
Laser Sources

Solid State Lasers – Overview

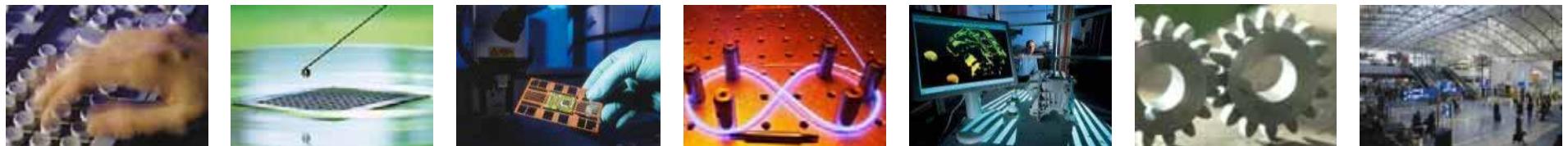
Dieter Hoffmann

Workshop: Laser technology and optics design
Fraunhofer ILT Aachen, 4 – 6 November 2013

Outline

- Introduction Fraunhofer ILT
- Diode Lasers for Pumping
- Rod Lasers and their Limitations
- Innoslab – Comparison to Fiber and Thin Disk Lasers

Fraunhofer Profile



- 66 Institutes
- more than 22,000 employees
- An annual research volume of €1.9 billion, of which €1.6 billion is generated through contract research

7 Groups:

- Information and Communication Technology
- Life Sciences
- Microelectronics
- Light & Surfaces
- Production
- Materials and Components – MATERIALS
- Defense and Security

The Fraunhofer-Gesellschaft in Germany

- 66 Institutes
- more than 22,000 Employees

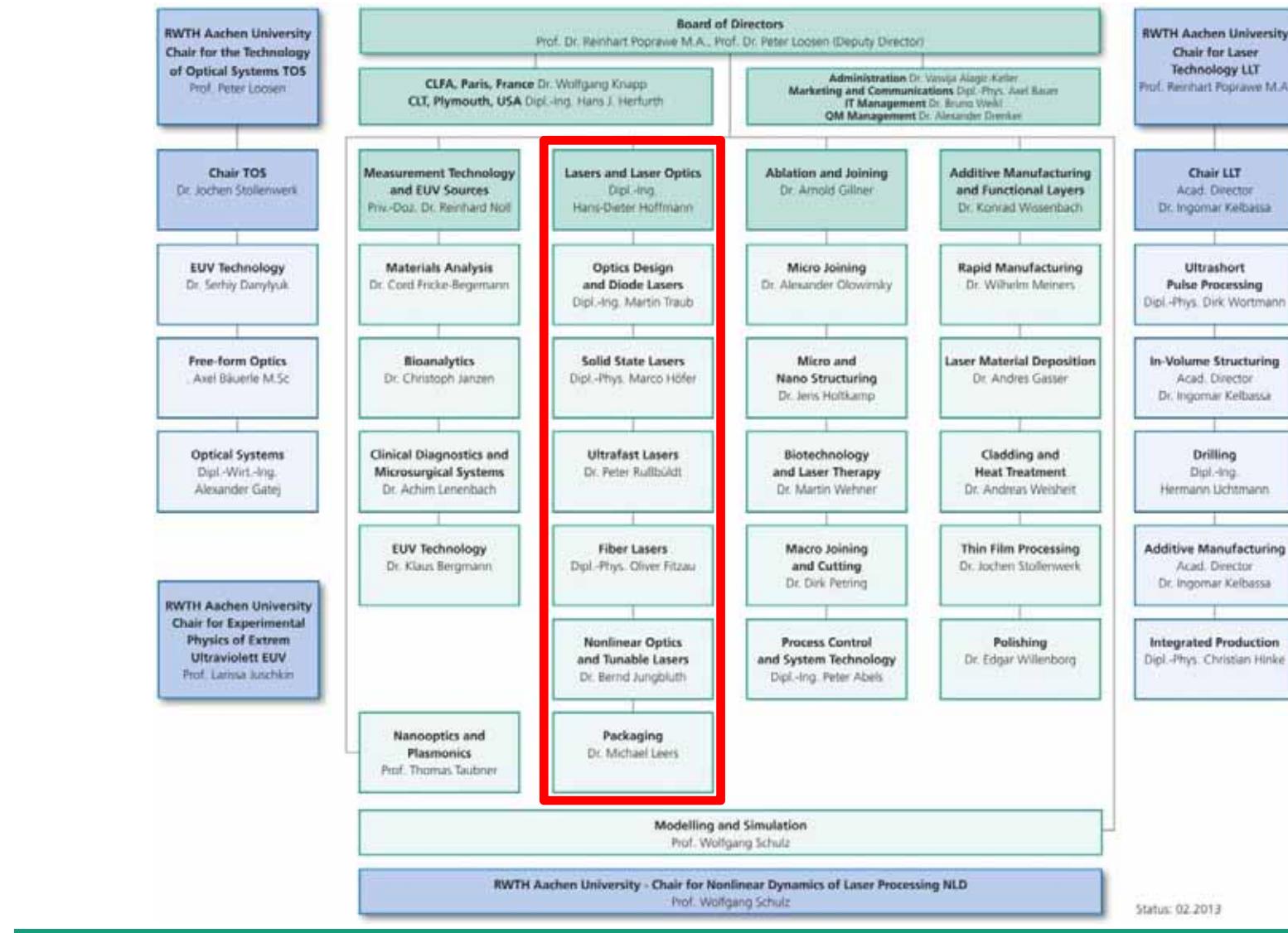


Facts and Figures of Fraunhofer ILT

- About 30 Mio Euro operating budget (without investments)
- About 6 Mio Euro investments per year
- 394 Employees
- DQS certified according to DIN EN ISO 9001
- 2 branches abroad :
 - Center for Laser Technology CLT in Plymouth, MI, USA
 - Coopération Laser Franco-Allemande CLFA in Paris, France
- One patent application per month on average
- Approx. 10 participations in trade fairs / 20 organized events per year



Structure of Fraunhofer ILT, LLT, TOS, NLD - RWTH Aachen



Status: 02-2013

Lasers and Laser Optics – Groups at ILT

A1.31

Optics design
und
Diode lasers



A 1.32

Solid State -
Lasers



A1.33

Ultrafast
Lasers



A1.34

Fiber Lasers



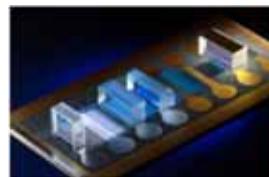
A 1.35

Nonlinear
Optics
and
Tunable Lasers



A 1.36

Packaging



- Beam Forming
- Beam Guiding
- Beam Combining
- Refractive / Diffractive Optics
- Free Form Optics

- ns, ps Oszillators and Amplifiers
- Single Frequency Lasers

- fs Oszillators and Amplifiers
- Pulse Compression

- Oszillators and Amplifiers
- Components
- Splicing, Cleaving, Characterization

- Frequency-conversion UV, VIS, NIR, MIR
- Tunable TiSa, Alexandrite, Dye-Laser

- Single emitters, Arrays
- Laser crystals
- Optics

Tailored Lasers for Industrial Use



Laser Beam Sources

- Power / Energy
- Spatial Quality
- Temporal Quality
- Spectral Quality



Applications

- Manufacturing Technology
- Measurement Technology
- Microelectronics (EUV)
- Life Sciences

Solid State Laser for Sparc Ignition of Gas Engines



Design and Parameters

- Q-switched DPSSL
- Multi 10 mJ output

Applications

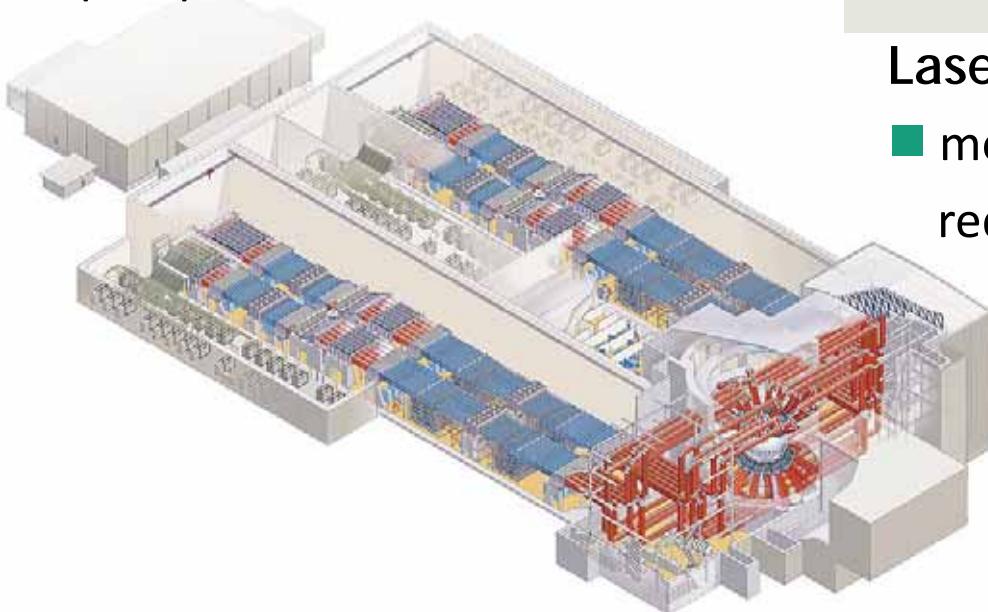
- stationary energy supplies
- Automotive ?



Solid State Laser for Fusion based Power Plants

NIF is operational now

- Only pulse generation stages are diode pumped
- High power amplifier is lamp pumped



