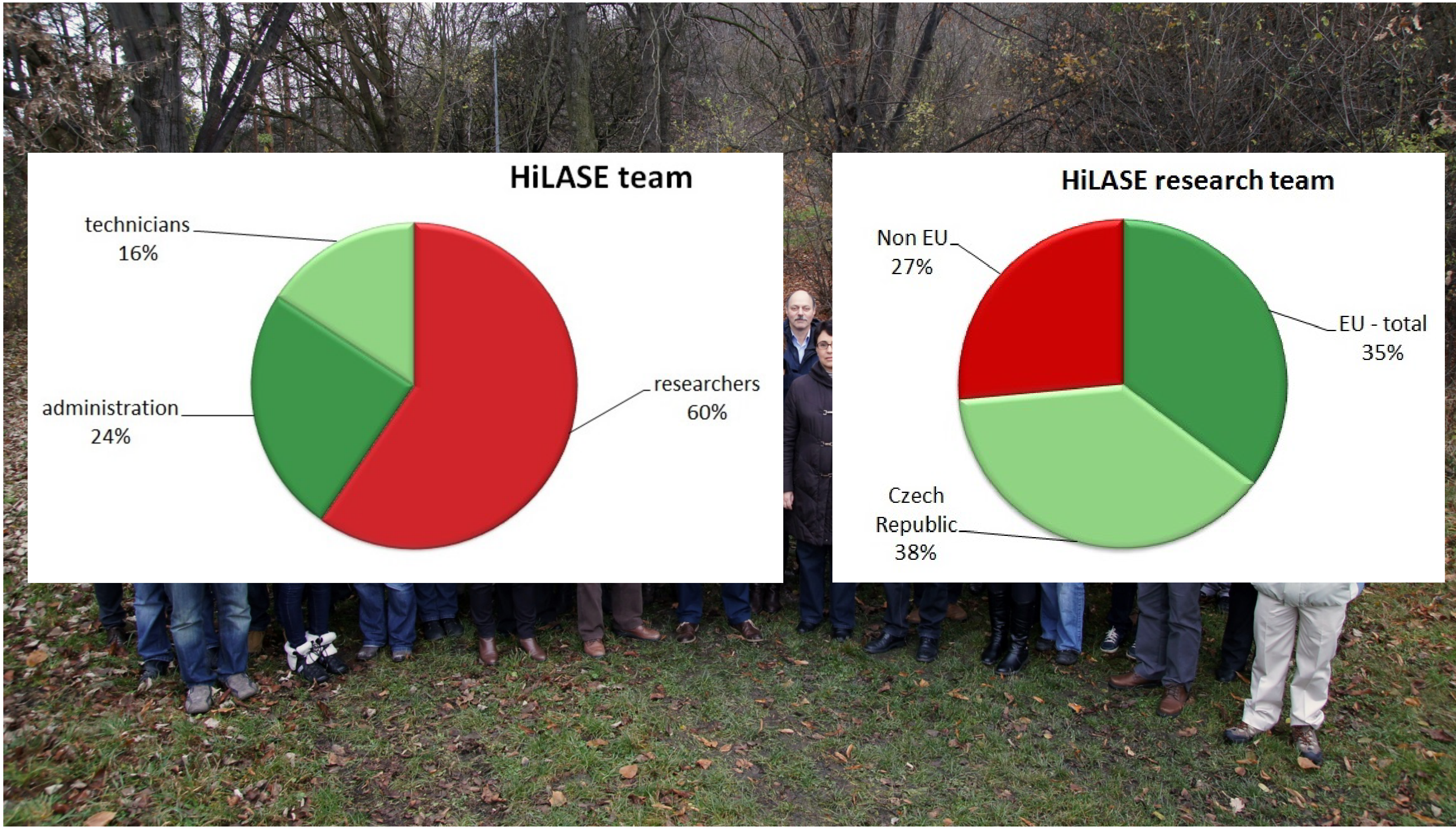
Upscaling novel geometries





International Team



Time schedule: 18 months ahead

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09 / 2011
Decision on grant

10 / 2011
Start of procurement and in-house R&D of key laser systems, incl. construction

09 / 2012
Start of construction of new building

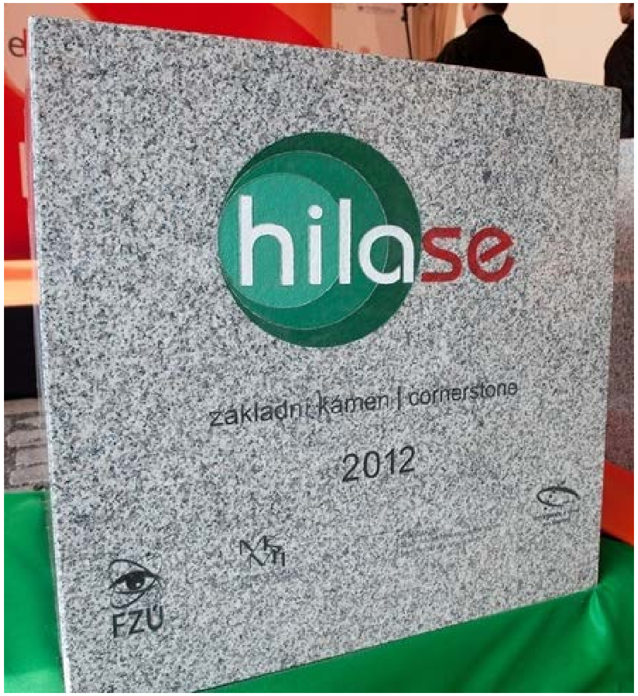
01-03 / 2013
Signing contracts for key laser systems

03-06 / 2014
End of construction, relocation from Prague to Dolní Břežany

01-08 / 2015
Installation and optimization of key laser systems

09 / 2015
Commissioning of HiLASE R&D Centre

HiLASE Cornerstone laying ceremony



October 9, 2012

Progress of construction: 12/2013

Visit of EU Commissioner for Research, Innovation and Science

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October 18, 2013

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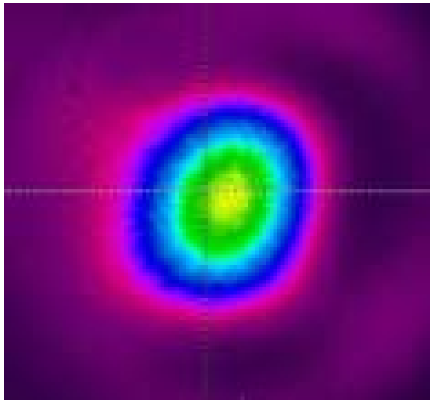
02/2014: Mid-term Review

Ready to move

March 25, 2014

Research Programme 1

Development of multi-J, kW class thin-disk laser system (L1)



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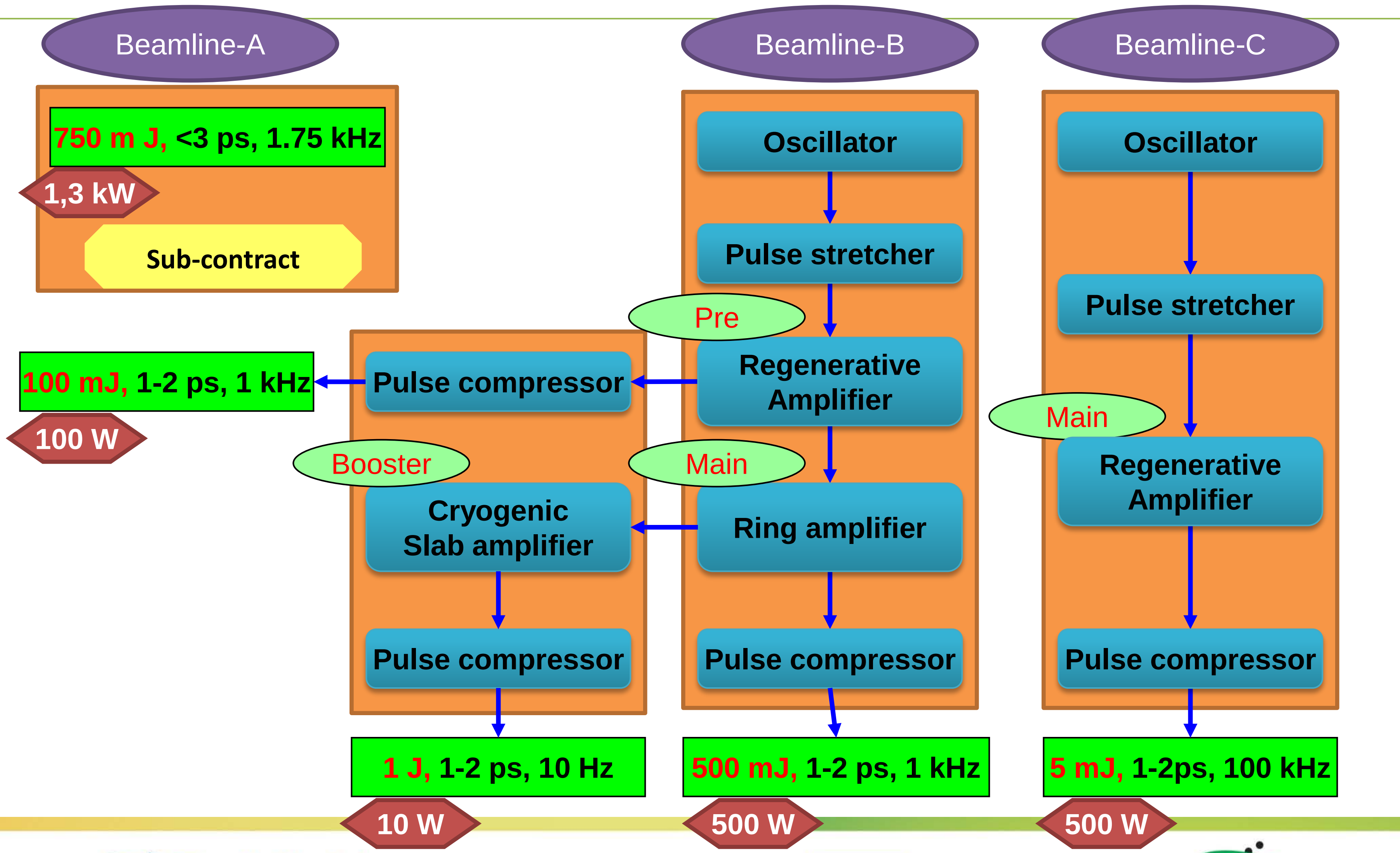
Concept of kW-class thin-disk DPSSL



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Applications of our thin-disk lasers

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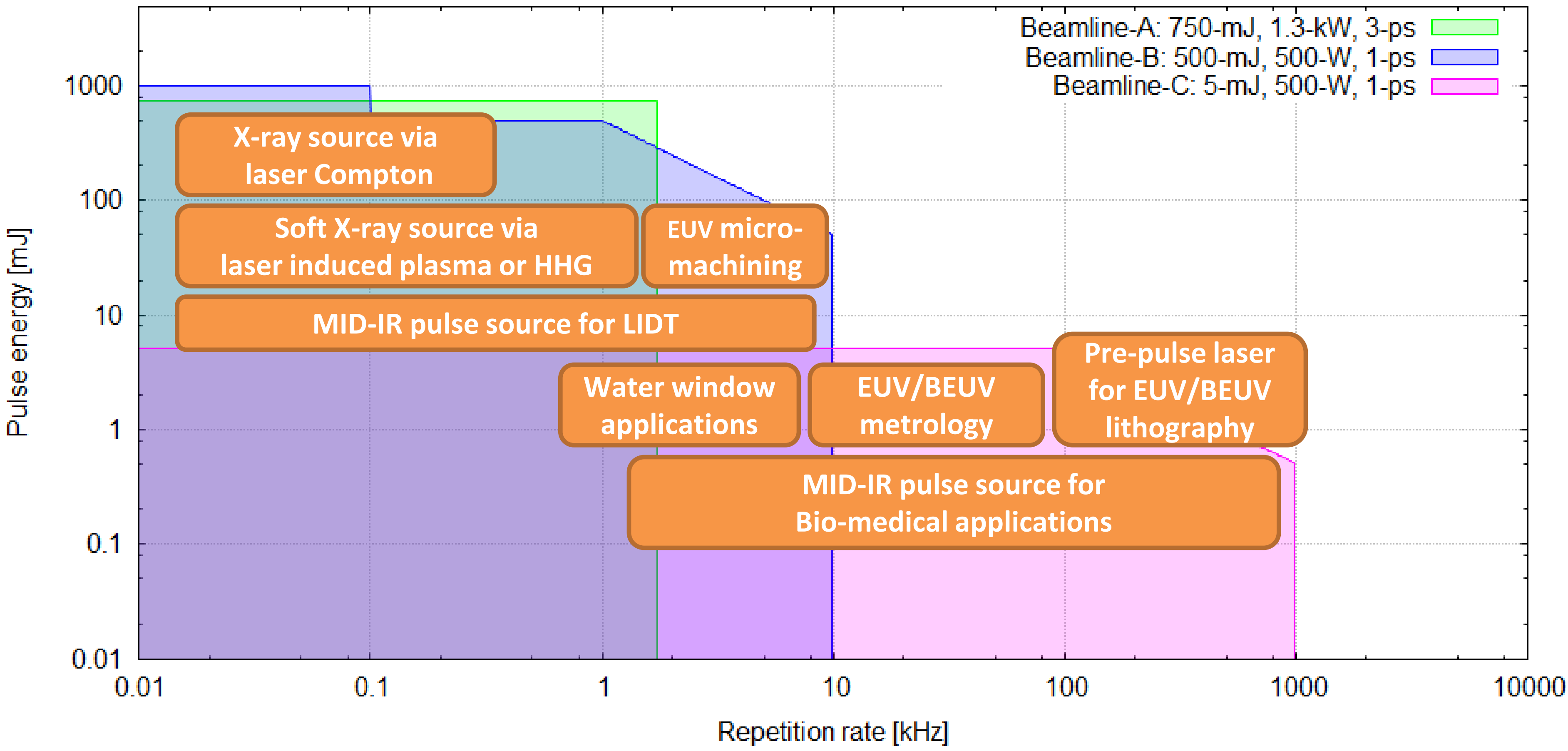