Source: Lawrence Livermore National Laboratory

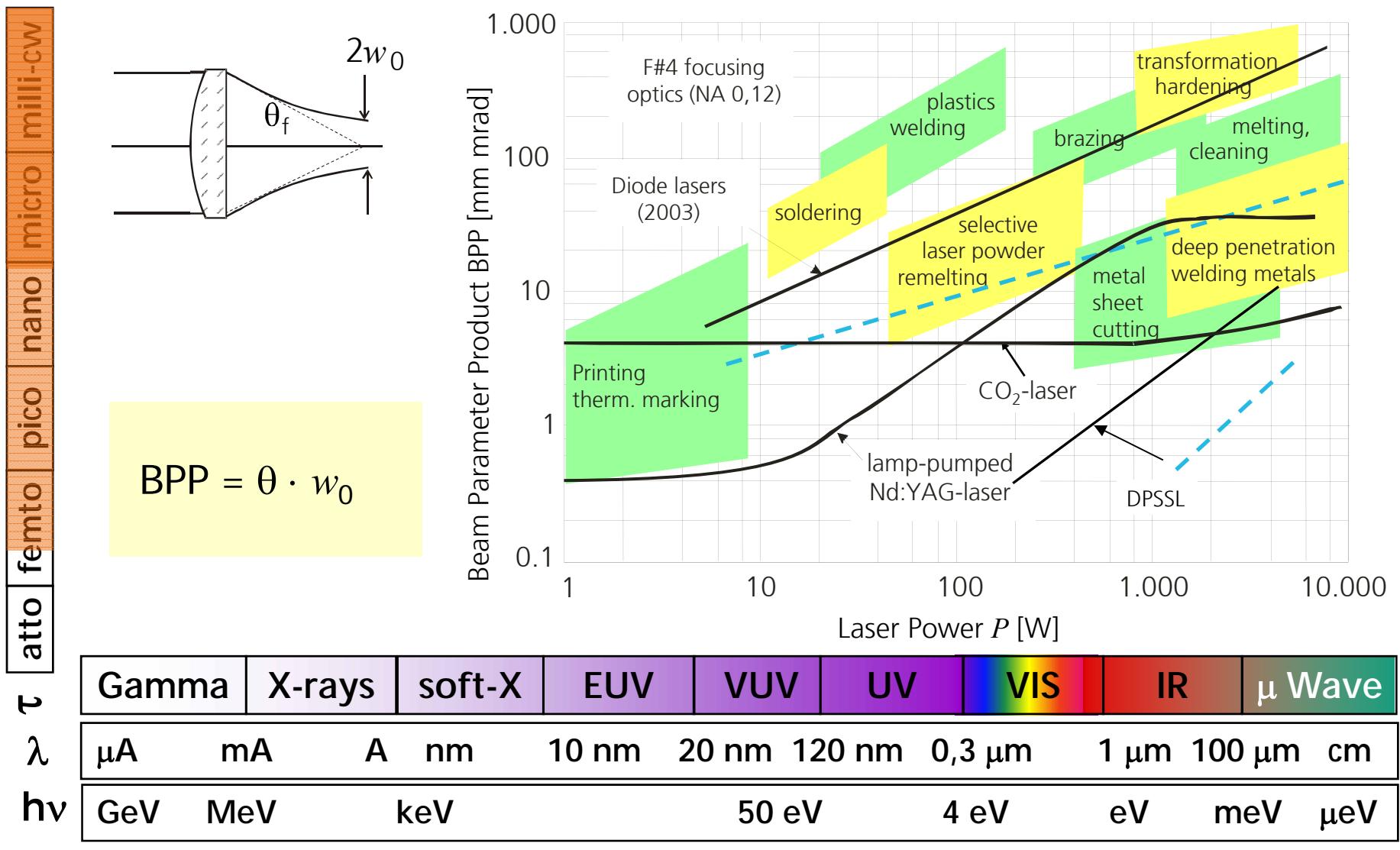
EUROPEAN Fusion Power Plant HiPER



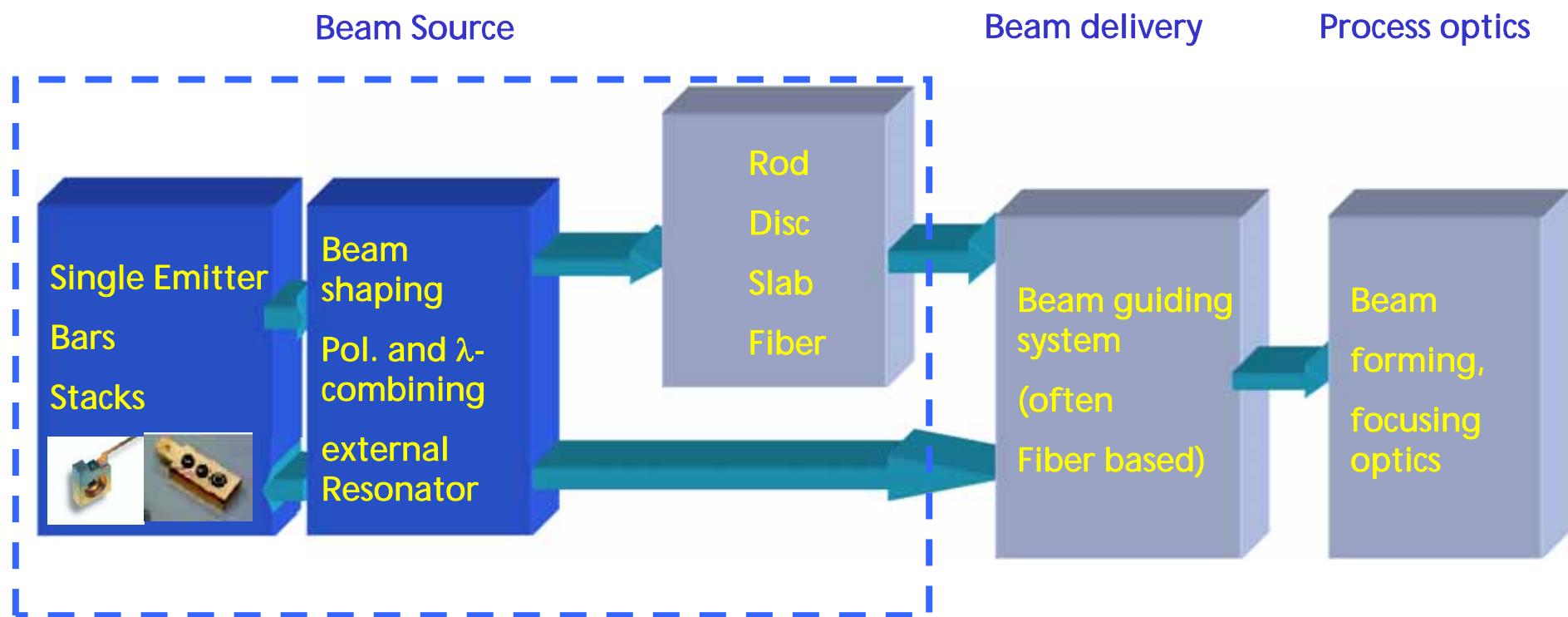
Laser based Fusion Plants like HiPER

- more than 1.000.000 DL bars initially required for fully diode pumped laser

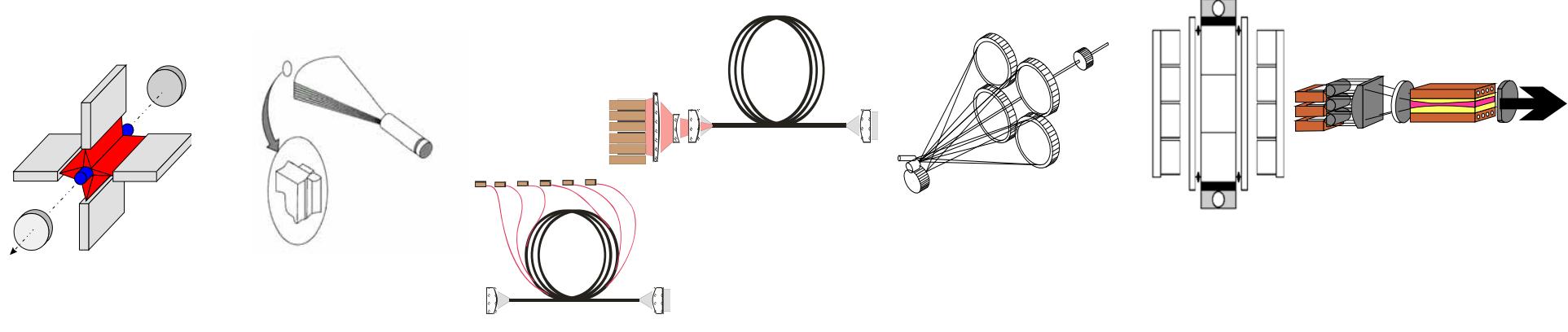
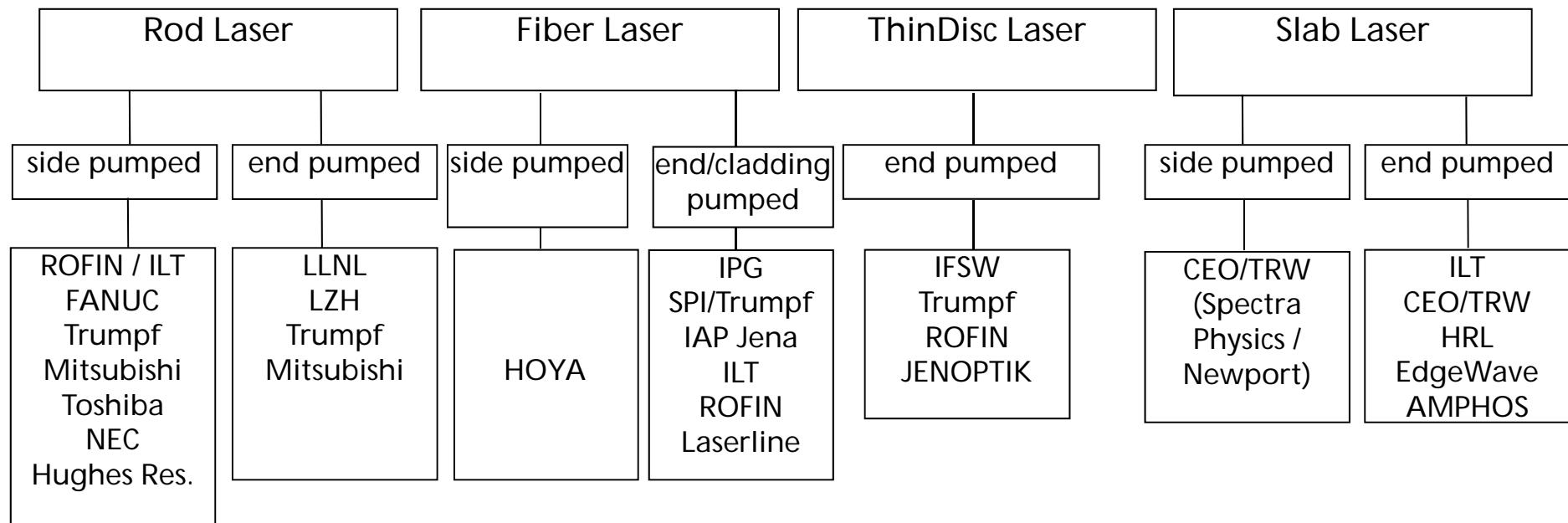
Parameter Range of Solid State Lasers



Laser building blocks

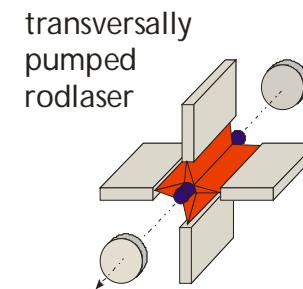


Basic Laser Designs – Diode Pumped



Required Pump Beam Quality for a 1kW Module

Concept	Pump Source		
	Mode Volume	Focus	BPP [mm*mrad]
Rod side pumped	Cylindrical	Line	4800
INNOSLAB			
Disc			
Fiber			



slow

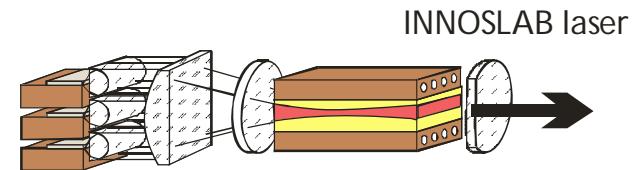
$$\begin{aligned}BPP &= w_0 \cdot \Theta \\&= 60\text{mm} \cdot 100\text{mrad} \\&= 6000\text{mm} \cdot \text{mrad}\end{aligned}$$

fast

$$\begin{aligned}BPP &= w_0 \cdot \Theta \\&= 0.5\text{mm} \cdot 500\text{mrad} \\&= 250\text{mm} \cdot \text{mrad}\end{aligned}$$

Required Pump Beam Quality for a 1kW Module

Concept	Moden Volume	Pump Source	
		Focus	BPP [mm*mrad]
Rod side pumped	Cylindrical	Line	4800
INNOSLAB rectangular		Line	900
Disc			
Fiber			



slow / unstable

$$BPP = w_0 \cdot \Theta$$

$$= 20\text{mm} \cdot 200\text{mrad}$$

$$= 4000\text{mm} \cdot \text{mrad}$$

fast / stable

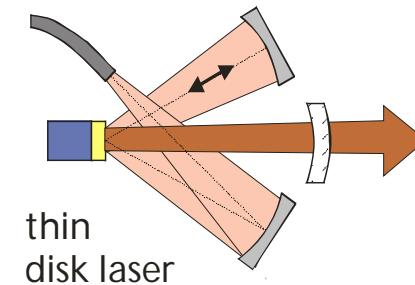
$$BPP = w_0 \cdot \Theta$$

$$= 6\text{mm} \cdot 8\text{mrad}$$

$$= 48\text{mm} \cdot \text{mrad}$$

Required Pump Beam Quality for a 1kW Module

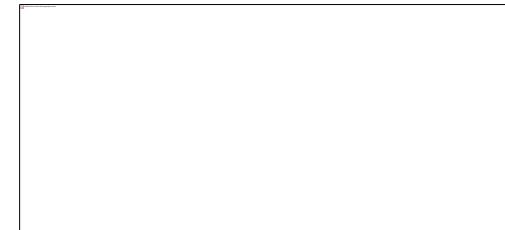
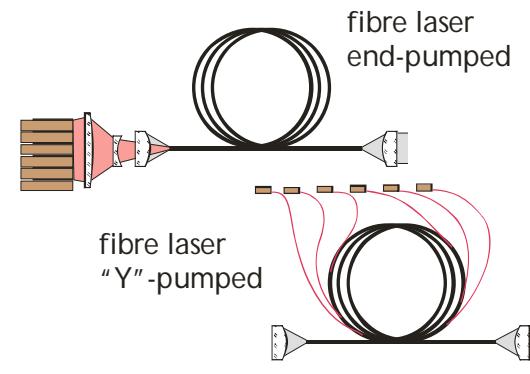
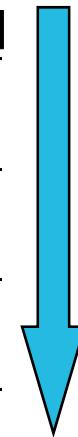
Concept	Pump Source		
	Moden Volume	Fokus	BPP [mm*mrad]
Rod side pumped	Cylindrical	Line	4800
INNOSLAB	rectangular	Line	900
Disc	Cylindrical	Circle	500
Fiber			



$$\begin{aligned}BPP &= w_0 \cdot \Theta \\&= 2.5\text{ mm} \cdot 250\text{ mrad} \\&= 500\text{ mm} \cdot \text{mrad}\end{aligned}$$

Required Pump Beam Quality for a 1kW Module

Concept	Moden Volume	Pump Source	
		Focus	BPP [mm*mrad]
Rod side pumped	cylindrical	Line	4800
INNOSLAB	rectangular	Line	900
Disc	cylindrical	Circle	600
Fiber	cylindrical	Circle	180



Single Emitters - Fiber coupled Multi Emitter Module

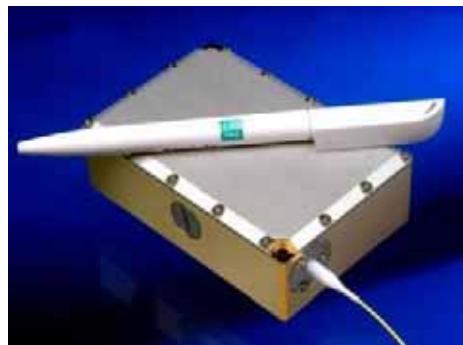


CW Output

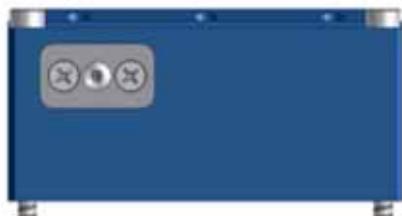
- P = 75 W @ fiber: 100 µm / NA 0.15
- industrial version available

Dimensions of the housing:

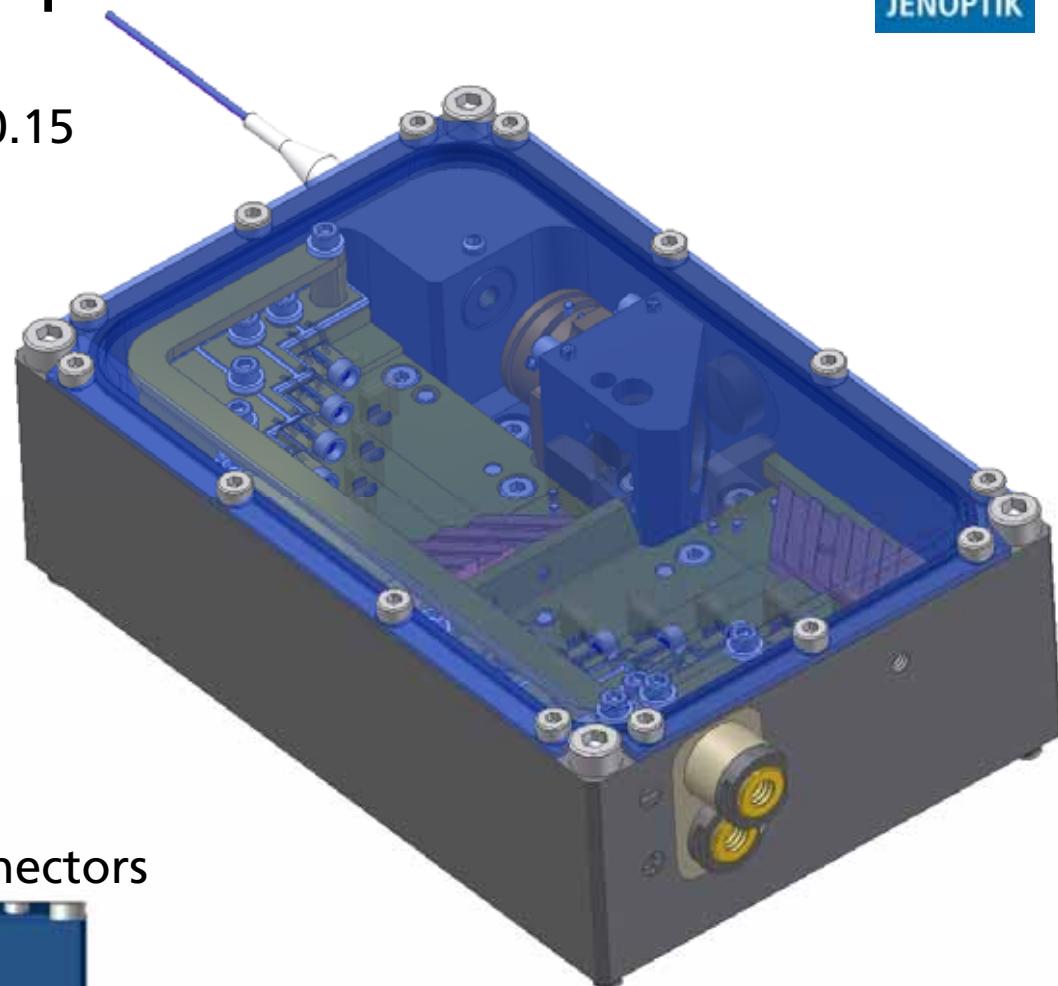
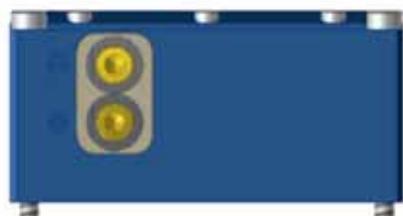
95 x 62 x 30 mm³



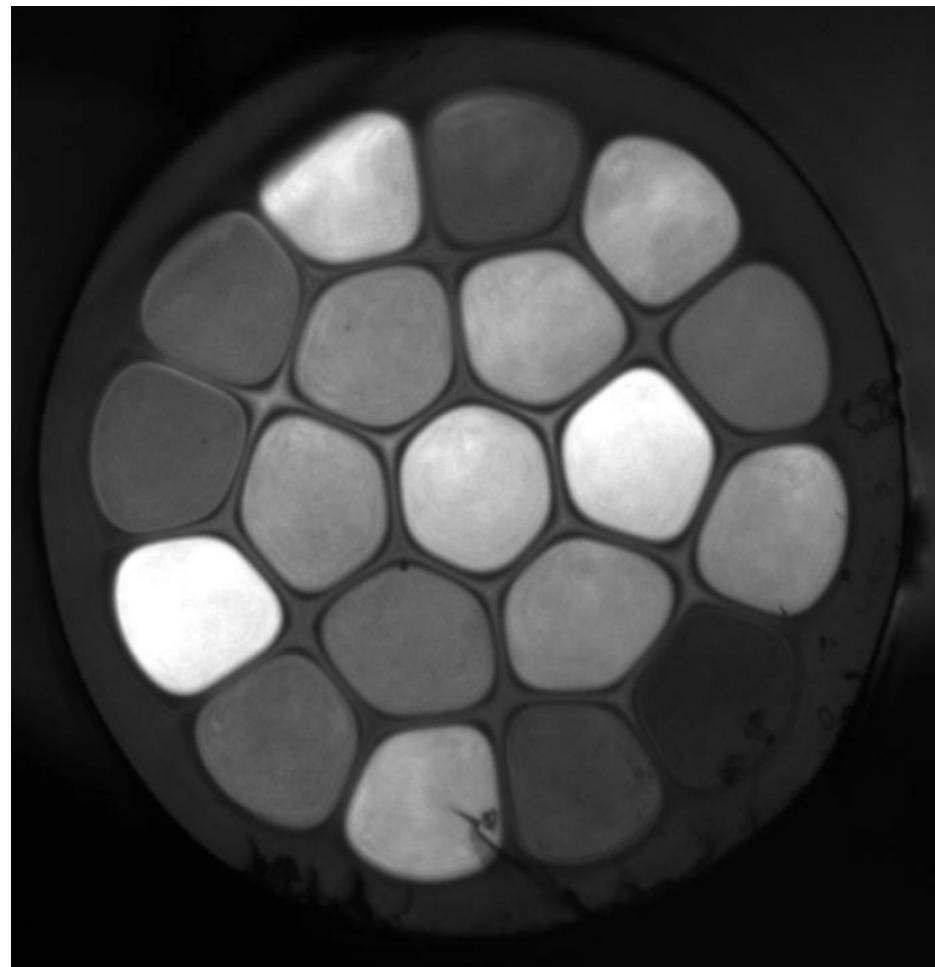
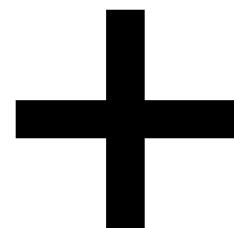
Fiber port



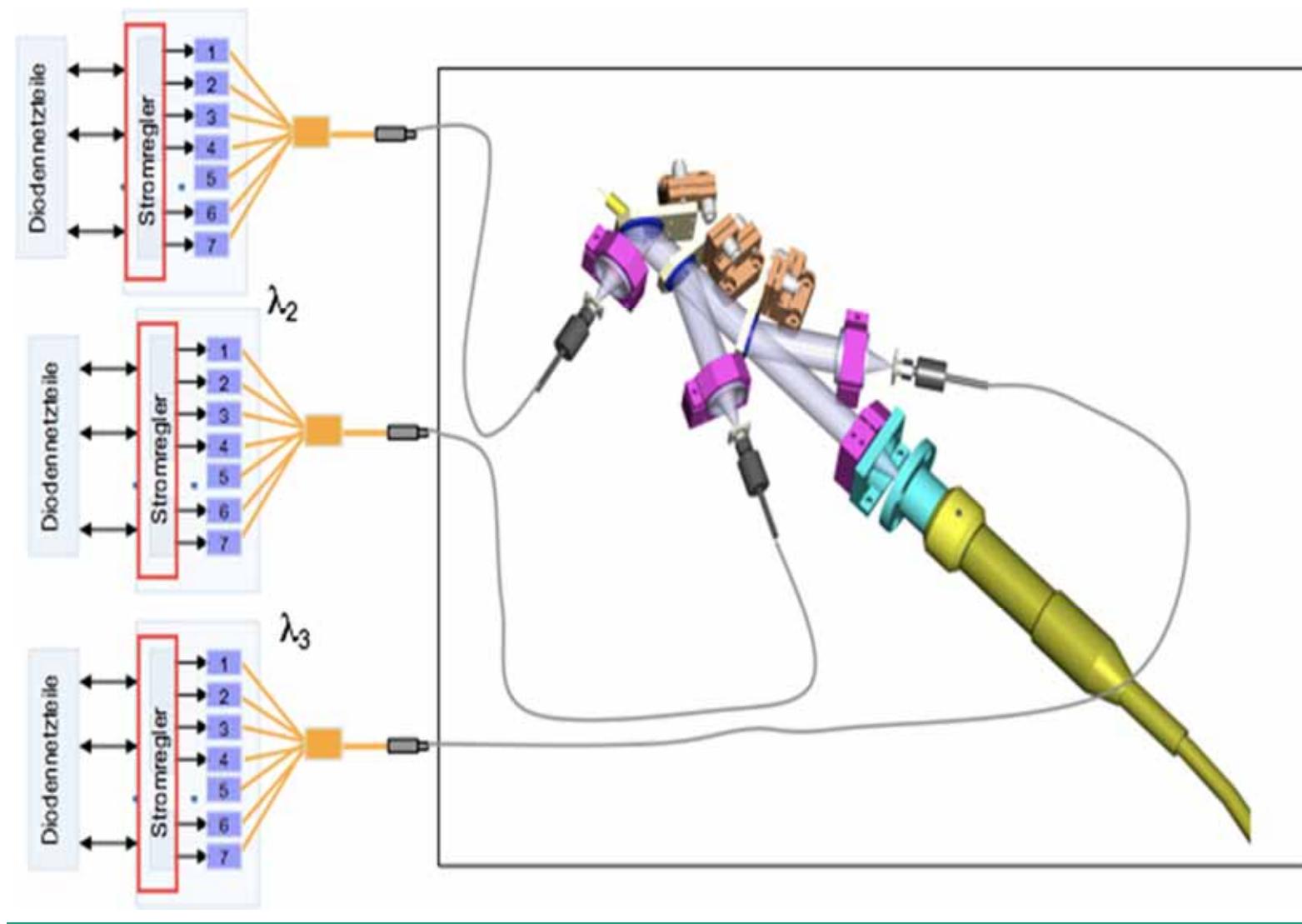
Electrical connectors



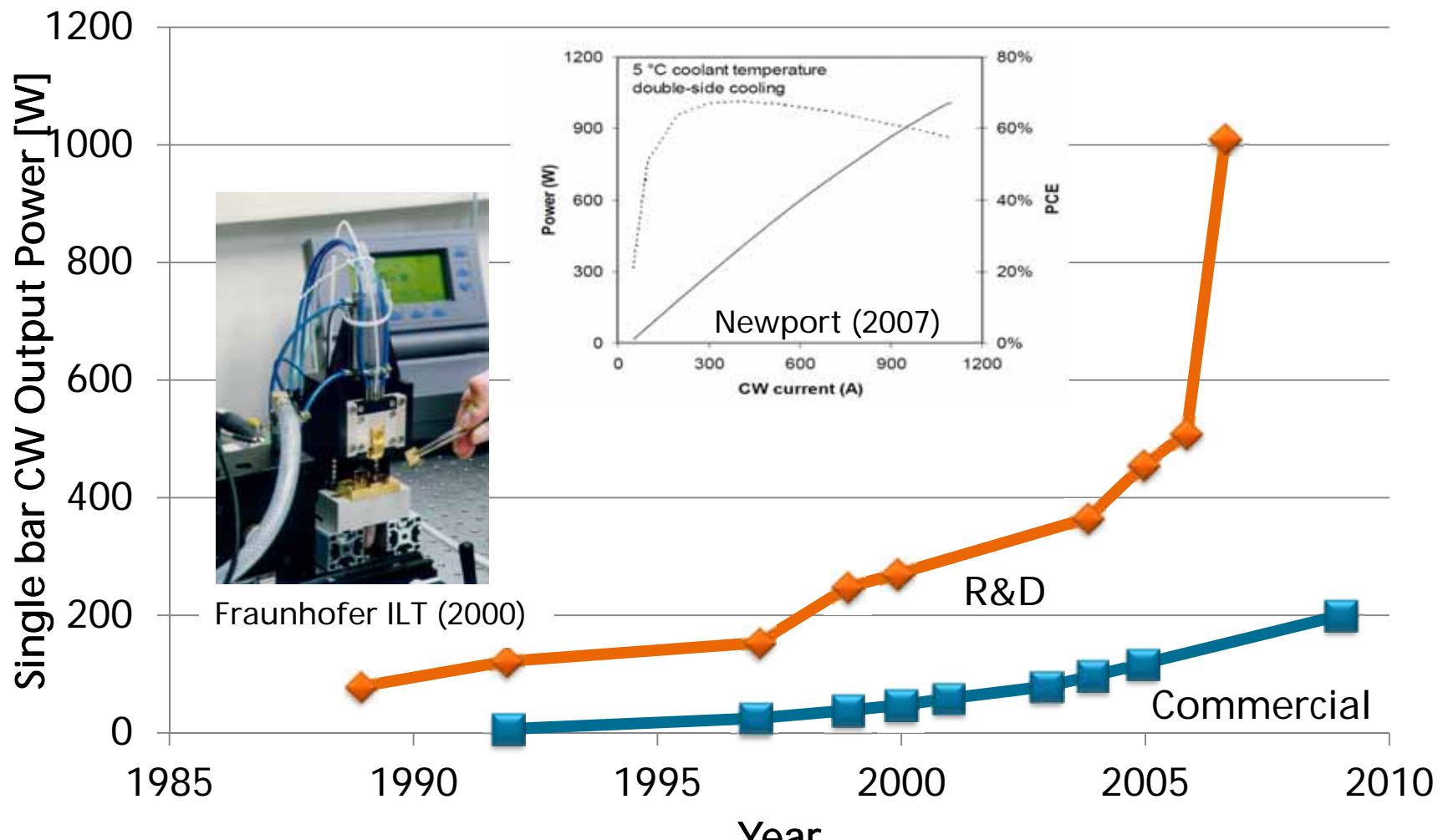
Single Emitters - Power scaling of fiber coupled Emitters



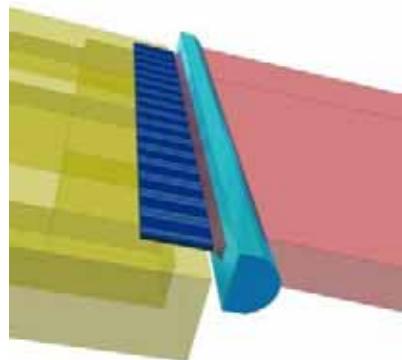
Single Emitter based kW Class Direct Diode Systems