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Design of new EUV source

➢Continuous dense gas jet target

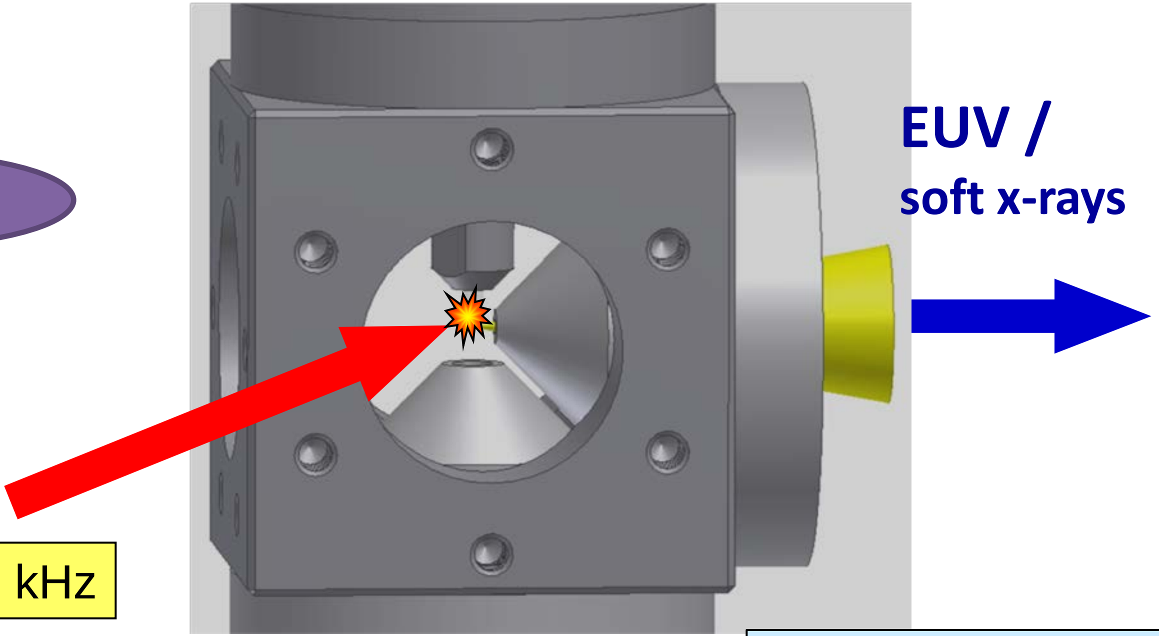
Xe, Kr, N_2

Differential pumping

Beamline B

ps laser

500 W



EUV /

soft x-rays

0.5 J, 1-2 ps, 1 kHz

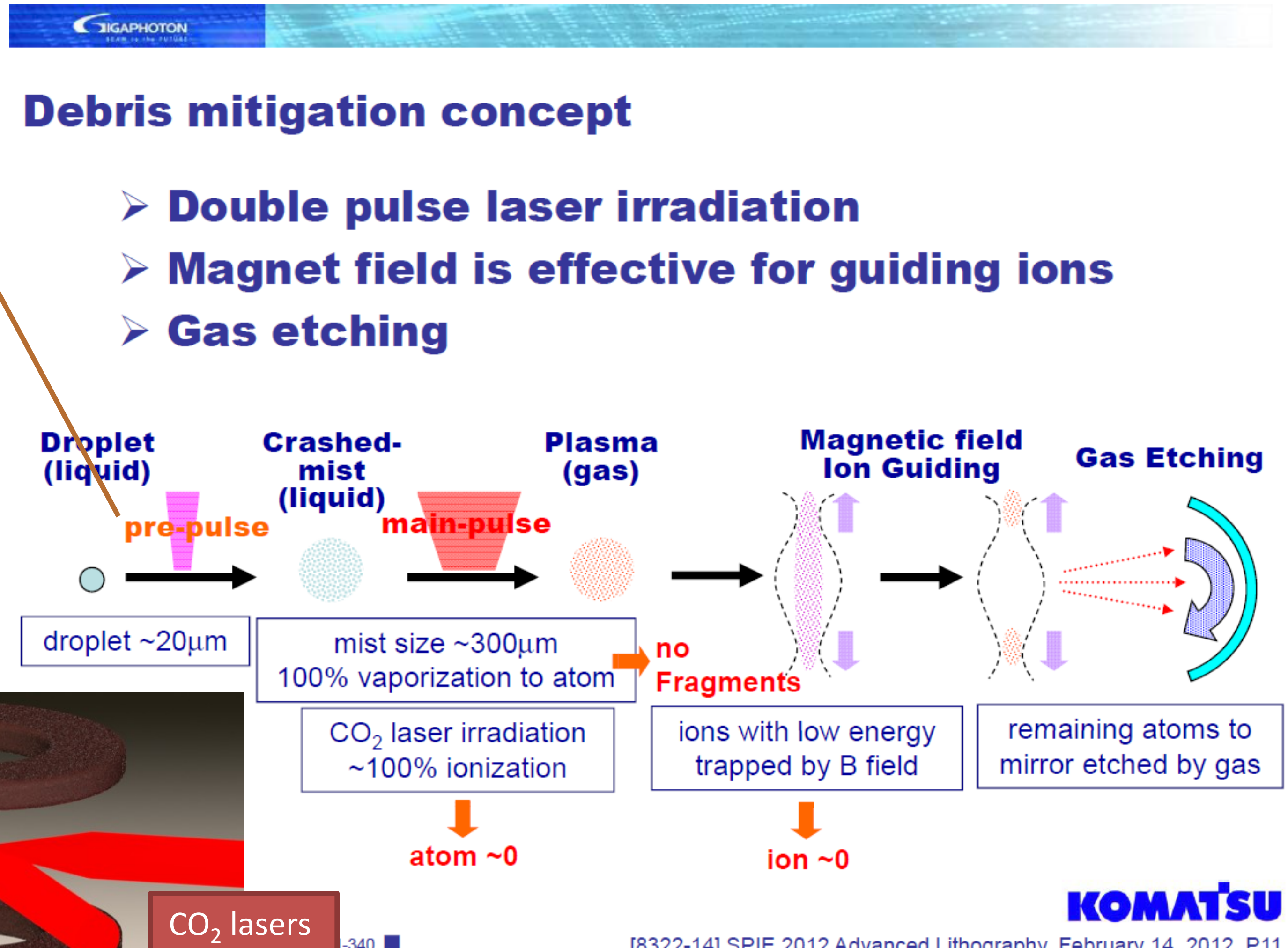
(0.5J, 8ns, 5Hz)

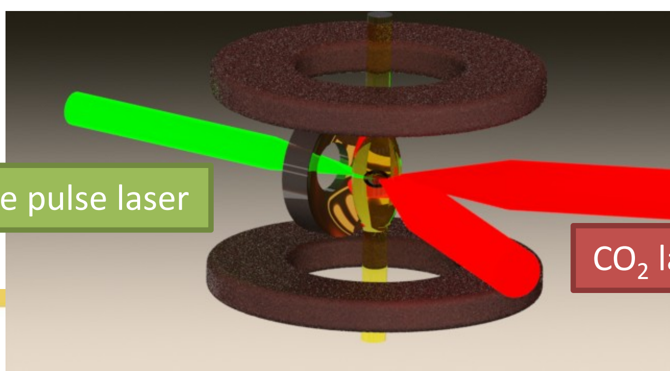
➢high brilliance
➢low debris

Pre-pulse Laser for HVM EUV Lithography

- Solid-state laser
- 3.3 mJ
- 150 kHz
- (500 W)
- <10 ps

Beamline C





Beamlines L1-B/C in progress

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100% In-house development

High Energy Regenerative Amplifier With pulsed zero-phonon-line pumping

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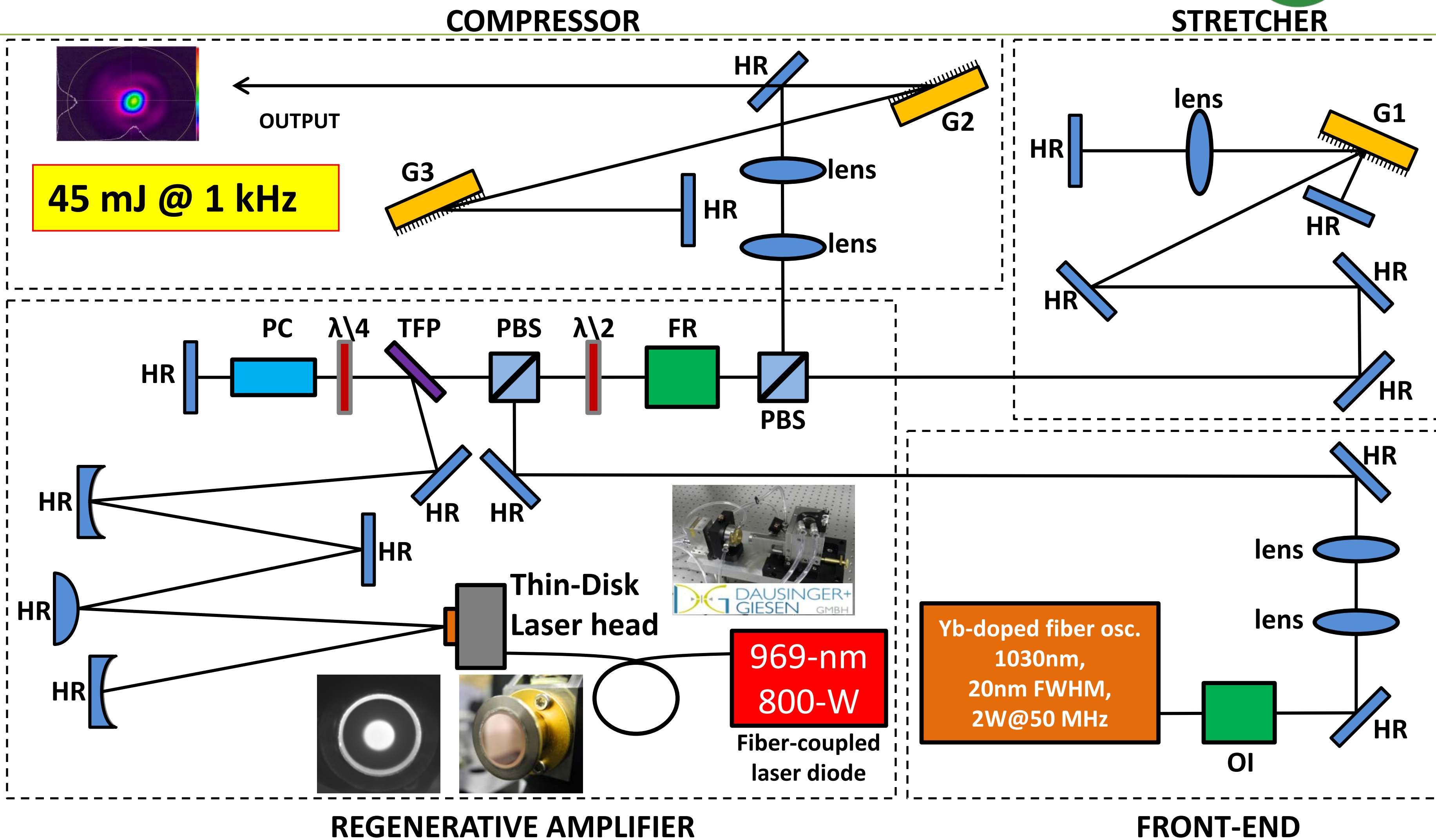

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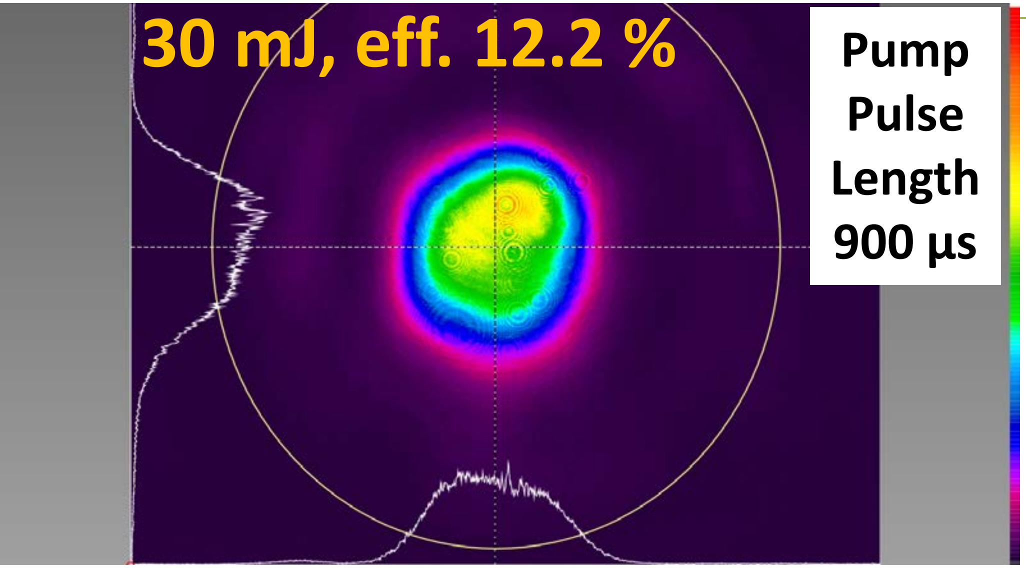
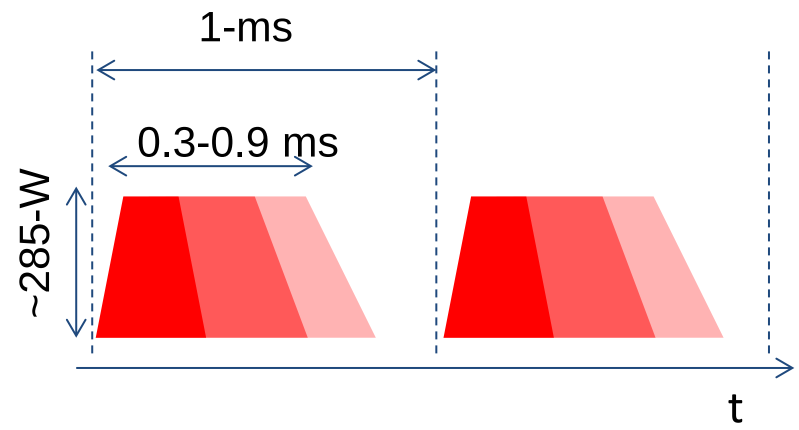
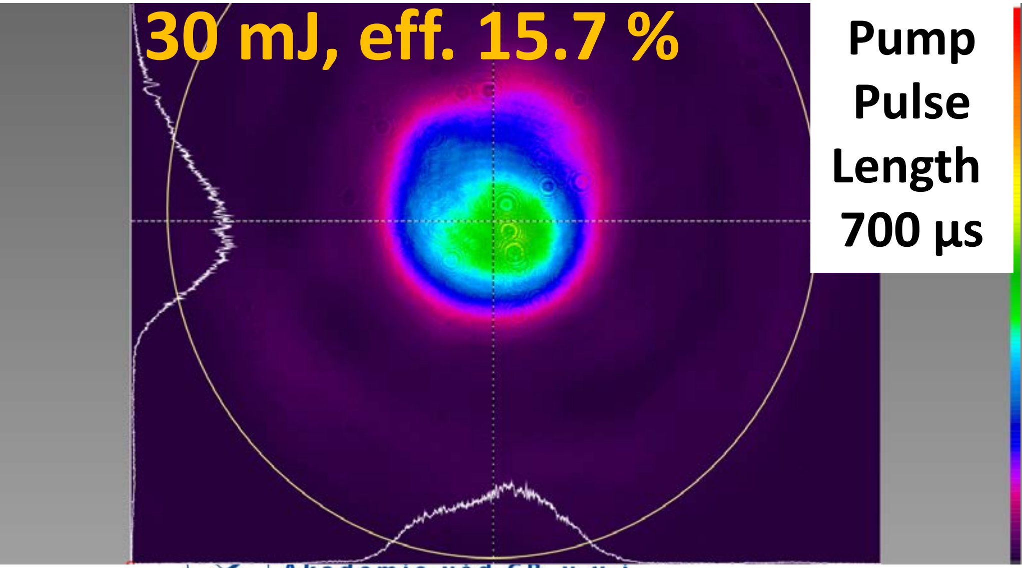
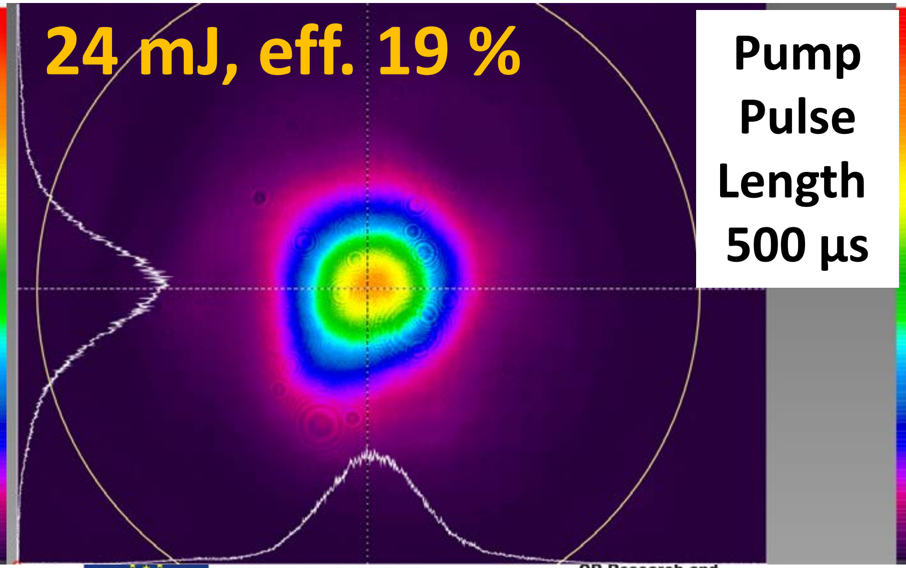
940-nm Pulsed Pumping in 1-kHz Regenerative Amplifier









969 nm vs. 940 nm pulsed pumping

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March 15, 2014 / Vol. 39, No. 6 / OPTICS LETTERS

Optimization of beam quality and optical-to-optical efficiency of Yb:YAG thin-disk regenerative amplifier by pulsed pumping

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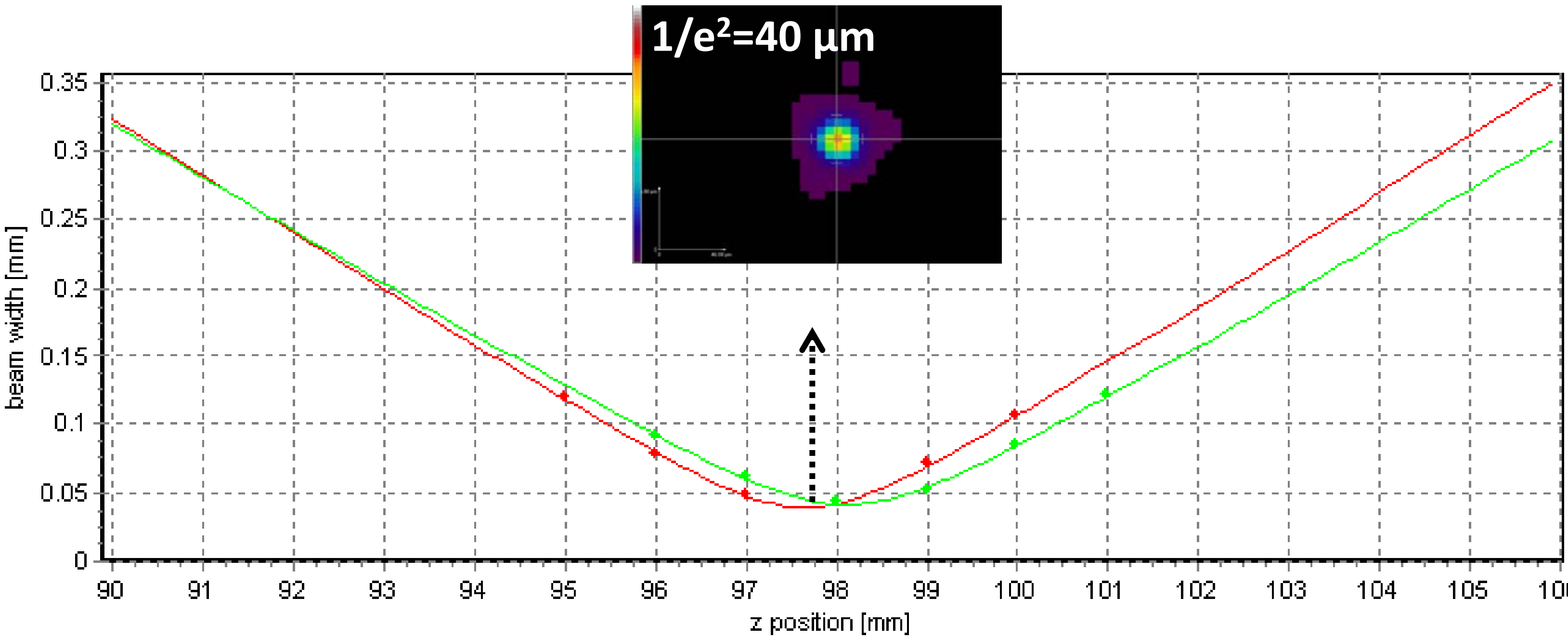
posted January 31, 2014 (Doc. ID 203036); published 0 MONTH 0000

We demonstrate an optimization method of beam quality and optical-to-optical (O-O) efficiency by using pulsed pumping. By changing the pulse duration and the peak intensity of pump pulse at the repetition rate of 1 kHz, the beam quality and O-O efficiency of the Yb:YAG thin-disk regenerative amplifier can be improved. We applied this method to the regenerative amplifier under the pumping wavelength of both 940 and 969 nm, and found that the method was effective in both pumping wavelengths. Although a Yb:YAG thin disk soldered on a copper tungsten heat sink, which has poor thermal properties compared with a thin disk mounted on a diamond substrate, was applied as a gain media, we obtained 45 mJ output with 19.3% O-O efficiency and nearly diffraction-limited beam.

OCIS codes: (140.3280) Laser amplifiers; (140.3480) Lasers, diode-pumped; (140.3580) Lasers, solid-state; (140.3615) Lasers, ytterbium; (140.5560) Pumping; (140.3538) Lasers, pulsed.

http://dx.doi.org/10.1364/OL.99.099999

M^2 measurement of HERA



M^2	
Horizontal	Vertical
1.25	1.23

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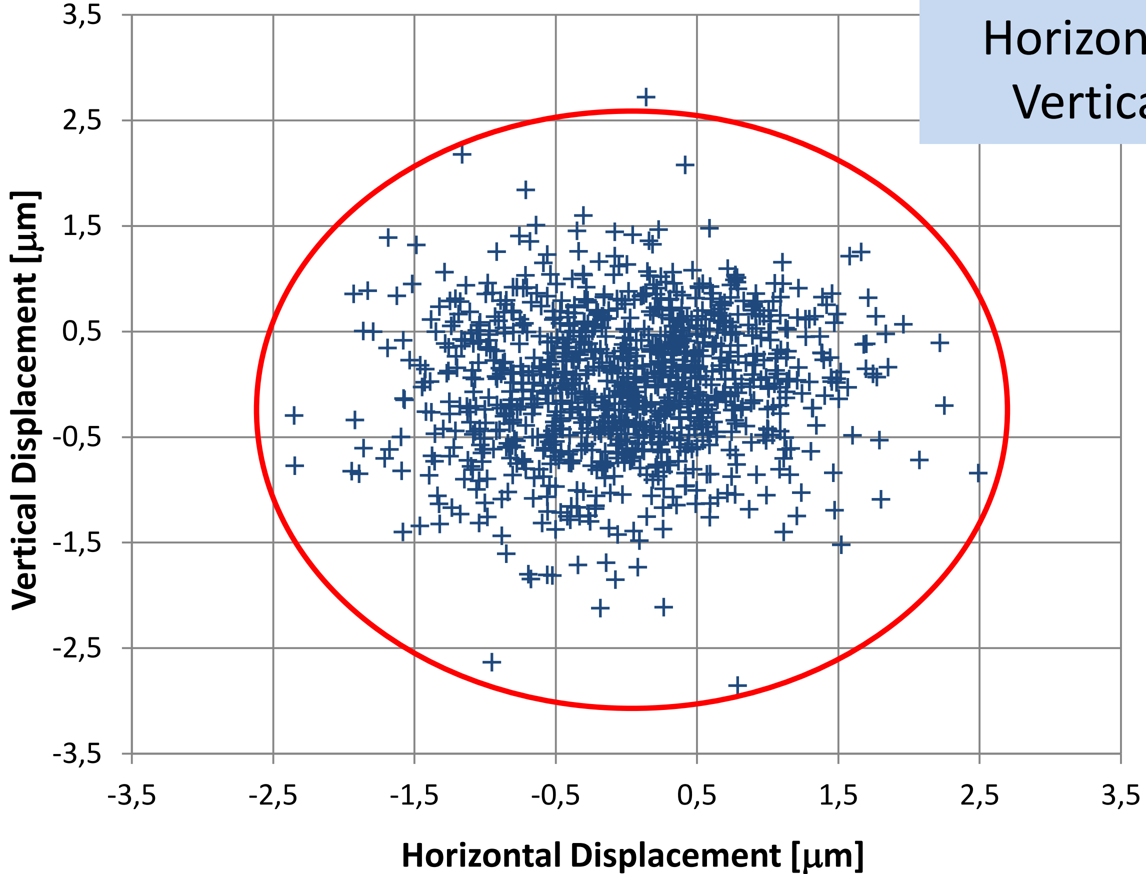
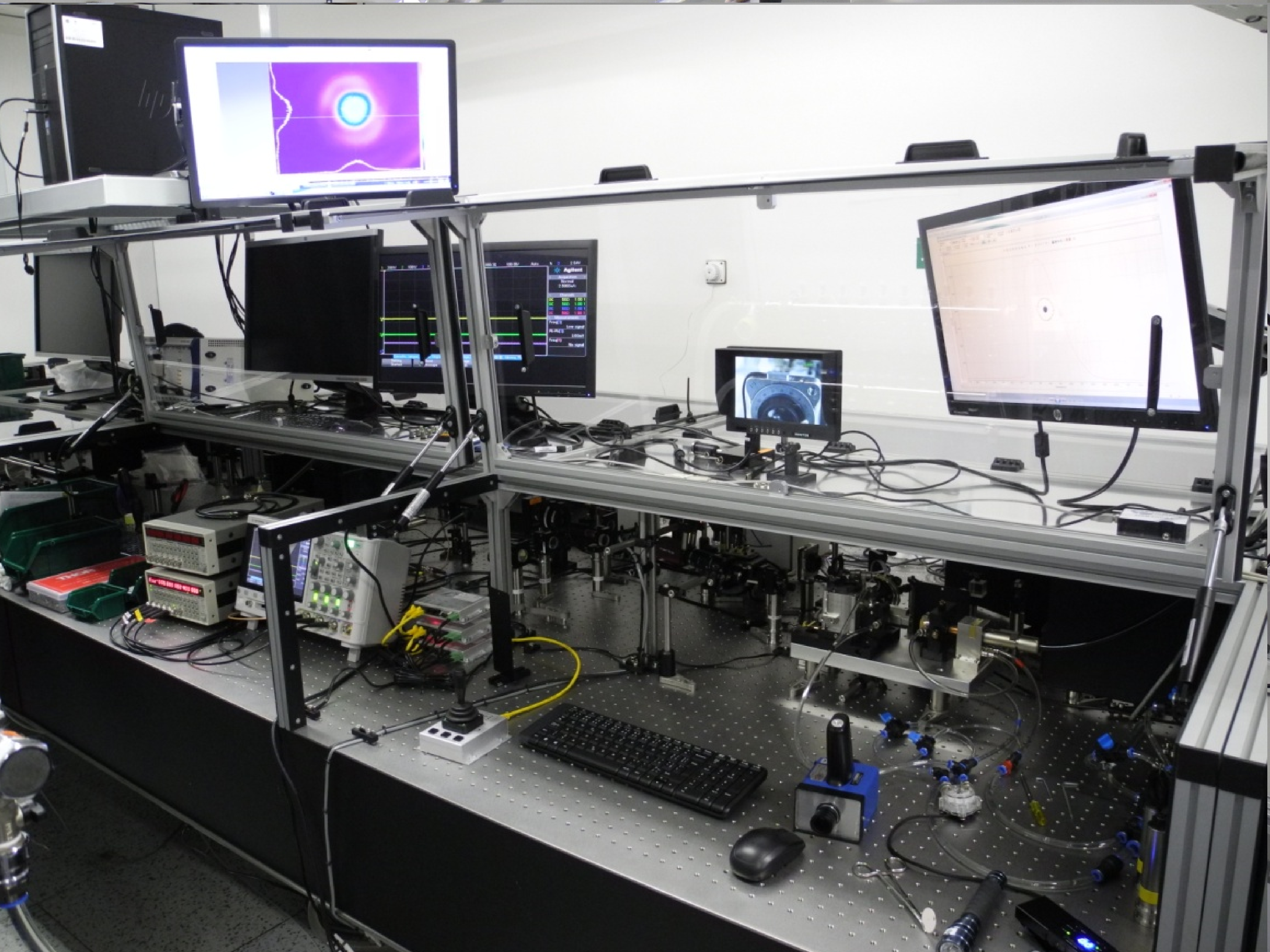
Beam pointing stability