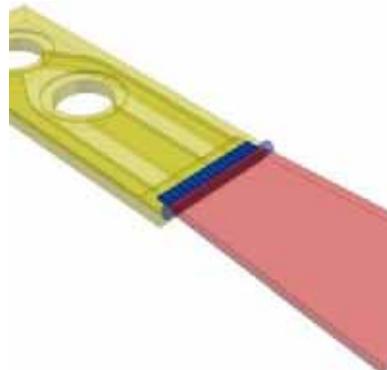
High Power Diode Laser Bars – Average Power Trend



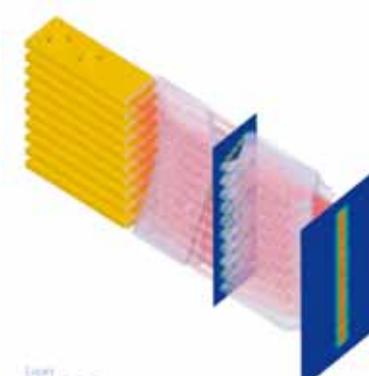
High Power Diode Laser Bars – Beam Forming



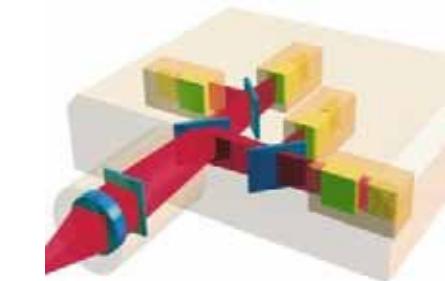
- Diode Laser Chip



- Diode Laser heat Sink

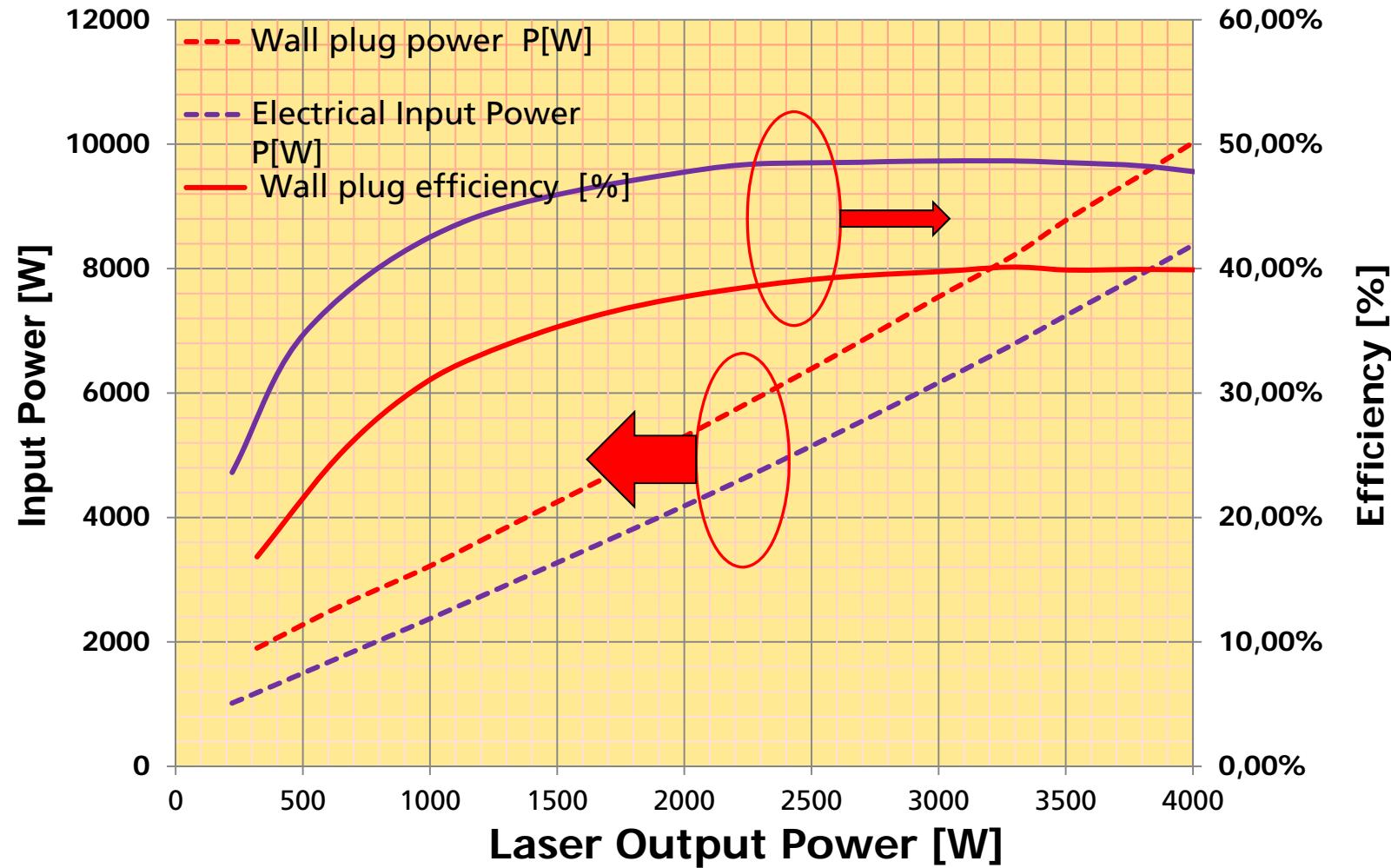


- Diode Stack



- Diode Laser head

High Power Diode Laser Bars - Source Efficiency



HPDL bars - Fiber coupled Diode Laser (LDF)

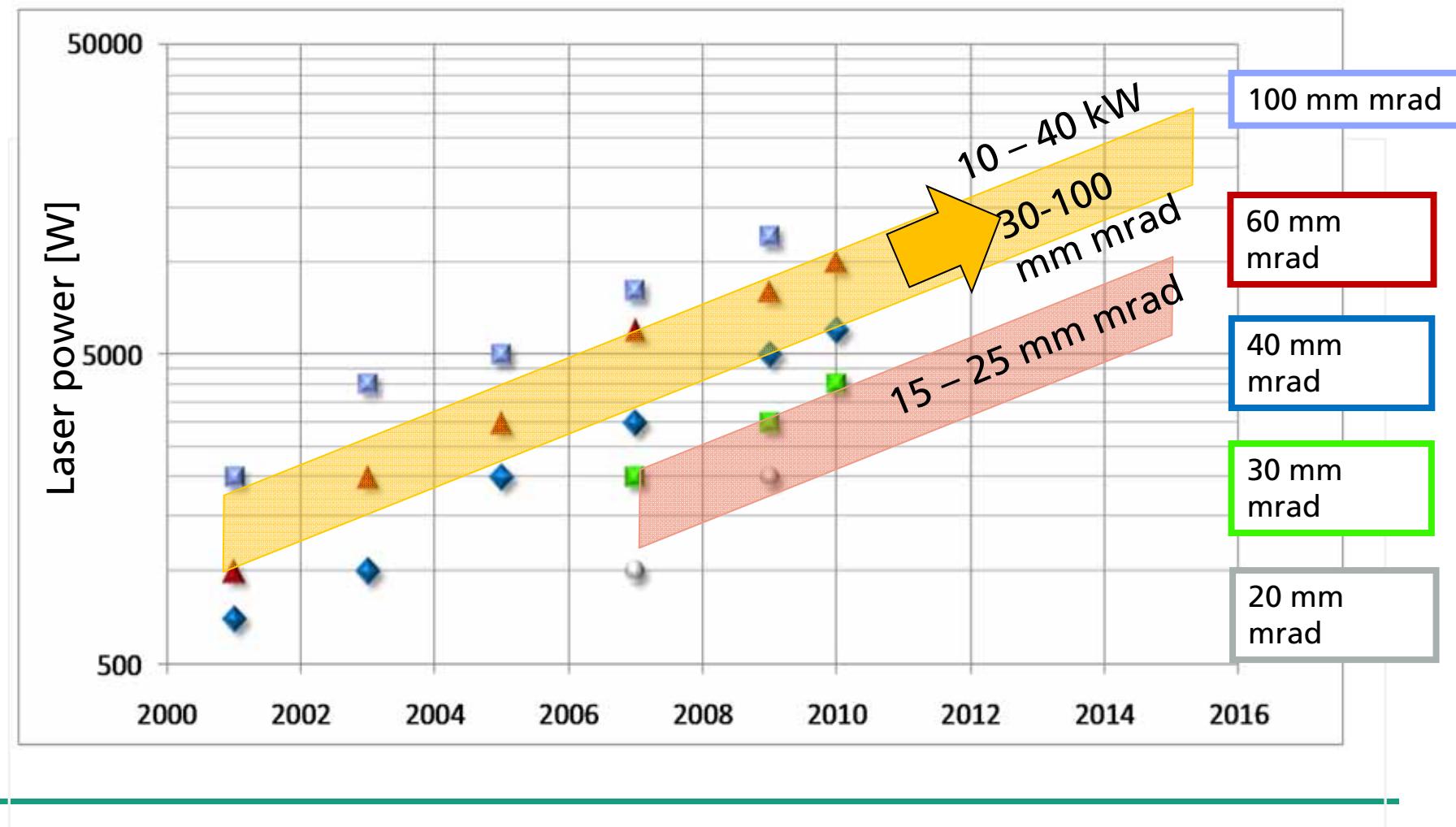


- Moveable diode laser (LDF)
 - Laser power from 1000 up to 15.000 W
 - Beam quality > 30 mm mrad
 - Foot print 0,9 m²

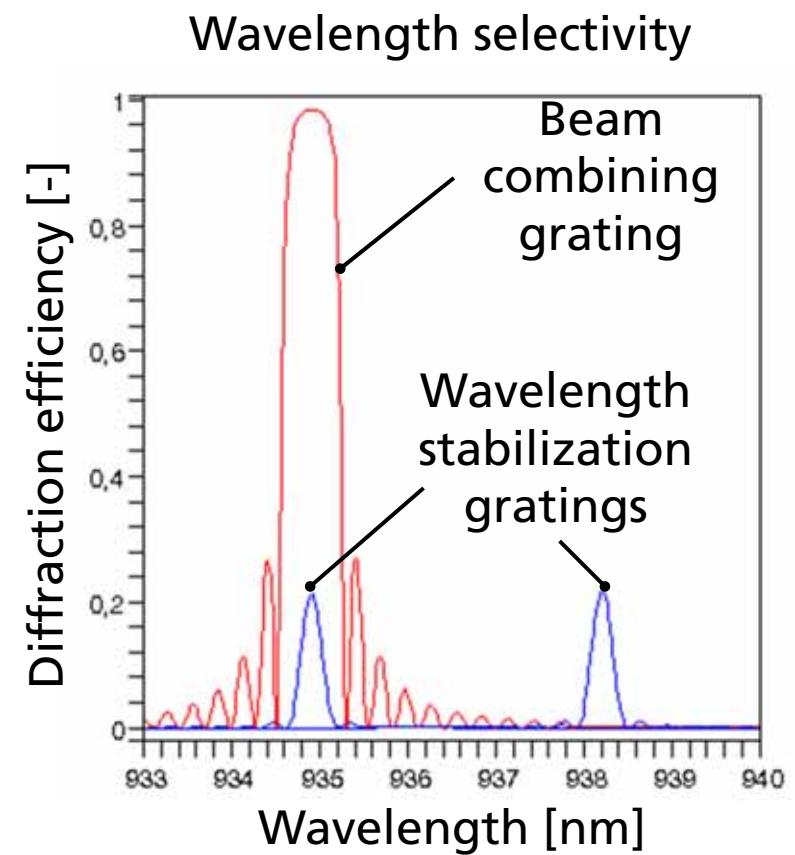
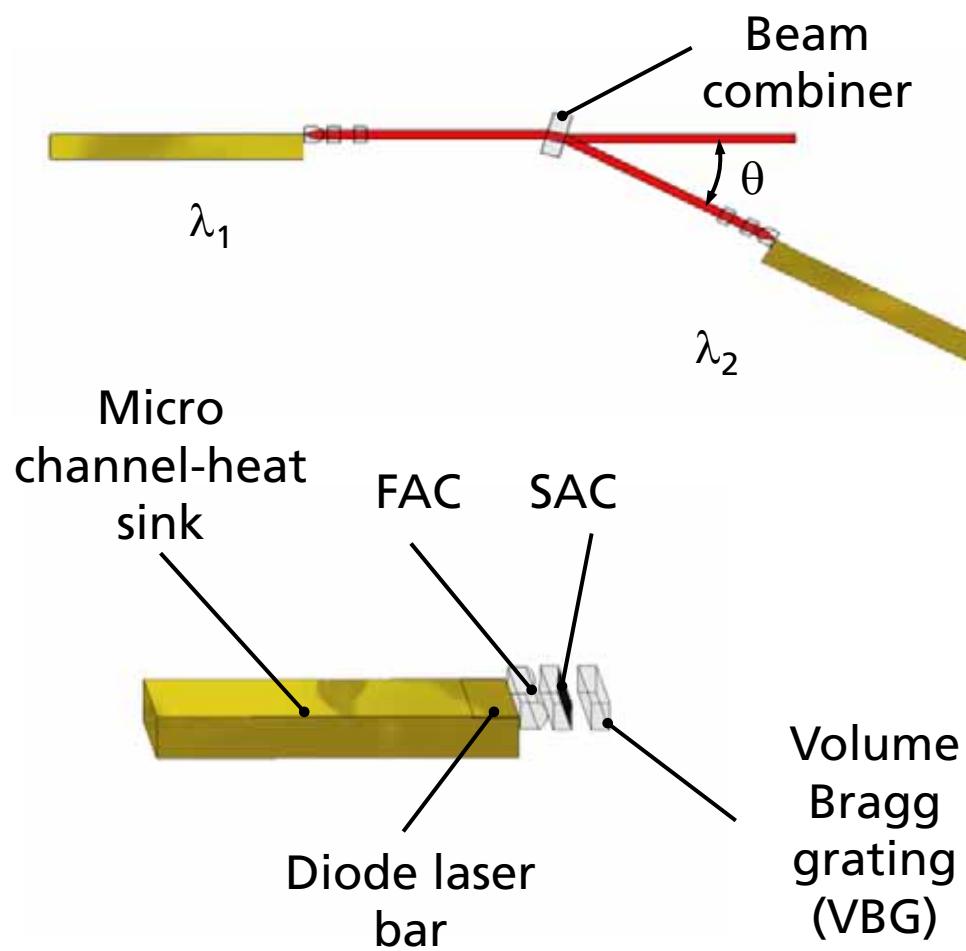
15.000 W @ 100 mm mrad