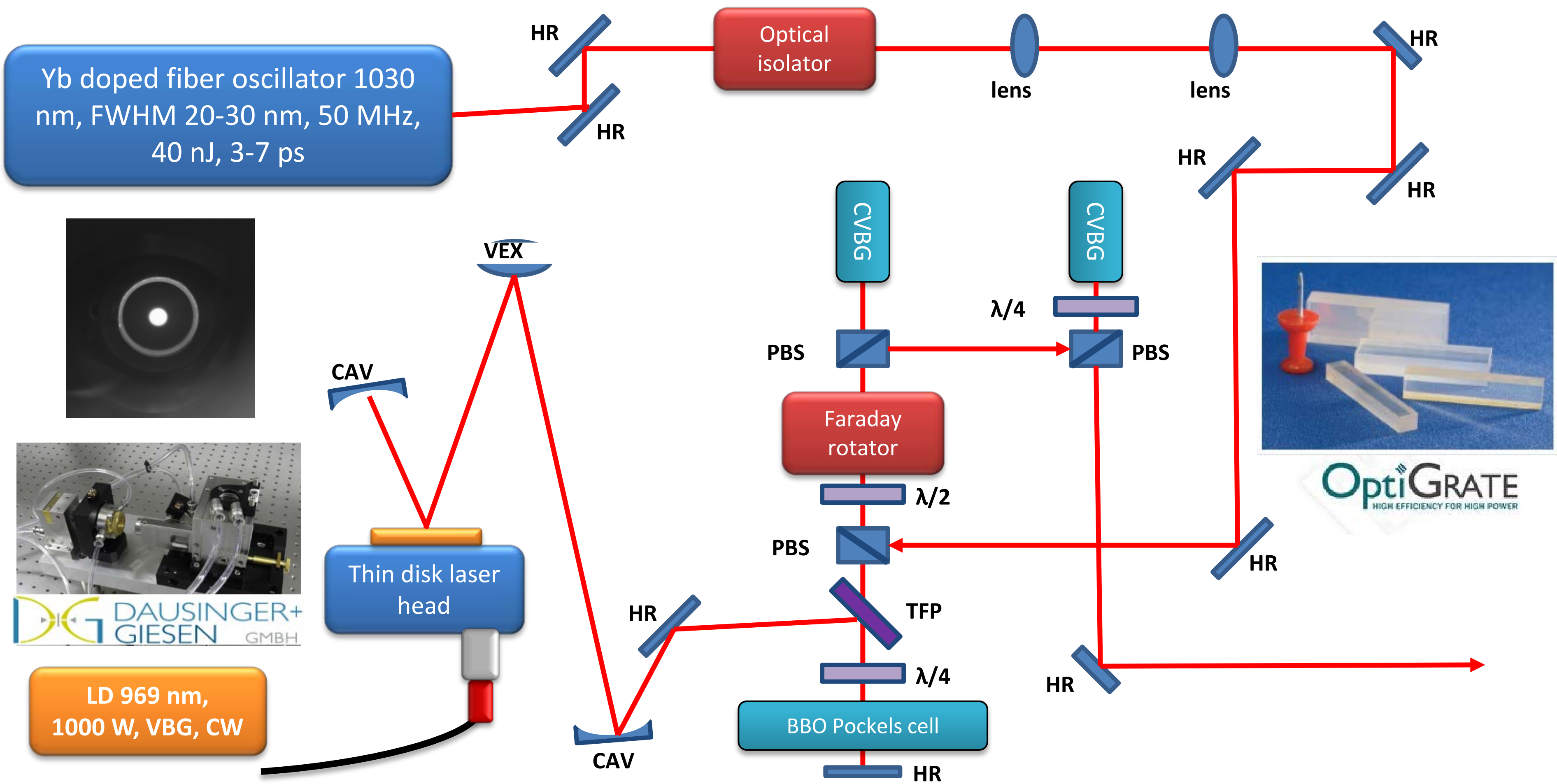
RMS pointing stability:
Horizontal- **3.8 μrad**
Vertical- **3.3 μrad**



Measurement time: **15 min**


Agilent

L1-C concept



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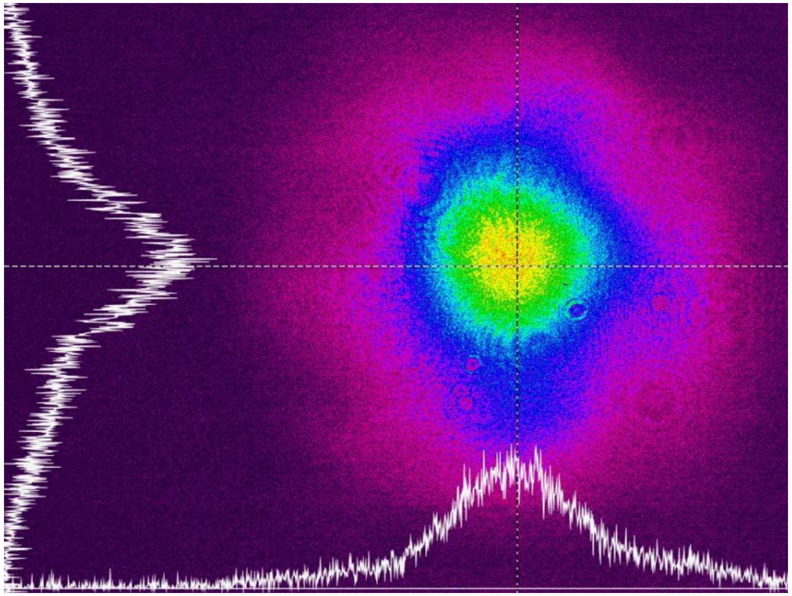
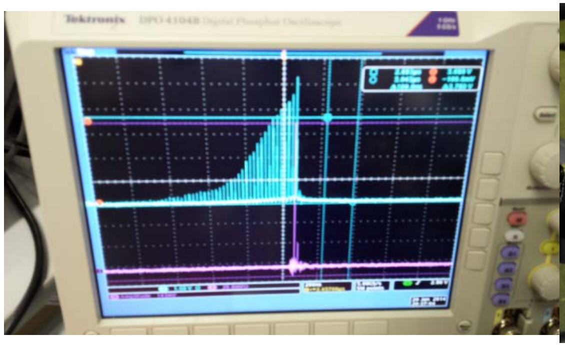
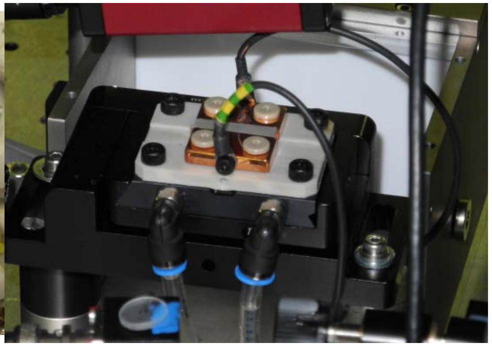
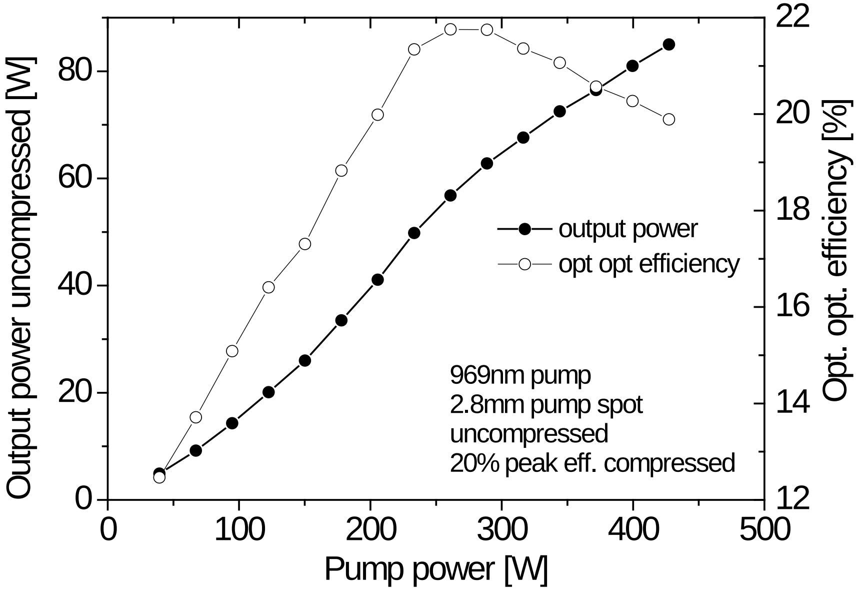
85 W achieved in pulsed regime



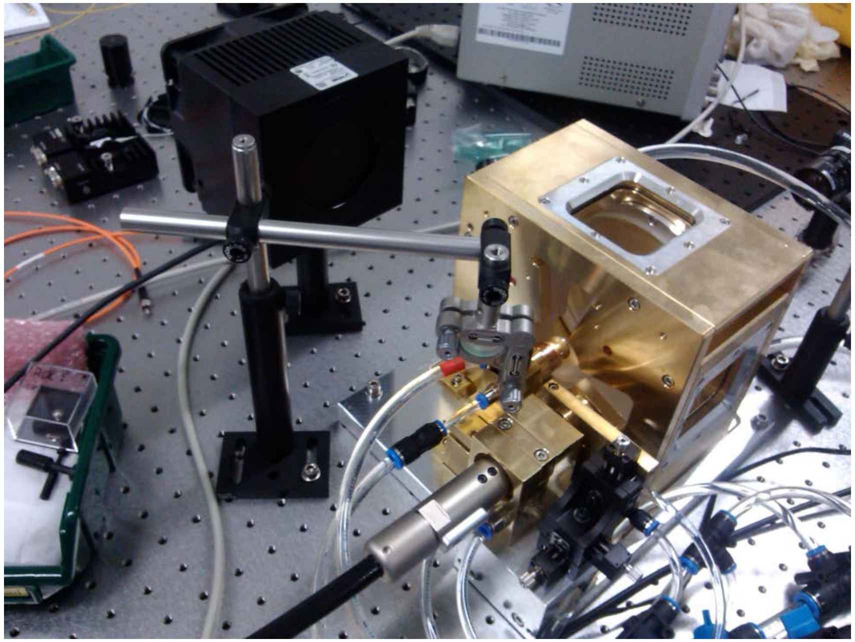
-22% opt.opt. efficiency (uncompressed)
-20% opt. opt. eff. Compressed (estimate)
-85W operation (before compression)
-measured for 15C water cooling
-BBO Pockels cell (7.2kV QW voltage, 100kHz)