4.000 W @ 30 mm mrad

High Power Diode Lasers based on bars - average power and beam quality trend



Power scaling by dense wavelength multiplexing (DWDM)



DWDM - Advantages and perspectives of wavelength stabilization

**Increased yield due
to wavelength tolerance**



**Reduced manufacturing
costs**

**no micro channel
heatsinks required**



**lifetime benefit due to
passive cooling, decreases
costs**

Pump source wavelength
matches the **absorption
maximum** of laser active
materials



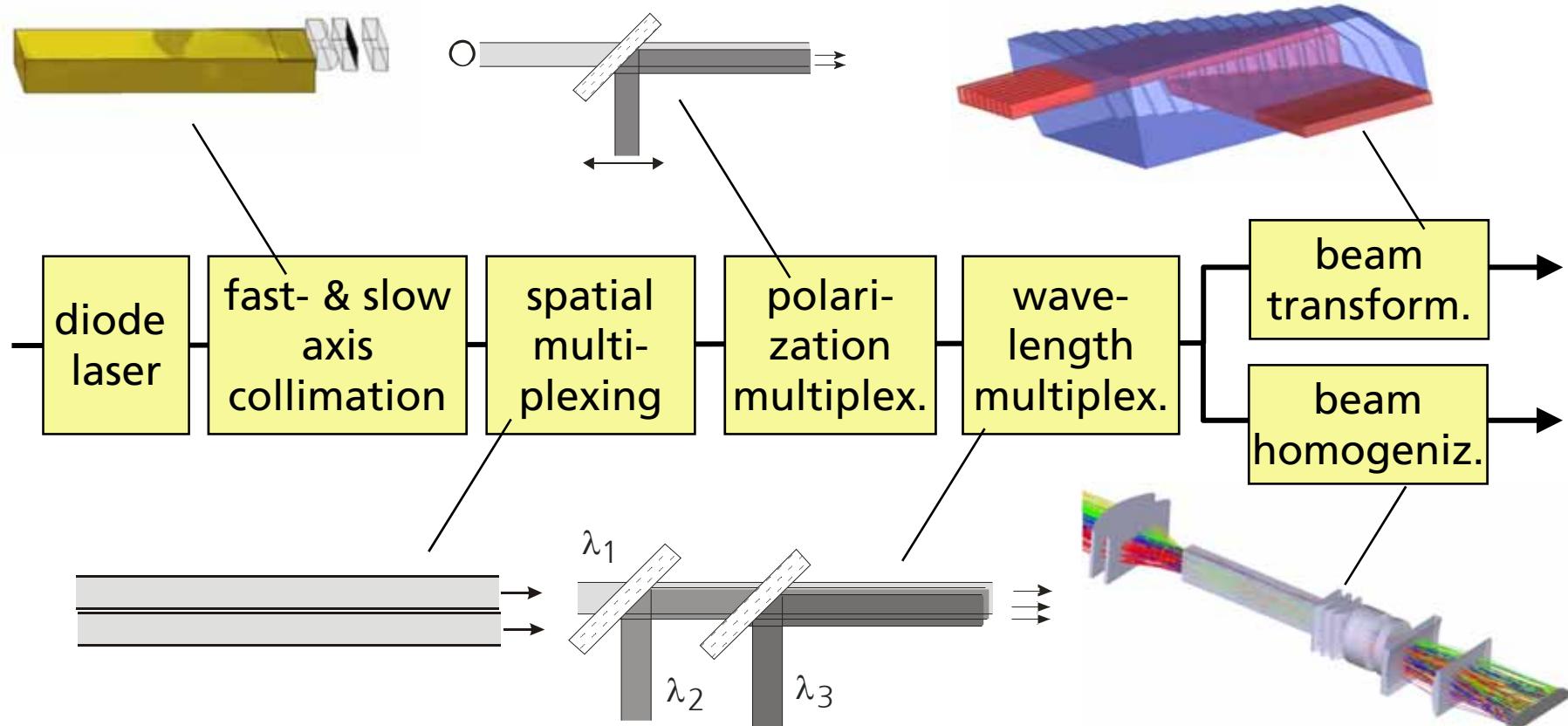
improvement of efficiency

Increasing the **brightness**
by dense wavelength
multiplexing

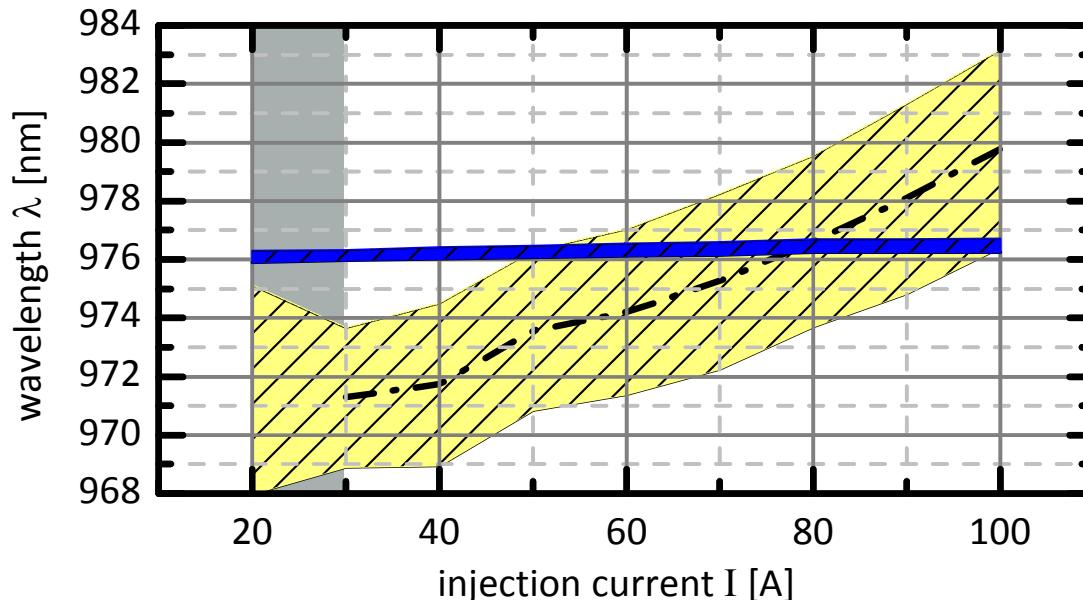


diode lasers replace solid
state lasers due to **reduced
total cost of ownership**

DWDM - Principle setup of a diode laser module

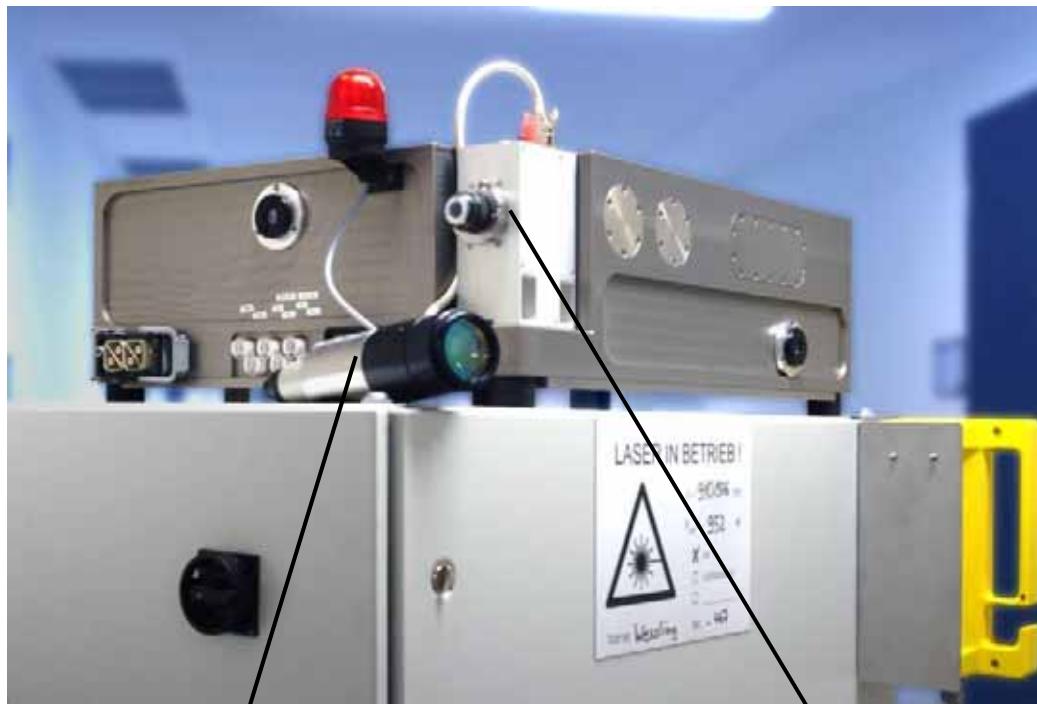


DWDM - Wavelength externally stabilized passively cooled diode laser bar



- Locking range $\Delta\lambda = 20\text{nm}$
- 95% power inclusion:
 $\delta\lambda < 0.5\text{nm}$
- Stabilization causes no losses
- Thermal shift without cooling:
 $d\lambda_c / dT = 0,006\text{nm/A}$
- Thermal shift with cooling:
 $d\lambda_c / dT = 0,003\text{nm/A}$
- Stabilization prevents early roll over effect

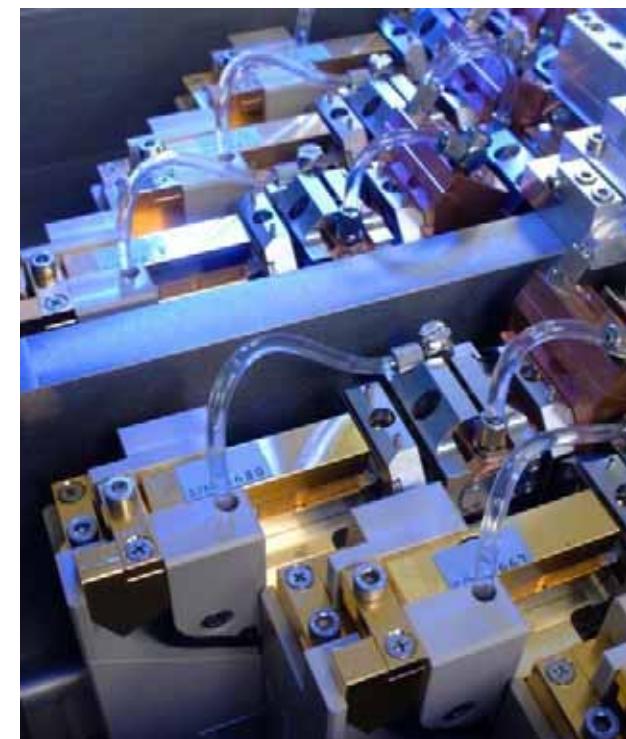
DWDM - KW Class Diode Laser ILT Prototype



Collimating and Focusing
Optics

Fiber coupling

2x3 DWDM units

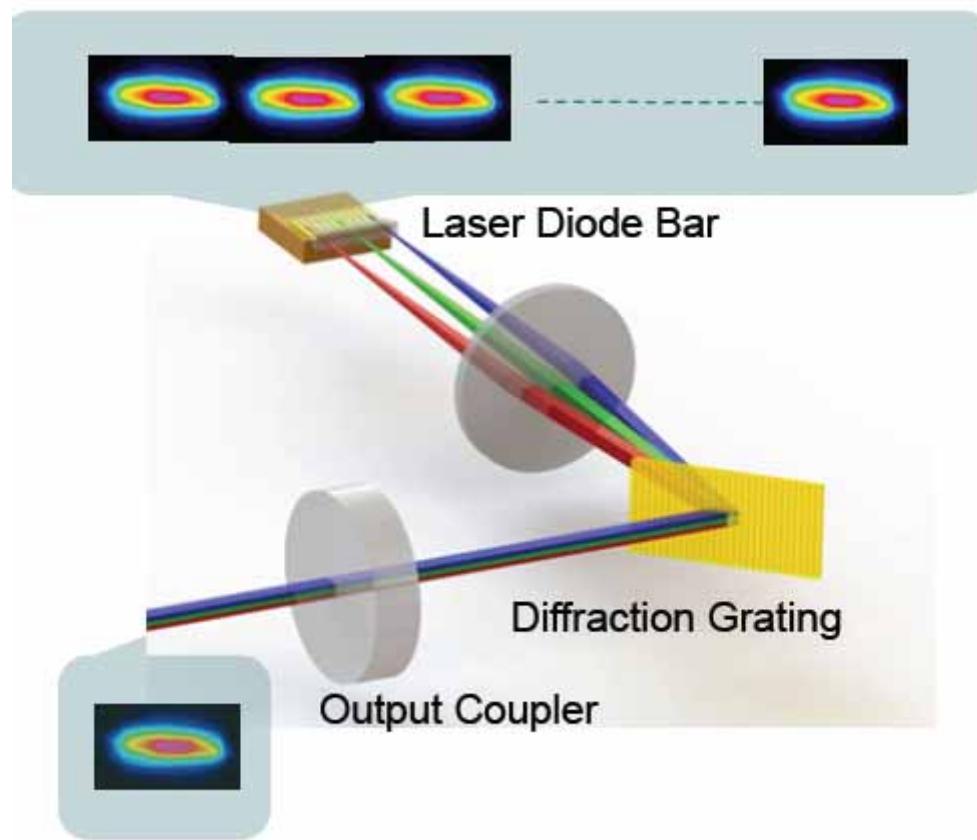
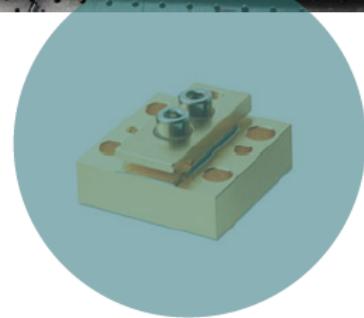
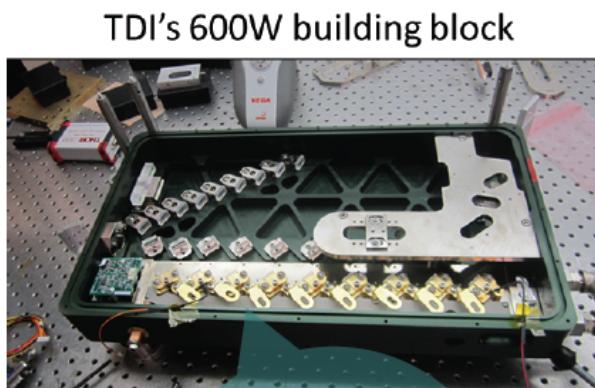


The system has been demonstrated for:

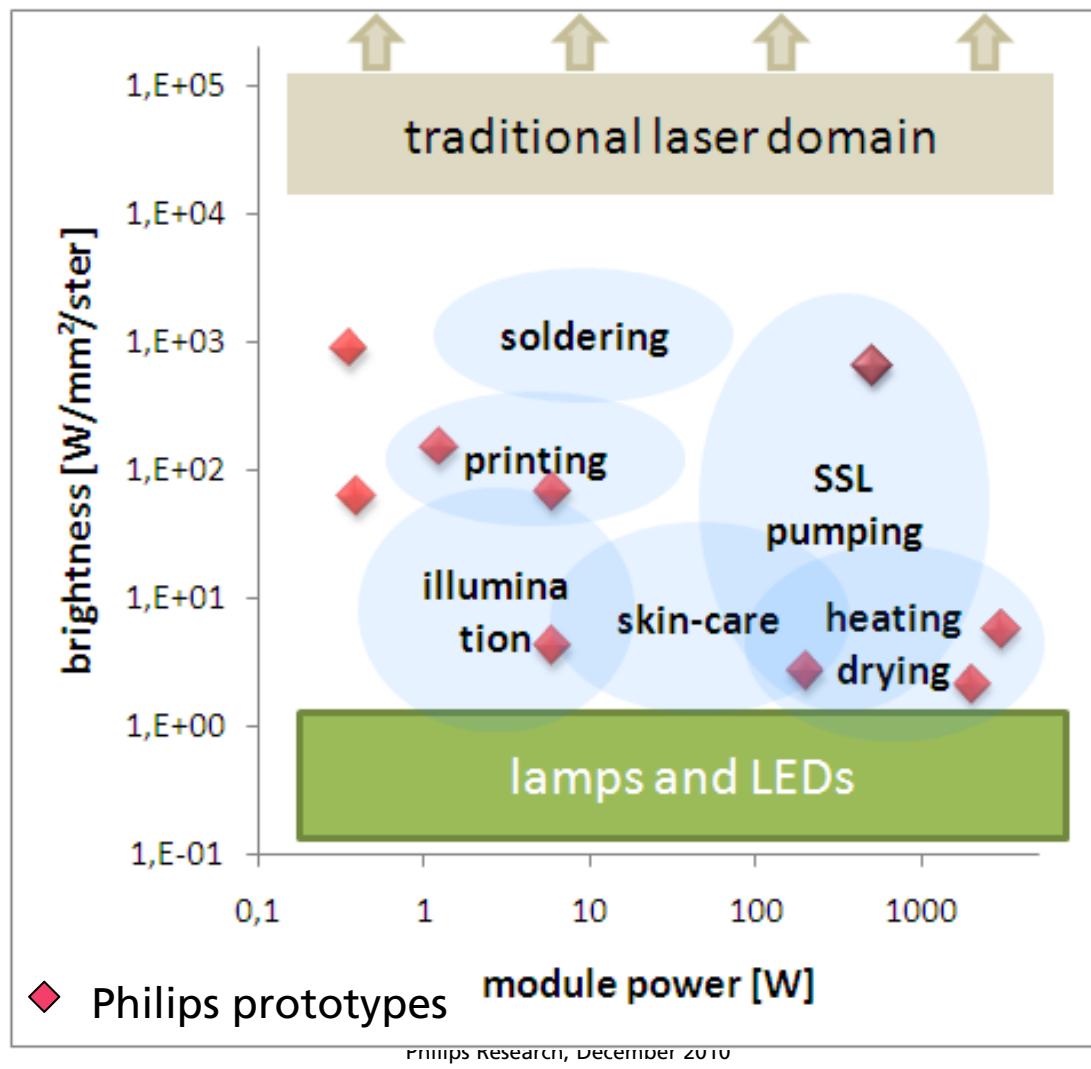
- steel welding
- fiber laser pumping

DWDM by Diffraction Grating - TERADIODE

- 2 kW out of a 50...100 μ m fiber
- Bandwidth: about 20nm / kW



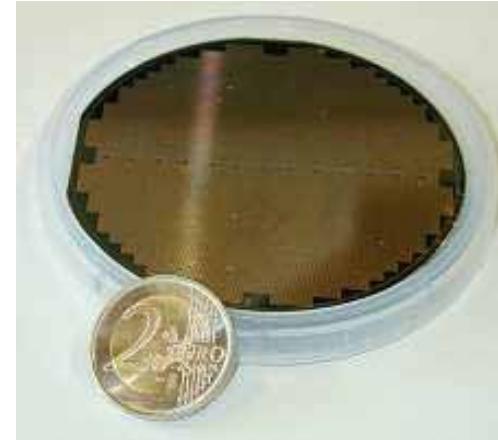
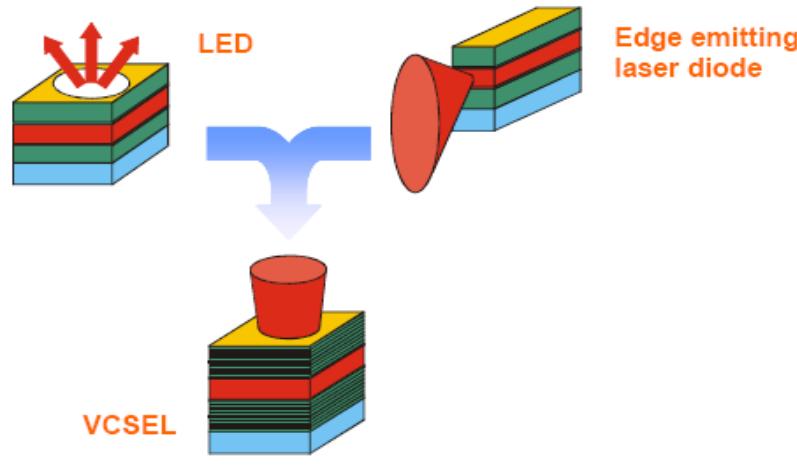
Vertical emitting high power diodes - VCSEL



VCSELs are ideal for **illumination and thermal processes** requiring brightness better than LEDs but not yet a “perfect laser”



VCSEL - Wafer scale production and synergy with LEDs enable lowest cost



a 3" wafer contains many 10,000s of fully processed and 100% tested VCSELs

VCSEL assembly will profit from the upcoming LED developments:



LED thermal challenges

X10
→



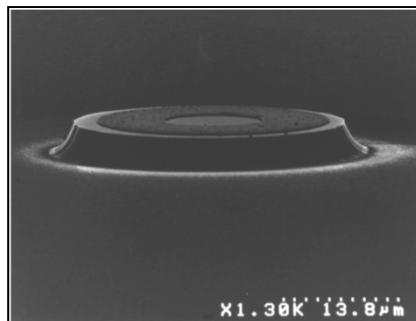
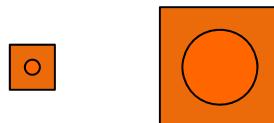
LED thermal challenges

X10
→

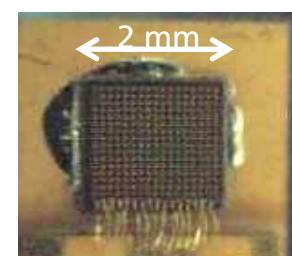
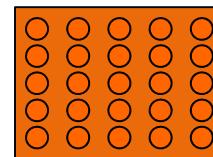


VCSEL arrays for power scaling

single emitters 3-100 μm
5-500mW

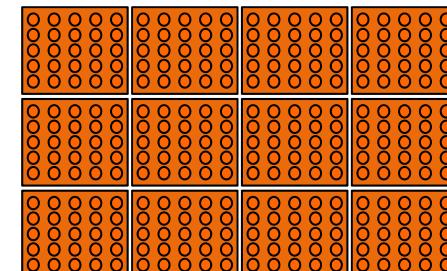


single chips
1-100W

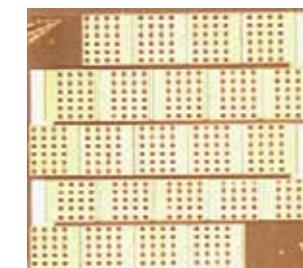


6W

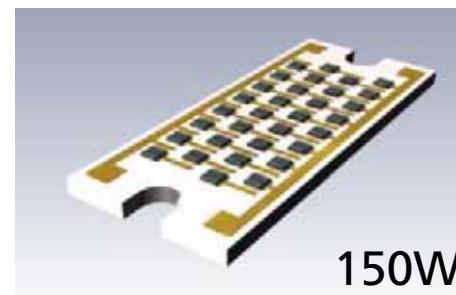
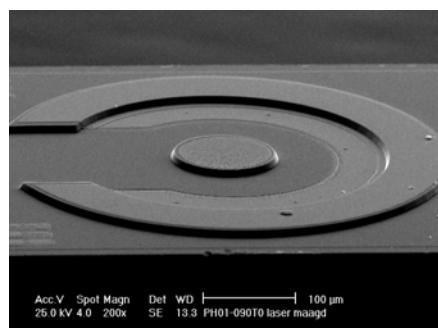
multi-chip modules
10-2000W