High power upgrade components



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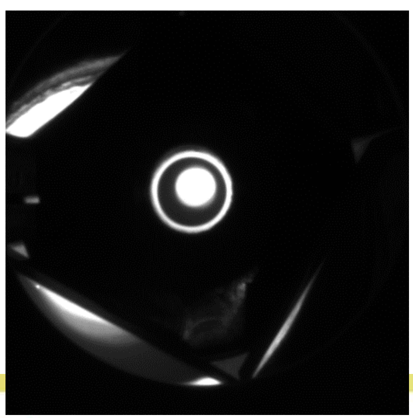
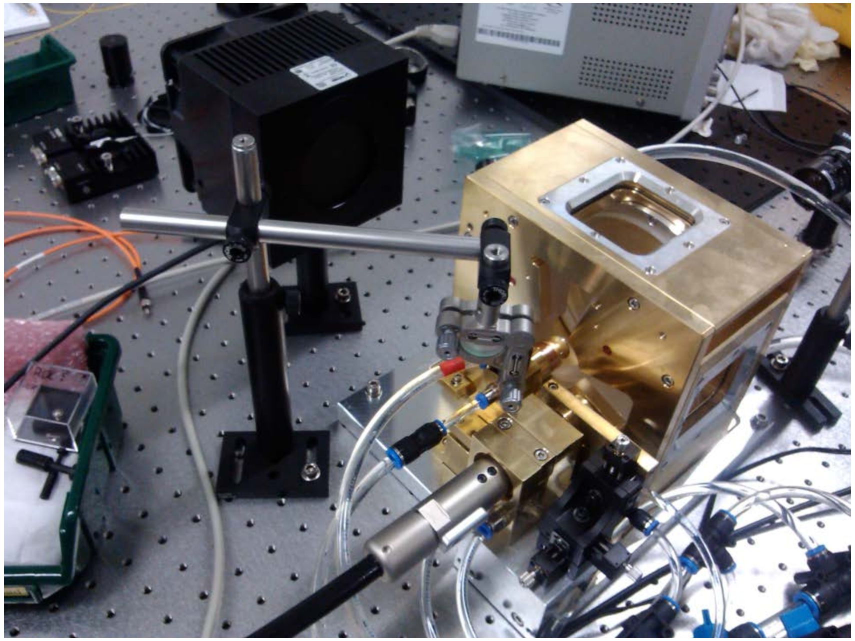
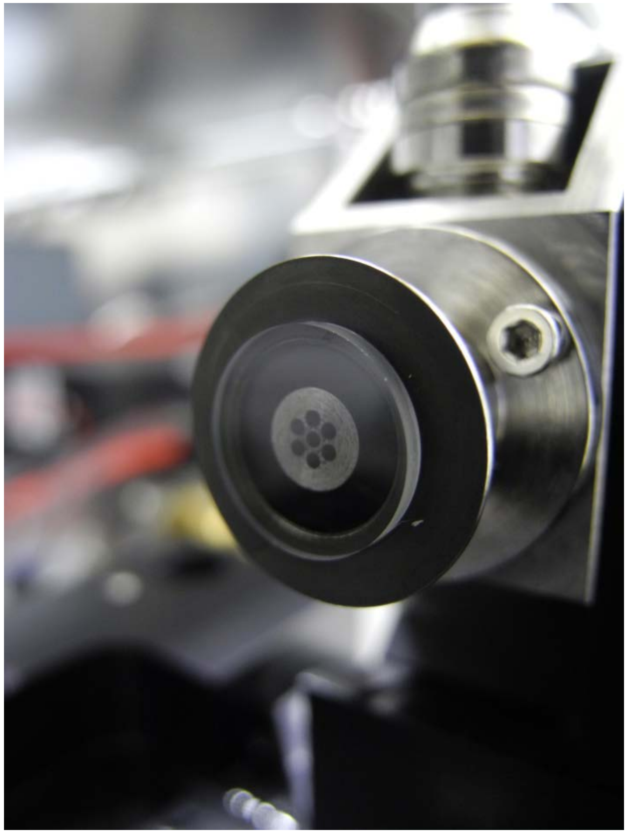


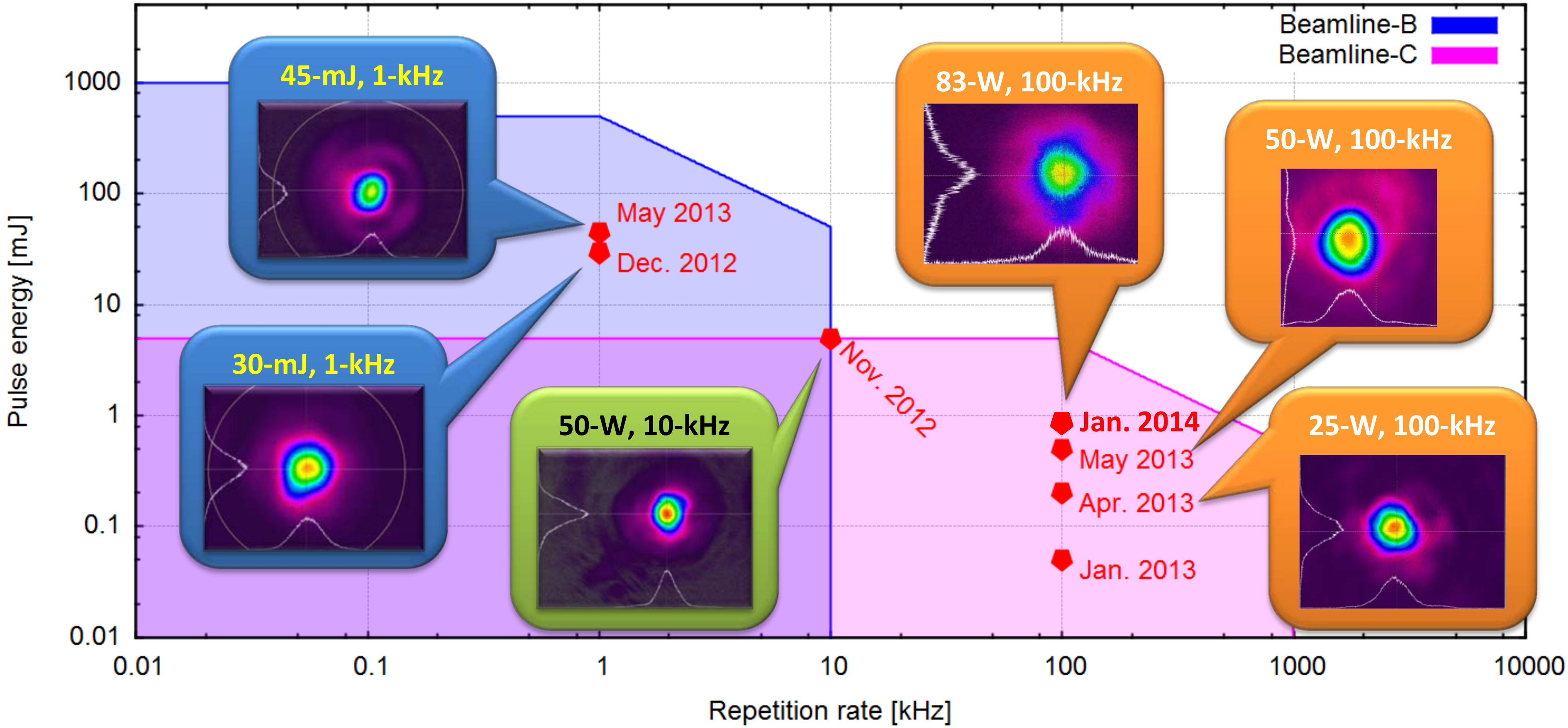
New thin-disk substrates and materials

- Diamond-bonded disks
  - single crystals
  - Ceramics
  - Undoped cap
- SiC bonded disks





Status of in-house development



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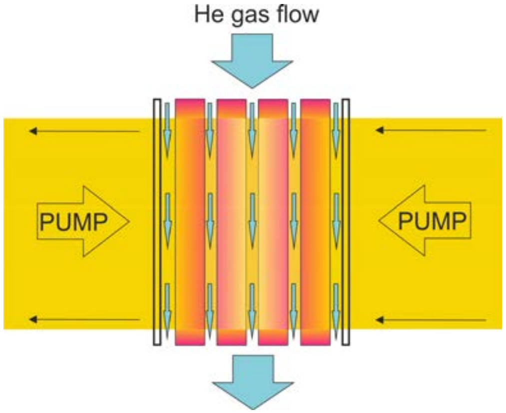
Development of 100 J / 10 Hz cryogenically cooled multi-slab DPSSL system scalable to kJ level (L2)



Strategic partnership with STFC/RAL

STFC
Central Laser Facility

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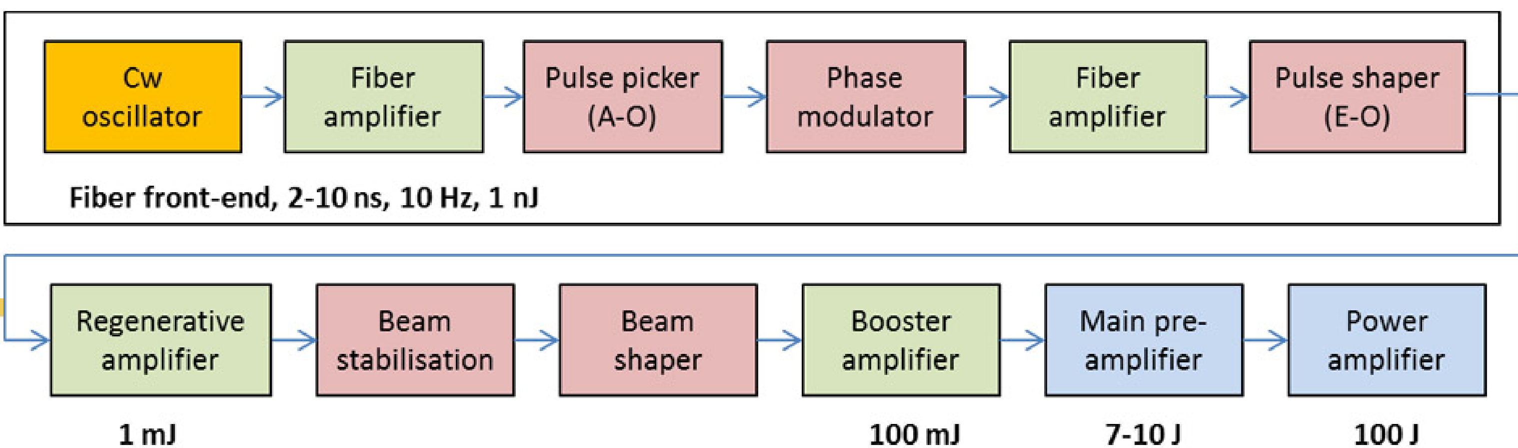

D1	✔
D2	✔
D3	✔
D4	✔
D5	✔
D6	✔
D7	
D8	
D9	
D10	
D11	
D12	
D13	

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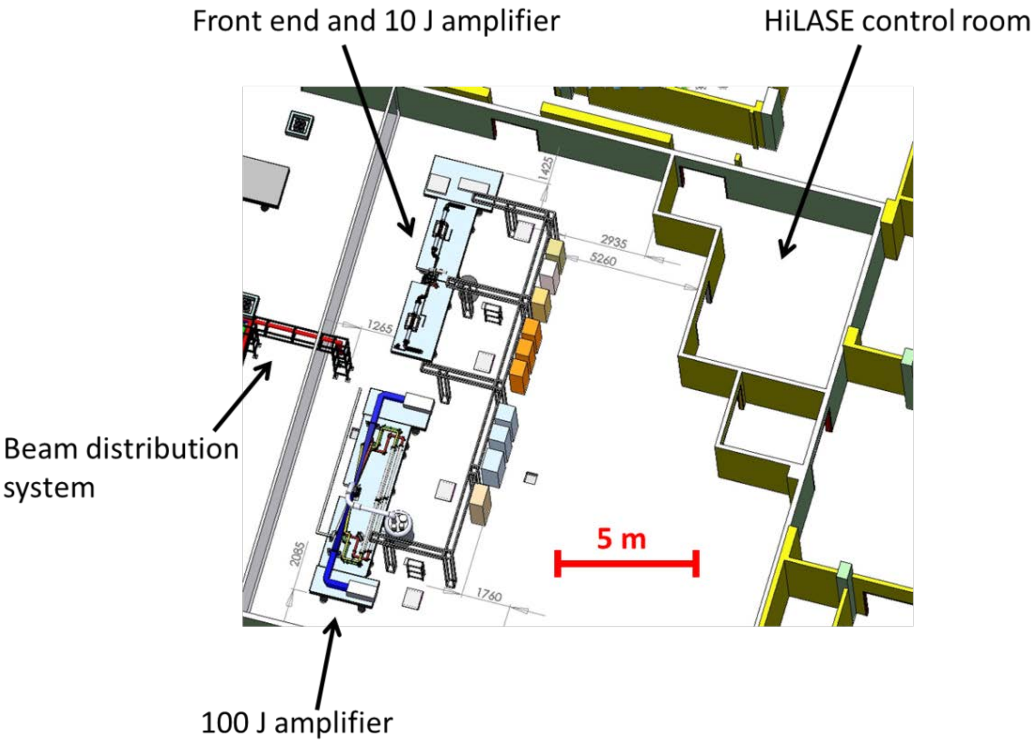
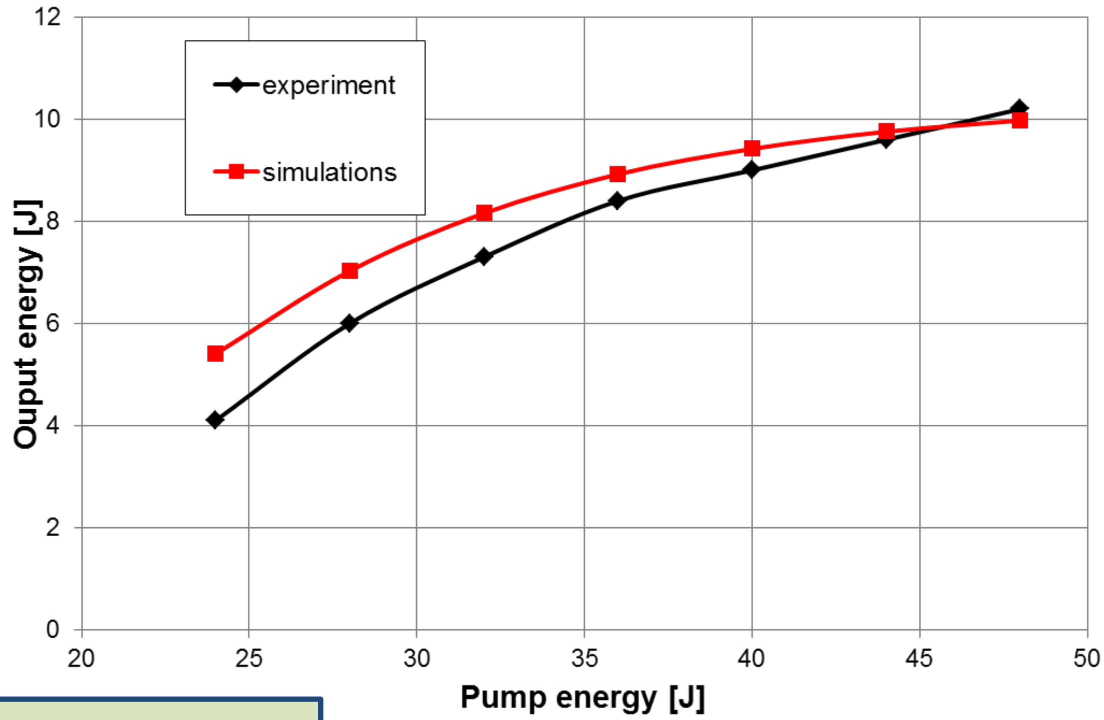
Beamline L2 under construction

Parameter	Specification
Pulse energy	> 100 J
Av. output power	> 1 kW
Pulse length	2-10 ns
Pulse shape	Programmable (150 ps steps)
Repetition rate	1 – 10 Hz
Output beam size	75mm*75mm (SG order > 8)
RMS modulation	< 1%
Wavefront quality	lambda/10
E-o efficiency	> 12 %



10J/10Hz operation demonstrated



- **Pump power**: 2 x 20 kW
- **Pump duration**: 1.2 ms
- **Seed energy**: 16 mJ

> Temporally shaped pulse
> Spatially modulated pulses

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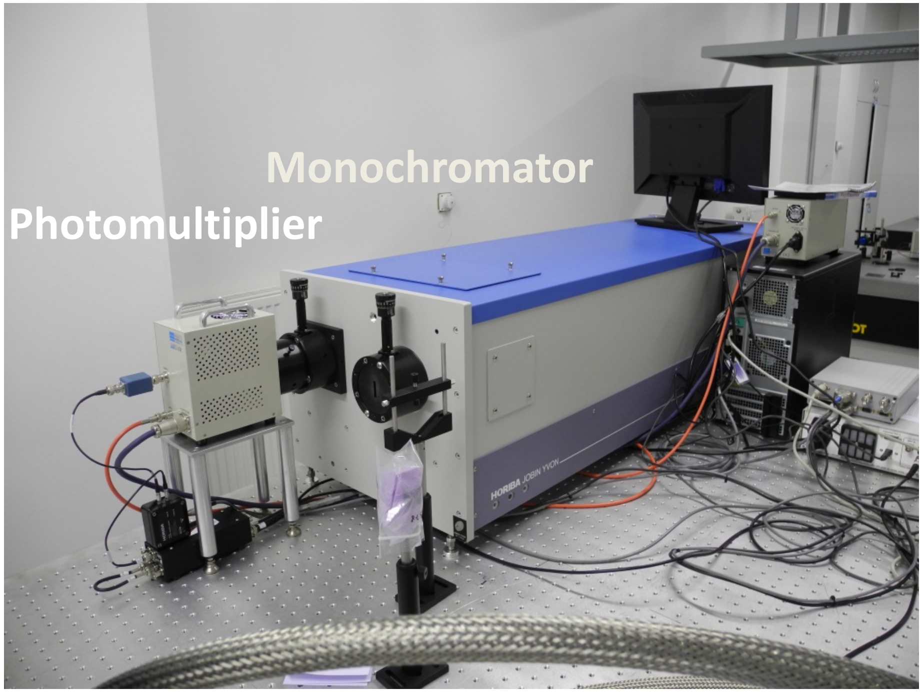
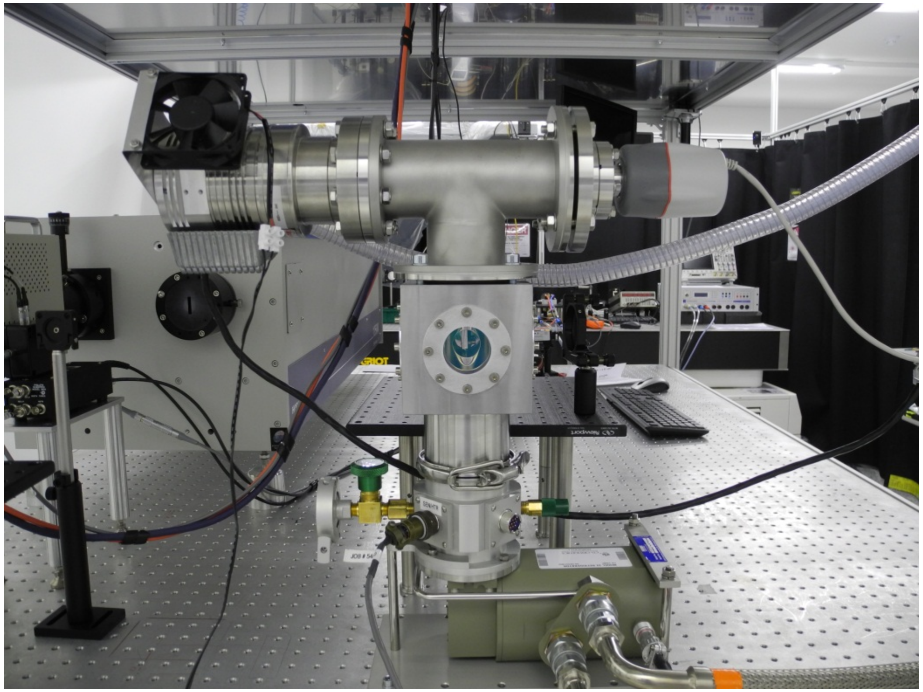
Spectroscopy at cryo temperatures





We plan to investigate Yb-doped materials:

Yb-doped silicate glasses,
Yb:YAP, Yb:LuAG, Yb:CaF_2,…

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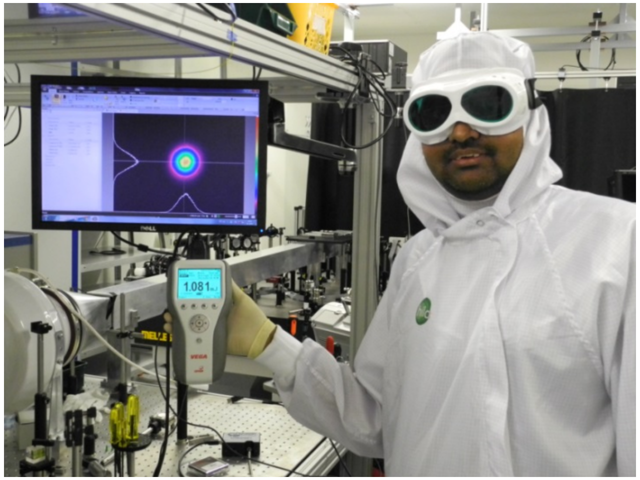
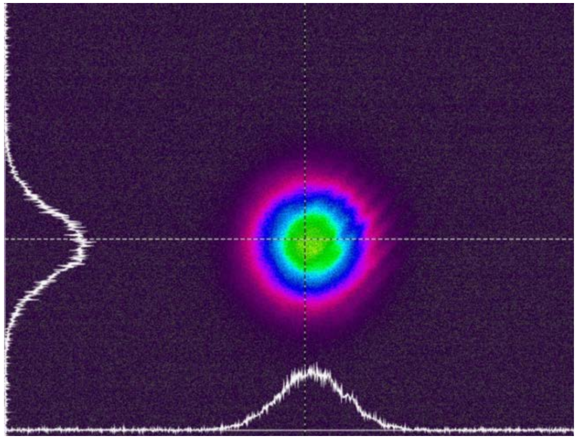
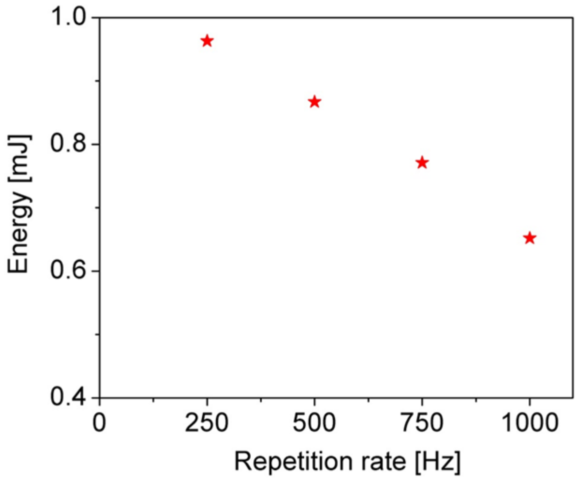
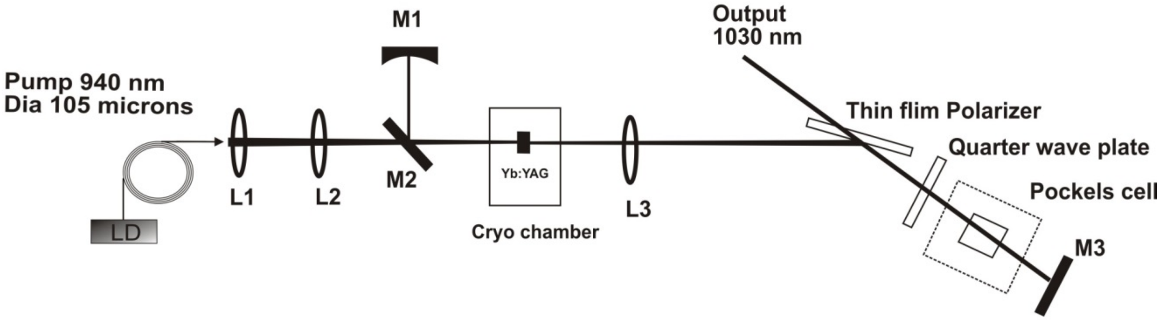
40 ns cryo laser cavity for LIDT tests





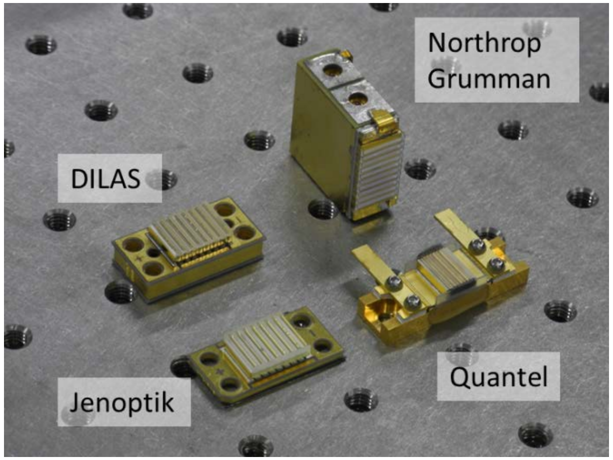
Cryo laser setup - Q-switching



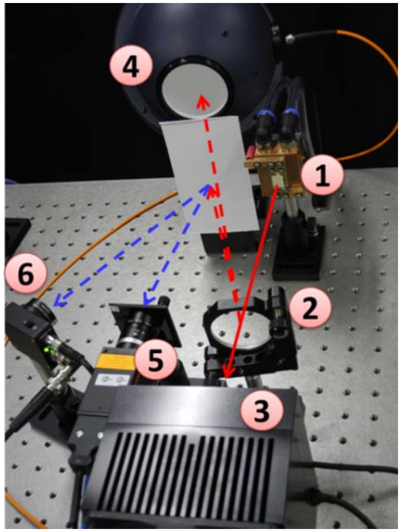


M1 - Concave mirror; M2 - Dichroic mirror; M3- Plane mirror; L3 - Plano convex lens

Diode stacks characterization



Parameters	QCW
Central wavelength	939 nm
Central wavelength tolerance	± 2nm
Spectral width (FWHM)	< 5-6 nm
Repetition rate (f)	10 Hz
Pulse duration (t)	0.8-1.2 ms
Output power per stack	> 2500 W