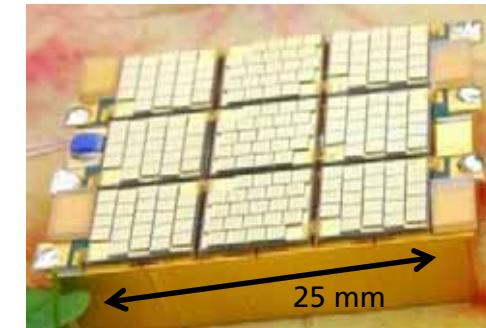
8 mm



60W

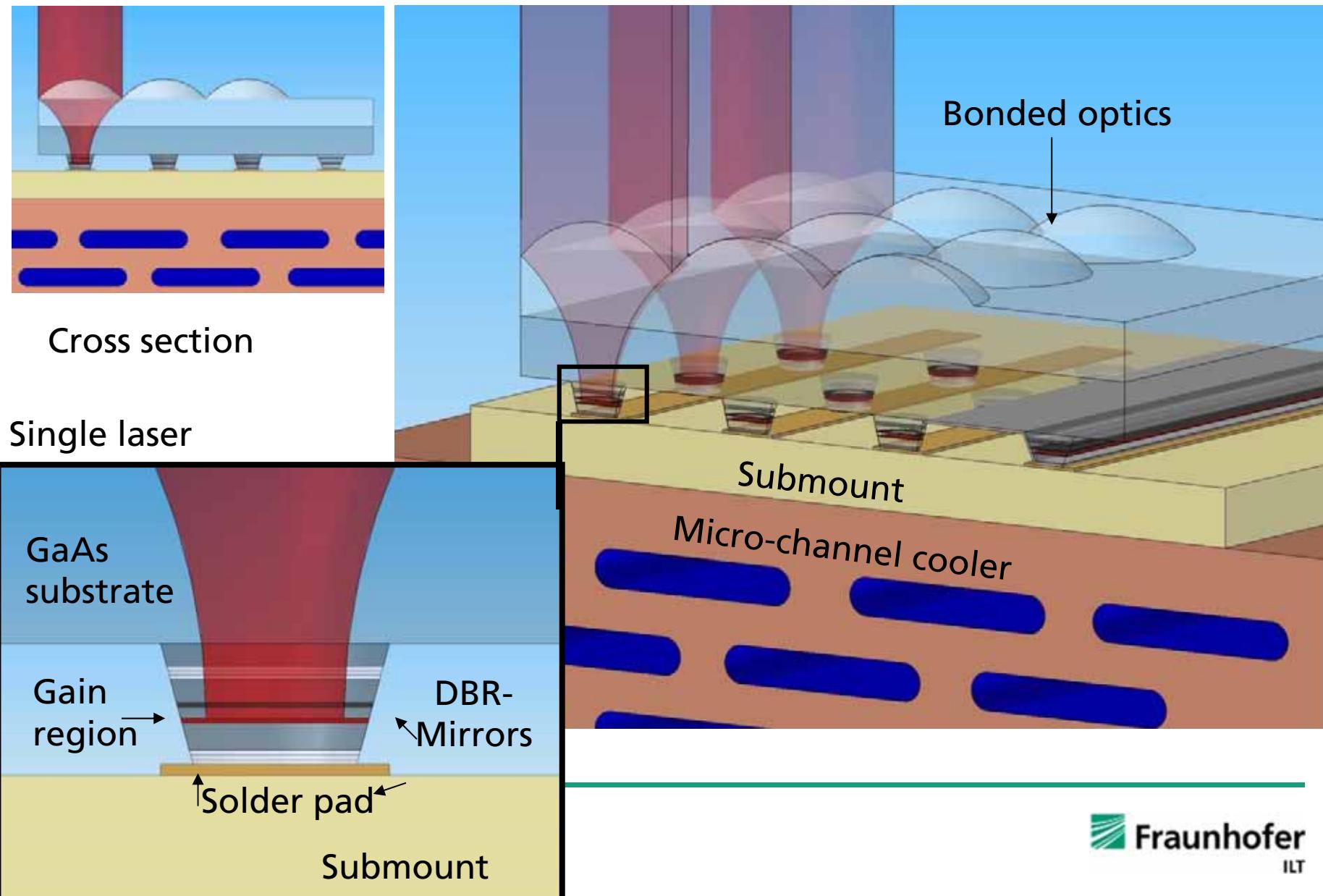


150W



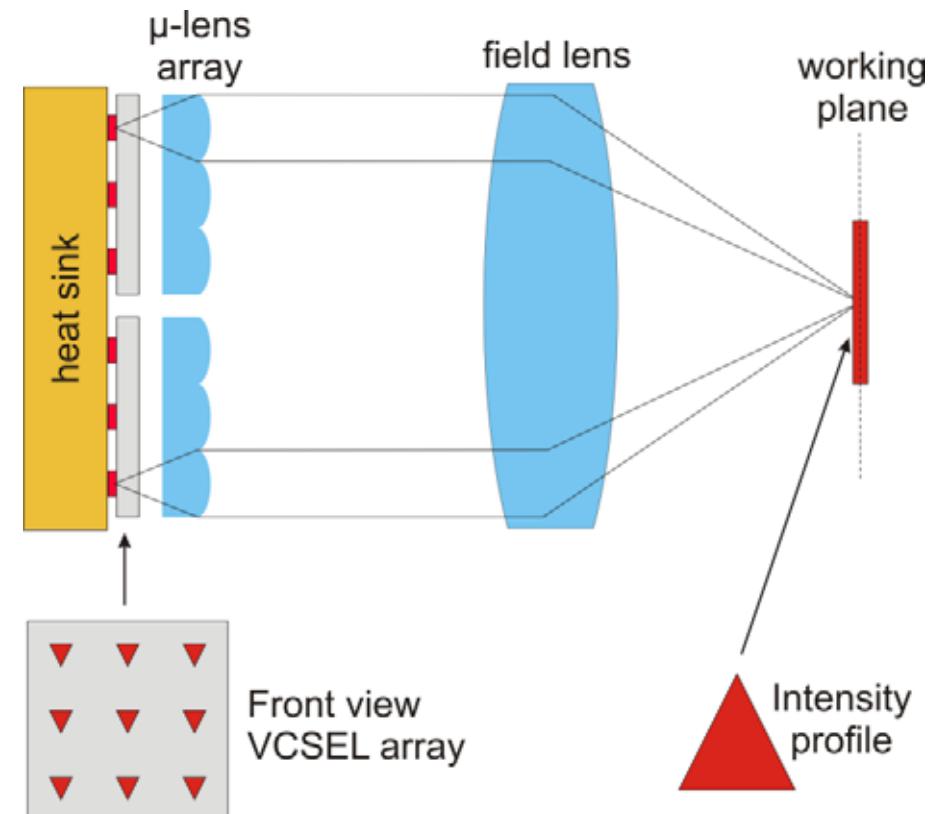
500W

VCSEL - Monolithic Wafer Scale Integration of Micro-Optics



VCSEL - Tailored intensity distributions by Monolithic Wafer Scale Integration of Micro-Optics

- individual VCSELs are collimated arrays of μ -lenses
 - ▶ **preserves power density**
- many VCSELs are superimposed by a field lens
 - ▶ **small differences are averaged out**
- the μ -lens and the field lens image the shape of the VCSEL (near field) to the target
 - ▶ **well controlled and tailored intensity distributions**



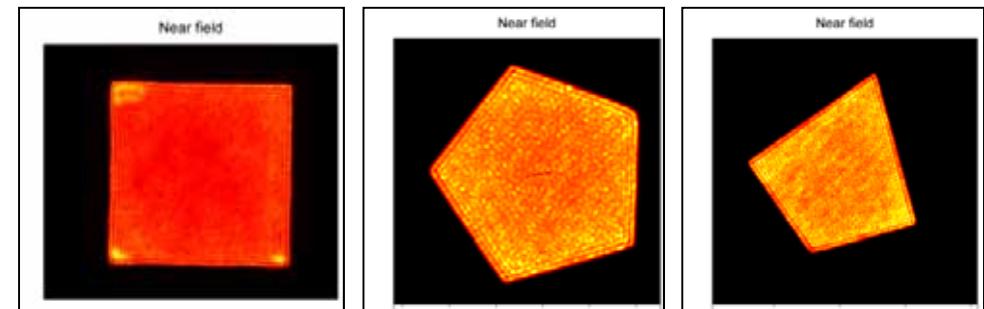
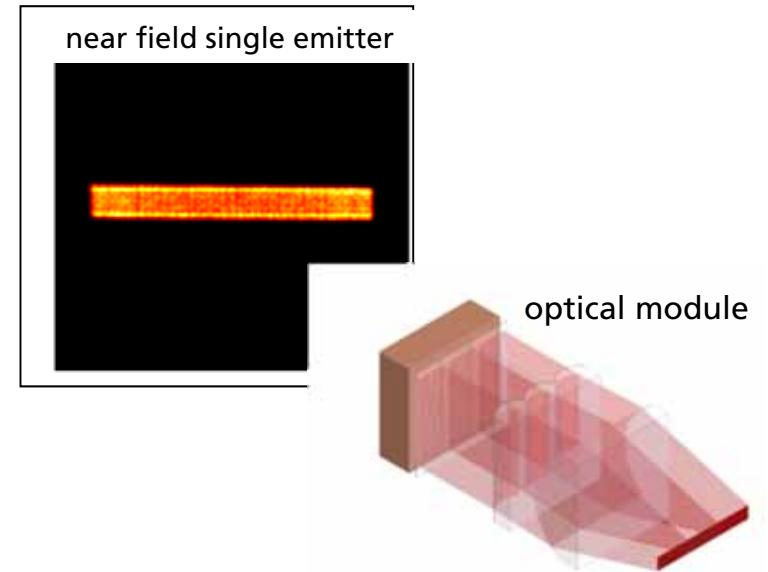
VCSEL - Examples for tailored distributions

Very high uniformity

- extreme uniformity along the line (1%)
- Superposition of thousands of individual emitters → very robust
- power density 6W/mm²
- modular and scalable up to meters

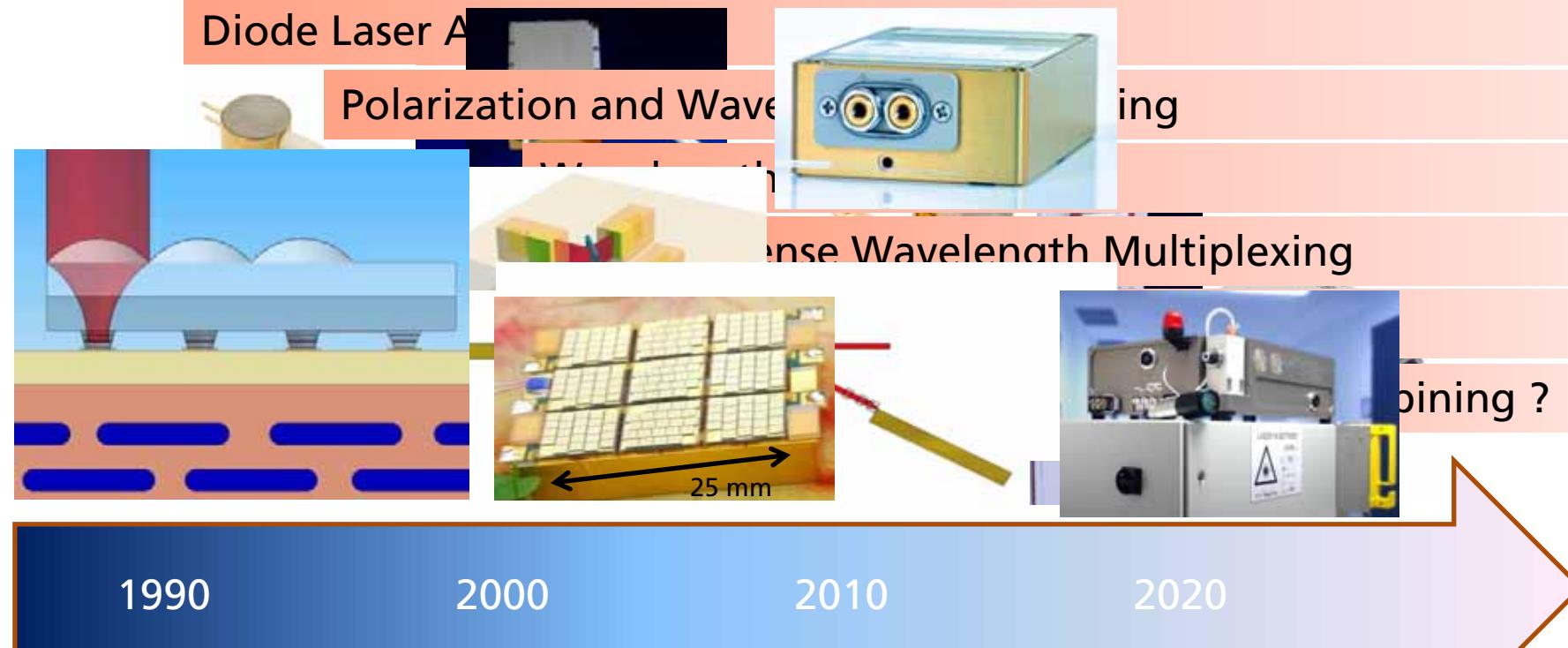
Arbitrary shapes

- VCSEL shape is well defined by lithographic processes and offers design freedom



Trends and Perspectives of Diode Lasers

Single Emitters

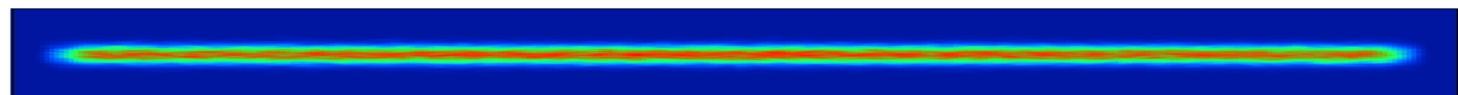


Reliability at High Power

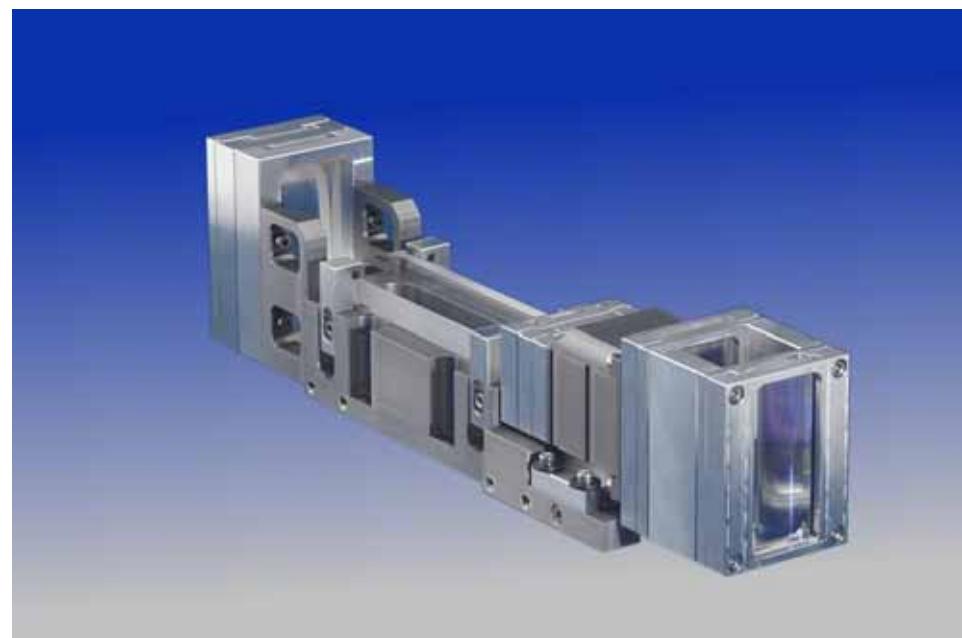
Prize and Production Scaling / Automation