1) Diode stack

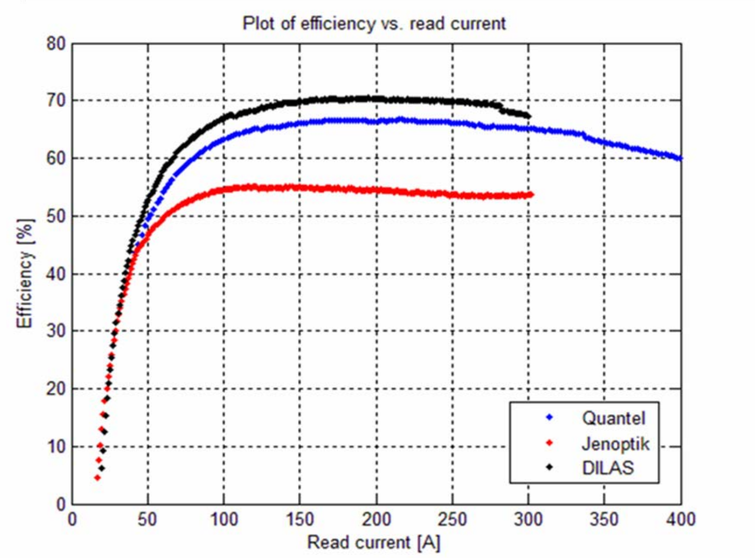
2) Wedge prism

3) Power meter

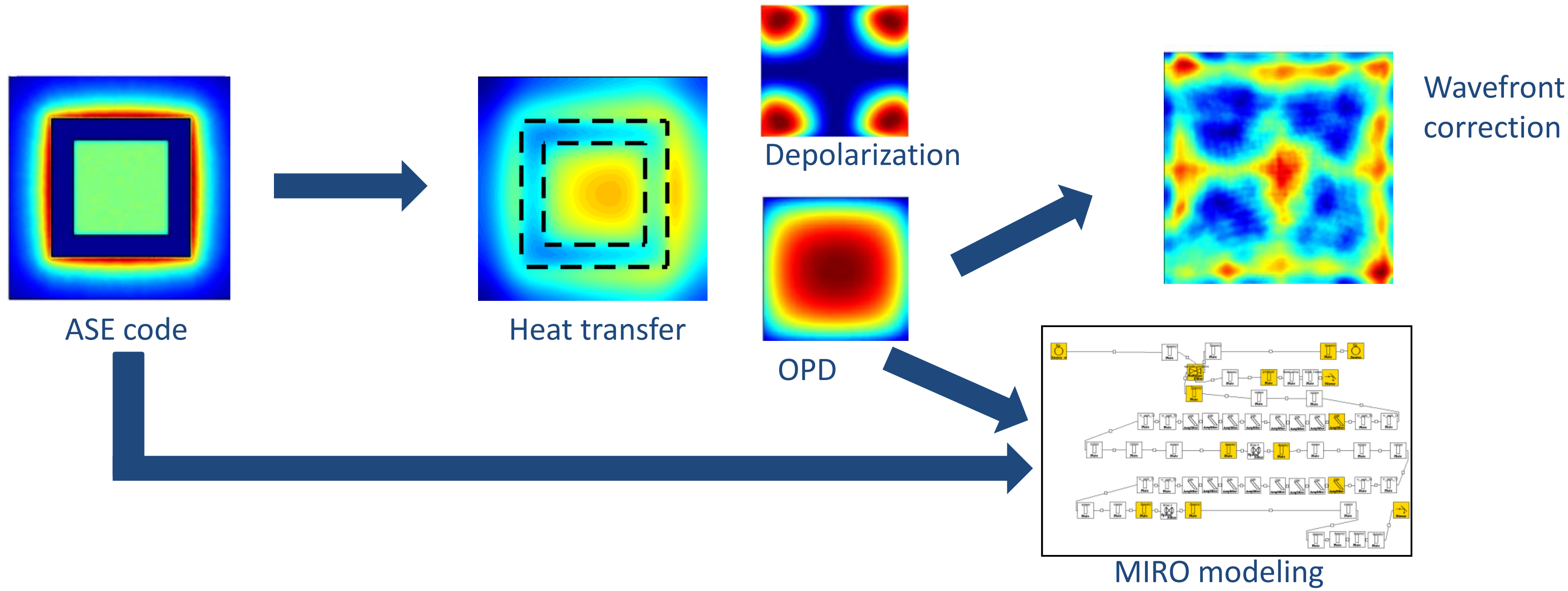
4) Integration sphere

5) CCD camera with nd filter

6) Fast photodiode with nd filter



Complex numerical modeling



	Input	Calculation	Output	Responsible
1)	Pump beam, geometry	**ASE modeling**	stored energy, heat load	**Magda S.**
2)	Heat load	**Thermo-optical modeling**	OPD, depolarization	**Ondrej S.**
3)	OPD	**MIRO modeling**	Output beam profile	**Martin D.**
4)	OPD	**Wavefront correction**	AO performance, wavefront	**Jan P.**

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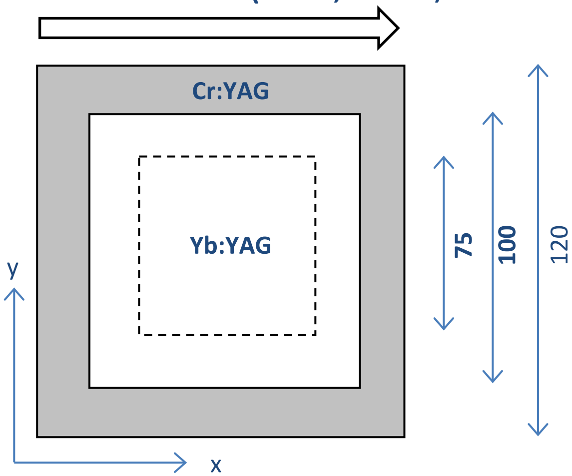
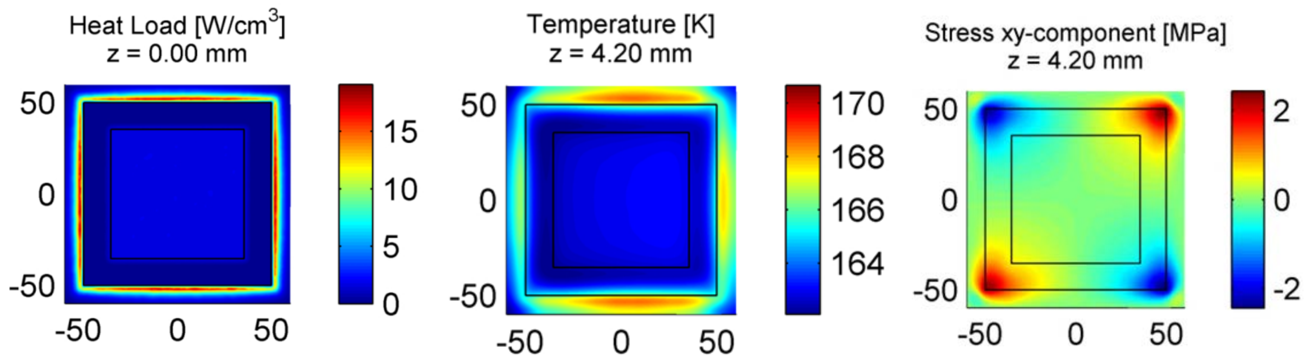
Thermo-optical modeling

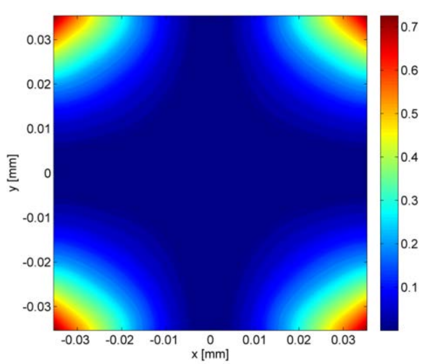
He flow direction (160 K, 10 bar)





A.L. Bullington, S. B. Sutton, A. J. Bayramian, J. A. Caird, R. J. Deri, A. C. Erlandson, M. A. Henesian ,"Thermal birefringence and depolarization compensation in glass-based high-average-power laser systems", Proc. SPIE, vol. 7916 (2011).

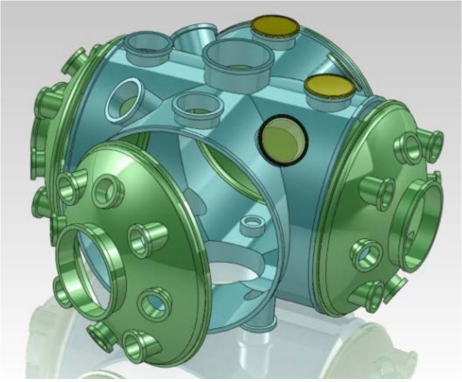
<u>O. Slezak</u>, A. Lucianetti, M. Divoky, M. Sawicka, and T. Mocek, "Optimization of Wavefront Distortions and Thermal-Stress Induced Birefringence in a Cryogenically-Cooled Multislab Laser Amplifier," *IEEE Journal of Quantum Electronics,* vol. 49, pp. 960-966, 2013.



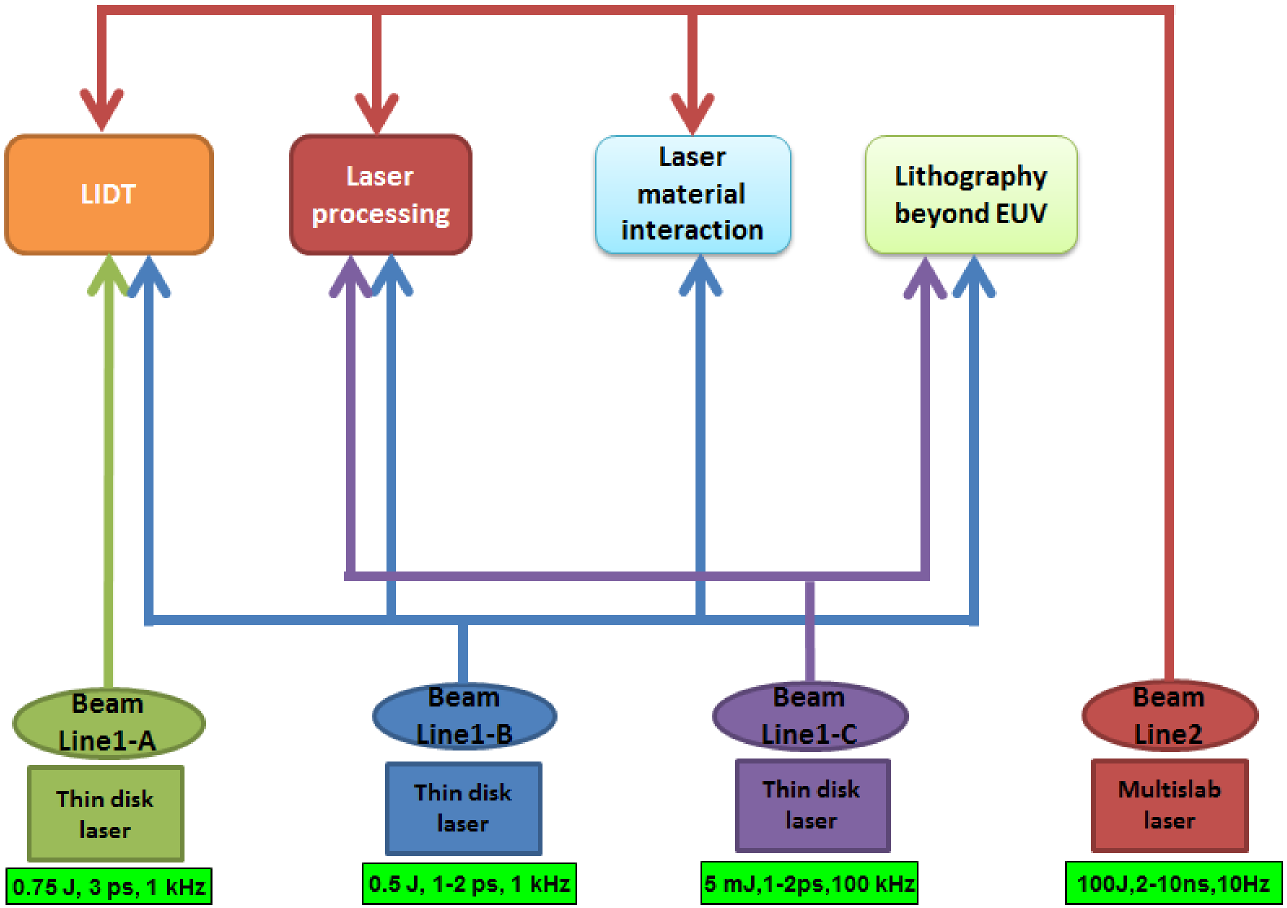
Average depolarization after 24 passes: 9.6 %

Research Programme 3

Development of high-tech industrial and scientific applications



Key R&D activities



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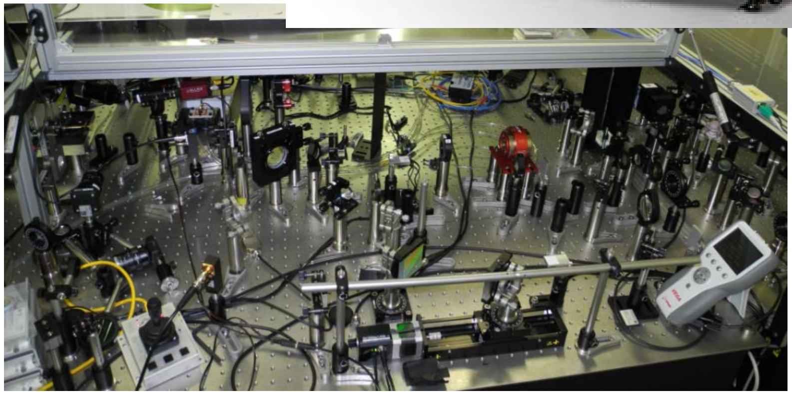
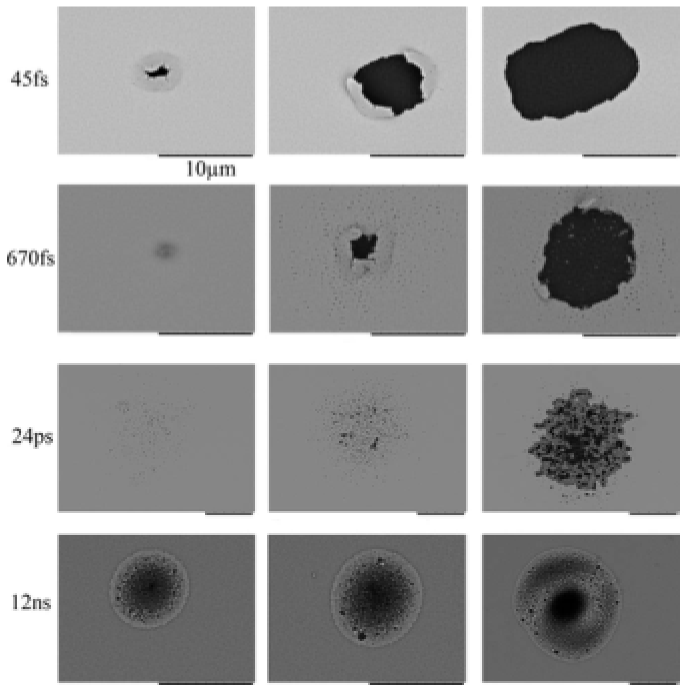
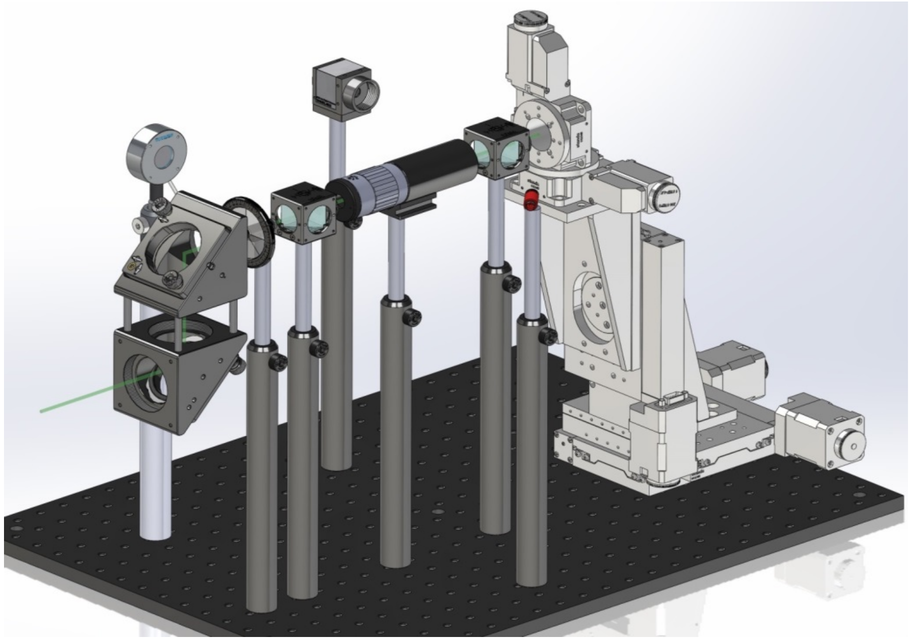
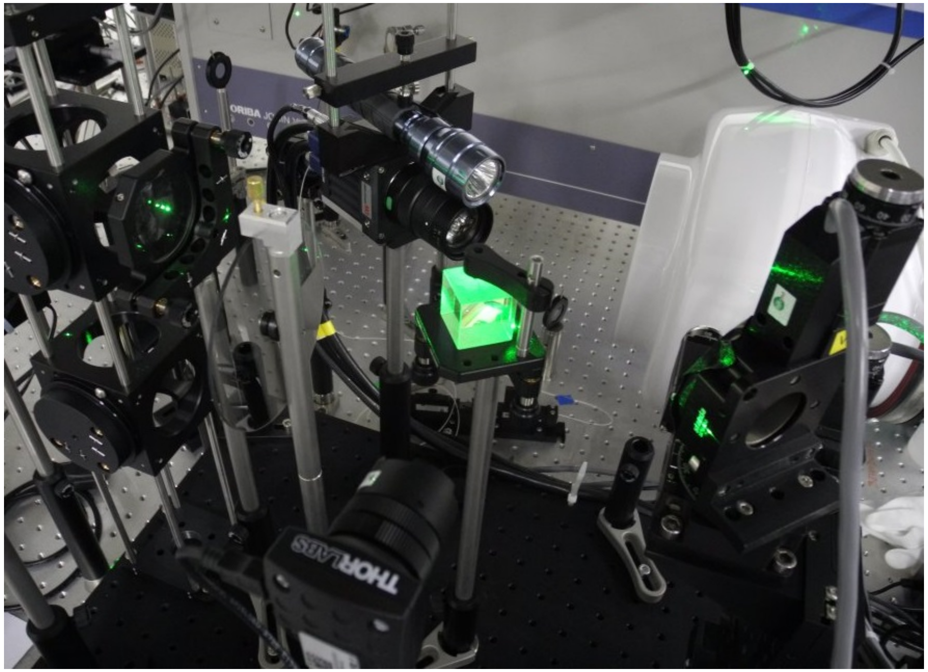
Laser Induced Damage Threshold (LIDT)





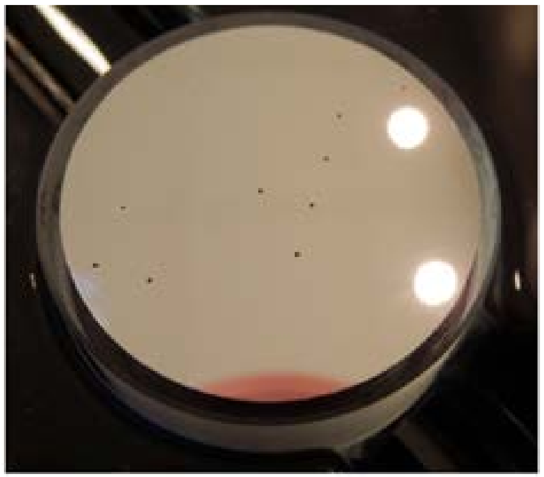
LIDT test station



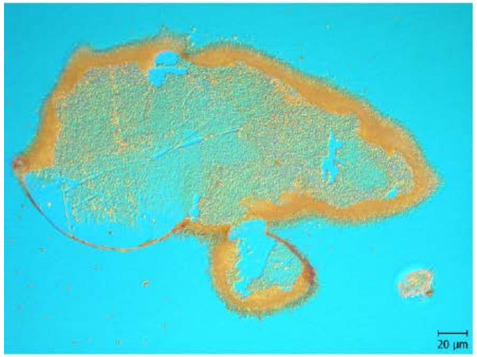


1: Attenuator
2: Beam focusing (2014)
3: Beam energy and beam
4: Scattering detection
5: XYZ motorized tower

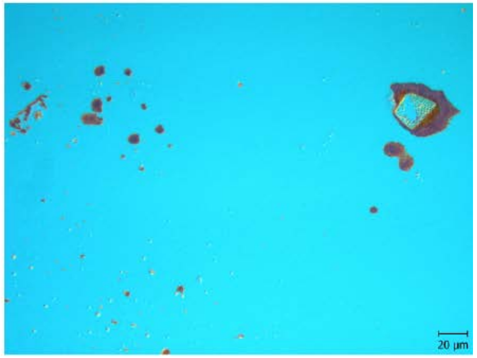
First tests



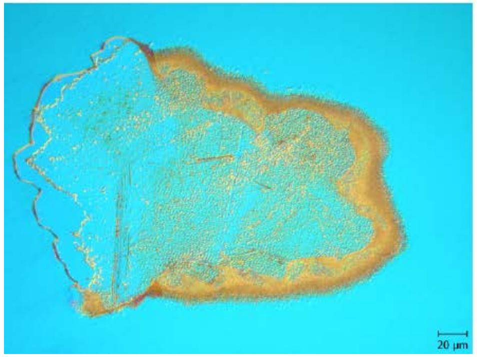
H011 spot 03



H011 spot 13



H014 spot 16



H014 spot 25

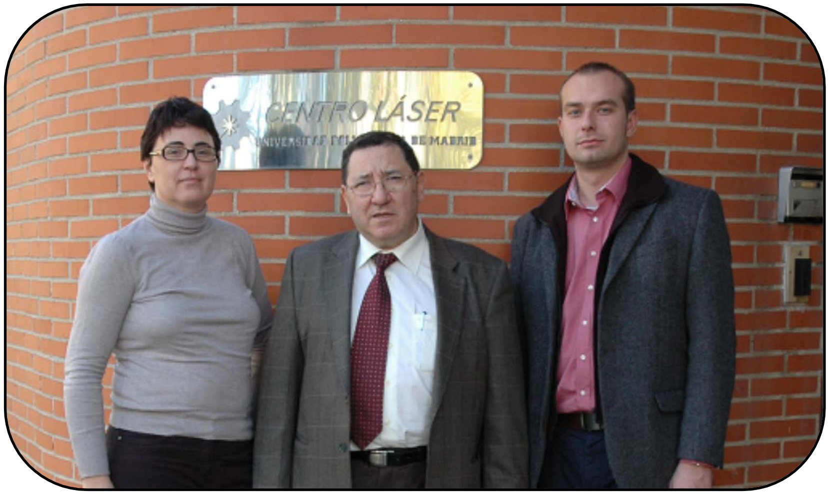
Laser Shock Peening

Shock Peening

In the process of establishing cooperation with:

- Prof. Ocaña (Centro Láser UPM, Madrid, Spain)
- Dr. Alessandro Fortunato (Alma Mater University, Bologna)
- Dr. Alessandro Candiani (University of Parma)

"HiLASE multi-slab laser system: a tool for efficient peening" 4th International Conference on Laser Peening and Related Phenomena Proc. Book, to be published



Roman and Danijela visiting Prof. Ocaña - November 2013

Cooperation with Industry

hilase

LIDT:

- crytur
- meopta
- toptec
- SAFRAN Sagem
- MELLES GRIOT
- SCHOTT glass made of ideas
- CORNING

LSP and processing :

- ČZ a.s.
- ŠKODA
- GE Aviation
- Aero | VODOCHODY
- Honeywell
- AIRBUS

Surface modifications

- PRAMET
- BEZNOSKA s. r. o. Vracíme radost z pohybu
- BRAVO
- Valeo

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Cooperation with Industry

hilase

Laser vendors
- Process development
- Popularization of lasers
- Marketing

Laser end-users
- Safety training and education
- Process development
- Existing process improvement

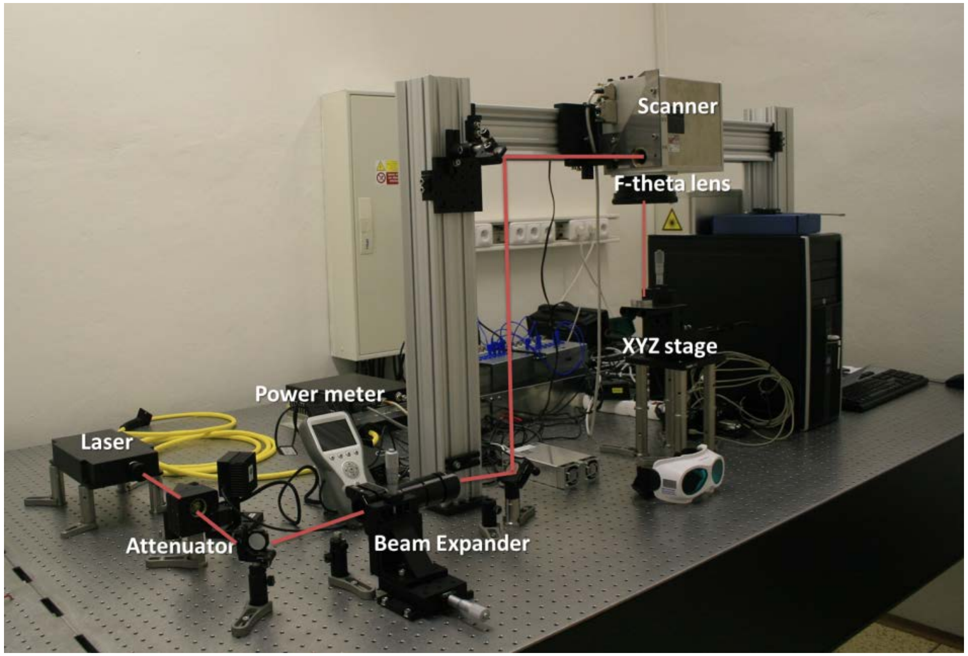
OMRON

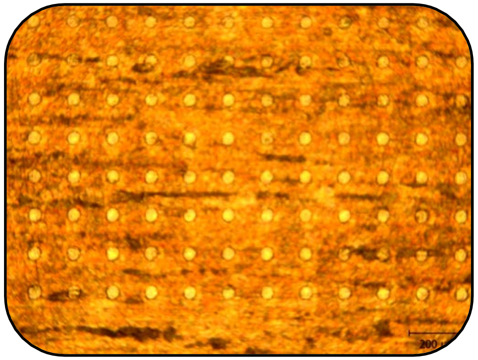
TRUMPF

STAALBOEK

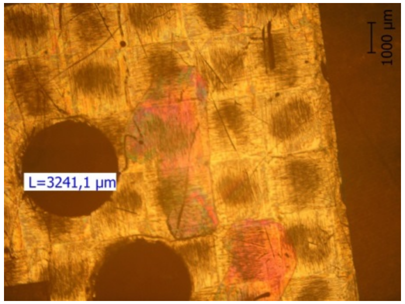
medicem

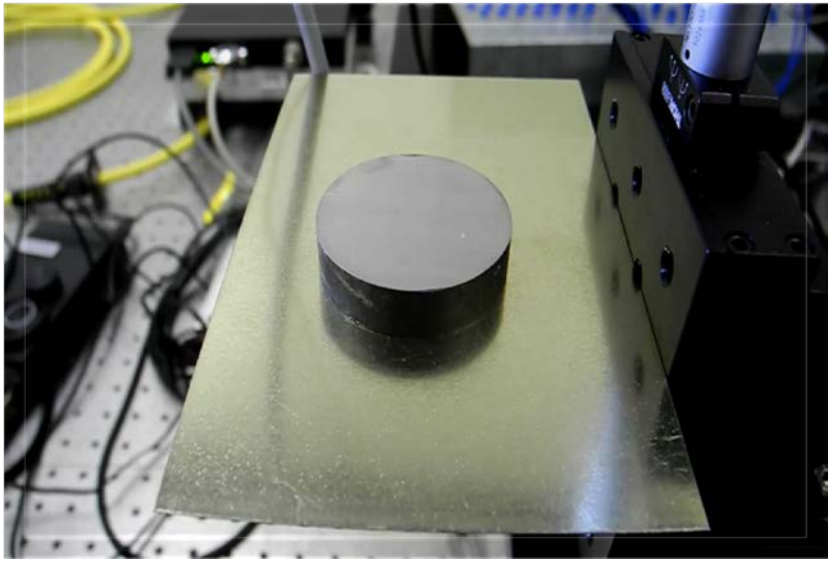
Laser μ-nano processing station





20-30 um holes
In metals





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Carbon Reinforced Plastics (CRFP), ITO thin films, …

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