Scaling of Power, Efficiency and Brilliance

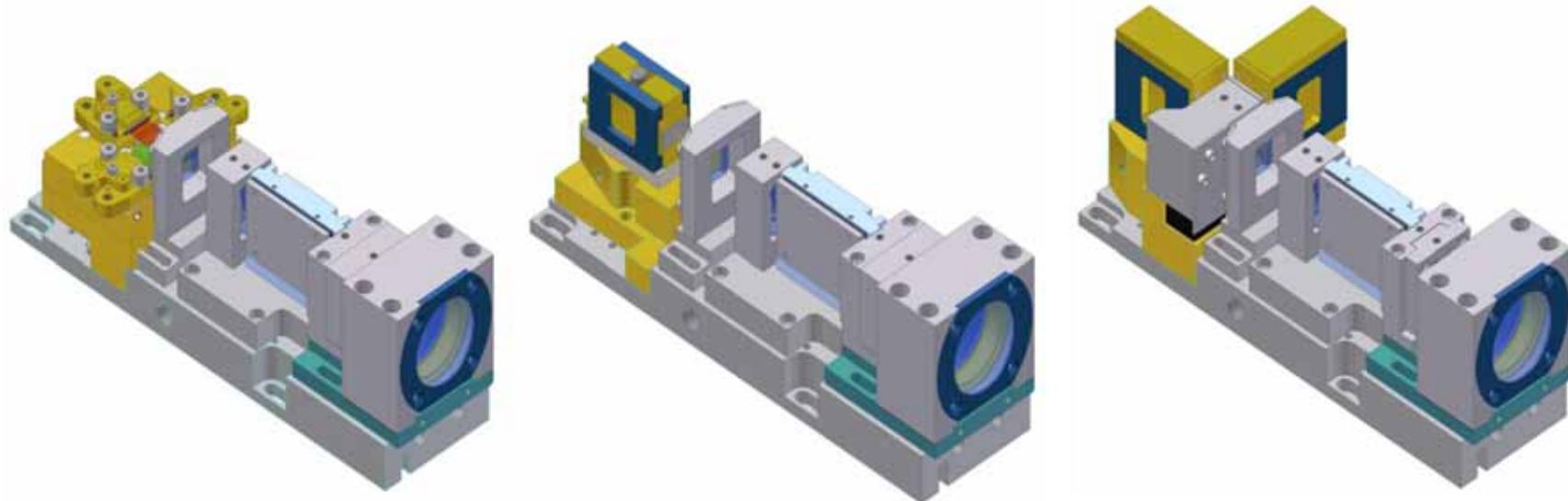
Pumping - Homogenized beam for a kW Class InnoSlab Laser



- homogeneous intensity distribution
- compensates for diode failure and inhomogeneous diode laser emission
- pump power 1.4 kW
- efficiency > 90 %



Modular Pumpoptics for InnoSlab lasers



Transfer efficiency 90 % to 95 %)

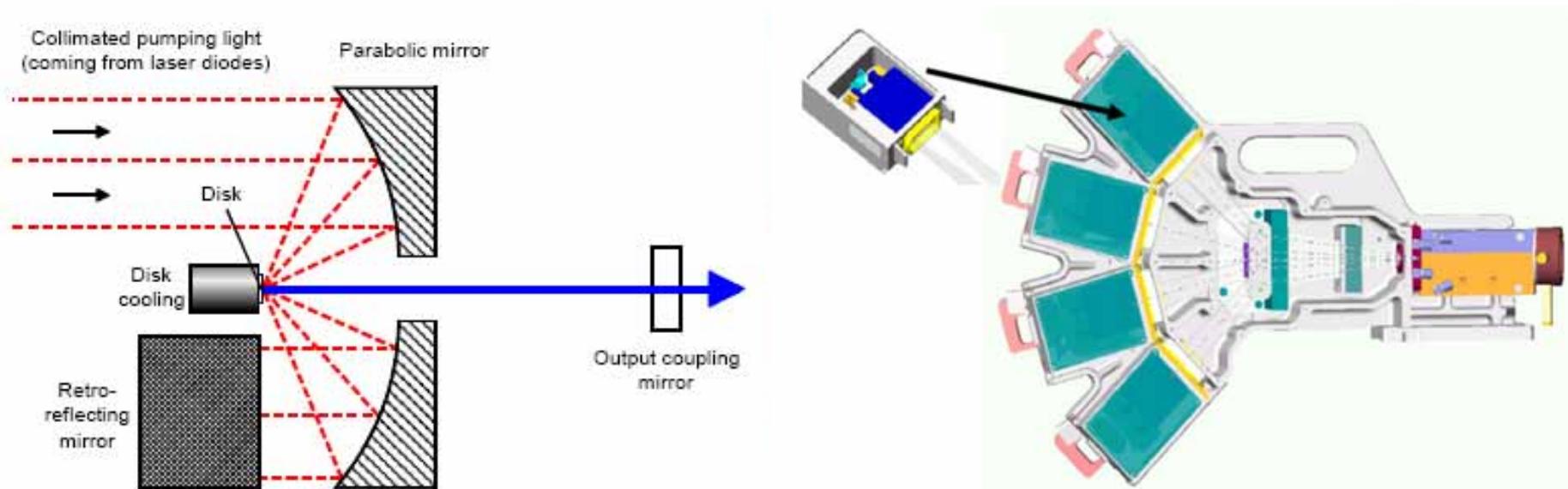
optical stack with 3
passive cooled diodes
ca. 150 W

single stack
ca. 280 W

2 stacks with
polarisation coupling
ca. 560 W

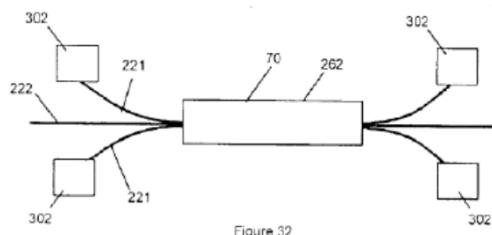
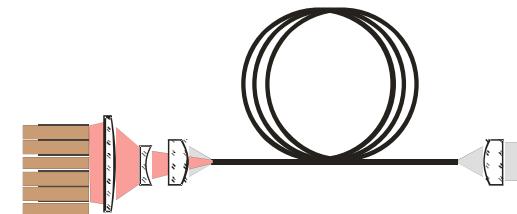
Pump optics for disc lasers (Example: Trumpf)

- Fiber based pump sources can be easily adapted but are more expensive at kW avg. power
- Pump homogenization by waveguide

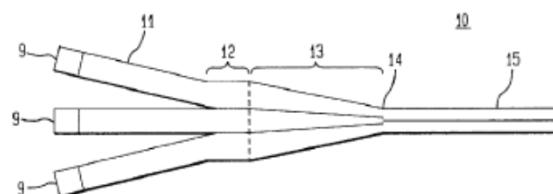


Pumpoptics for fiber lasers

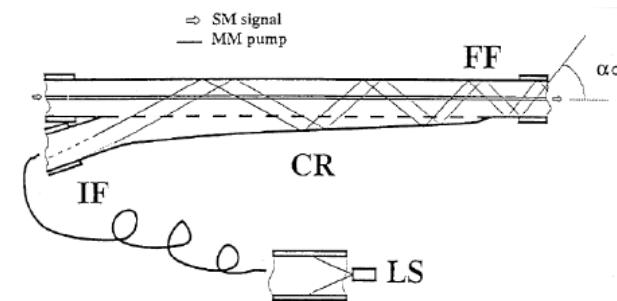
- Fiber based designs for coupling the pump power into the pump core
- pump homogenization provided by pump cladding
- most schemes provide separation of signal and pump beam



GT-Wave

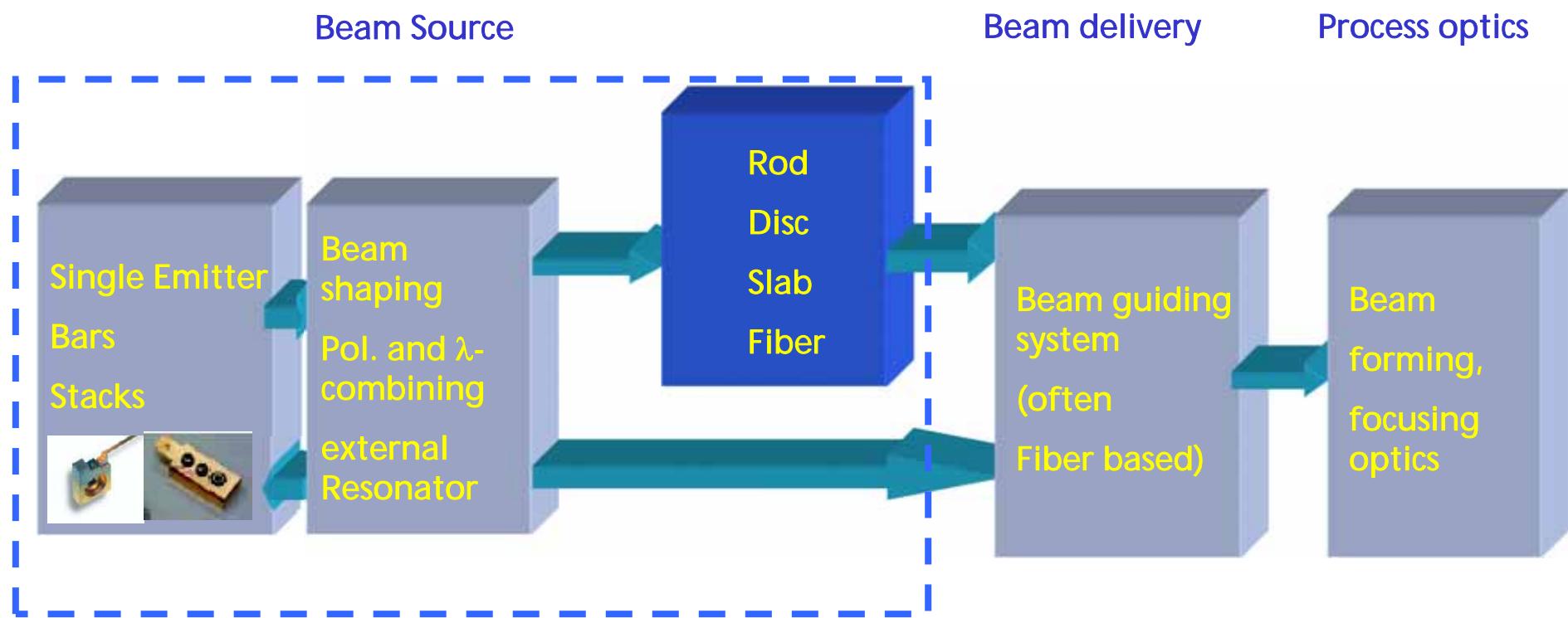


Tapered bundle endpumping
with signal feedthrough



Tapered fiber sidepumping

Laser building blocks



Outline

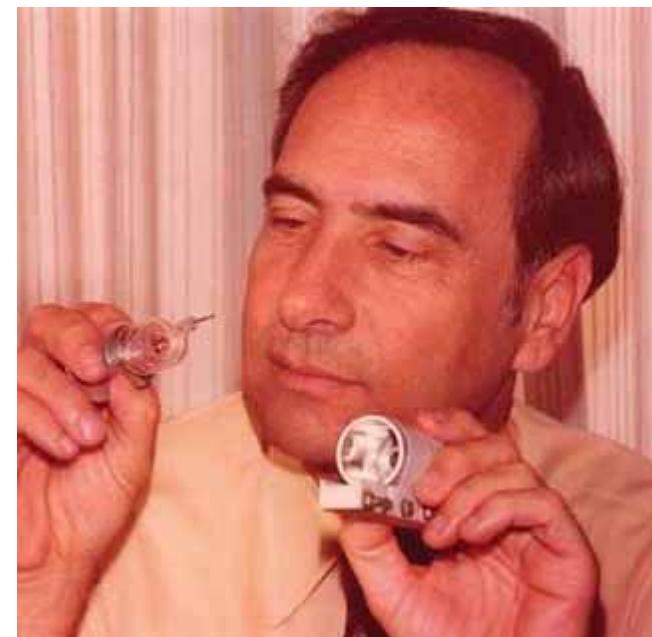
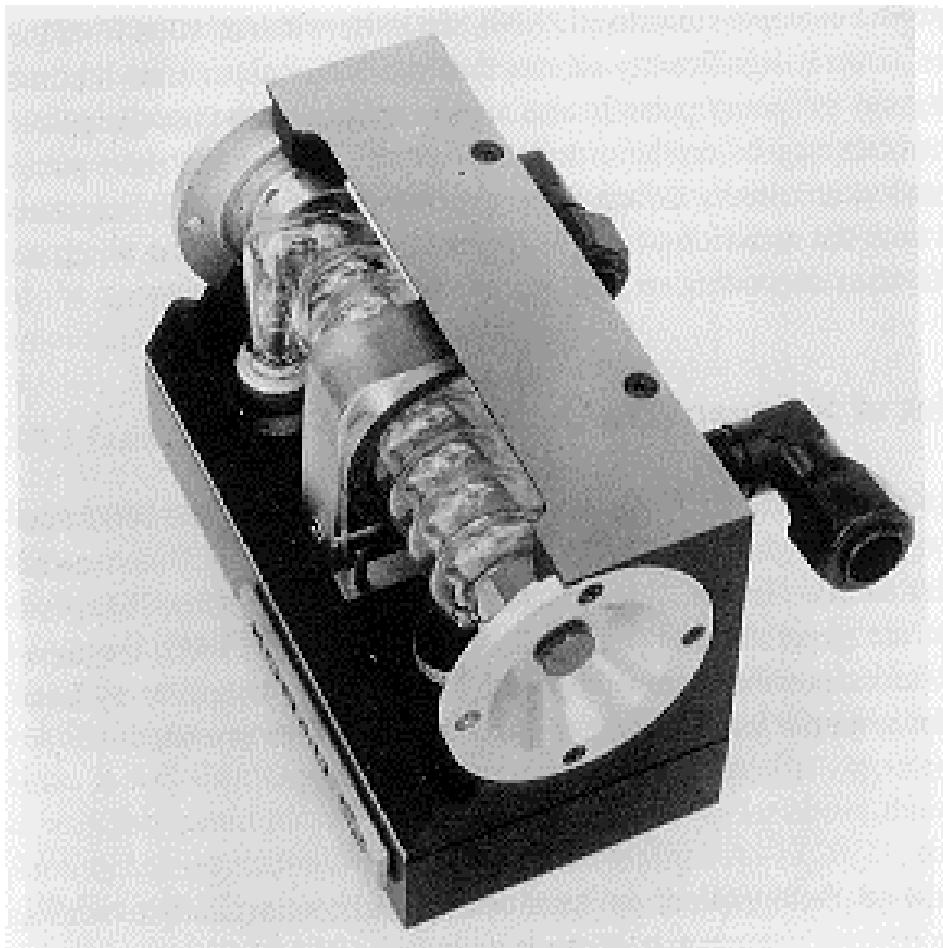
Introduction Fraunhofer ILT

Diode Lasers for Pumping

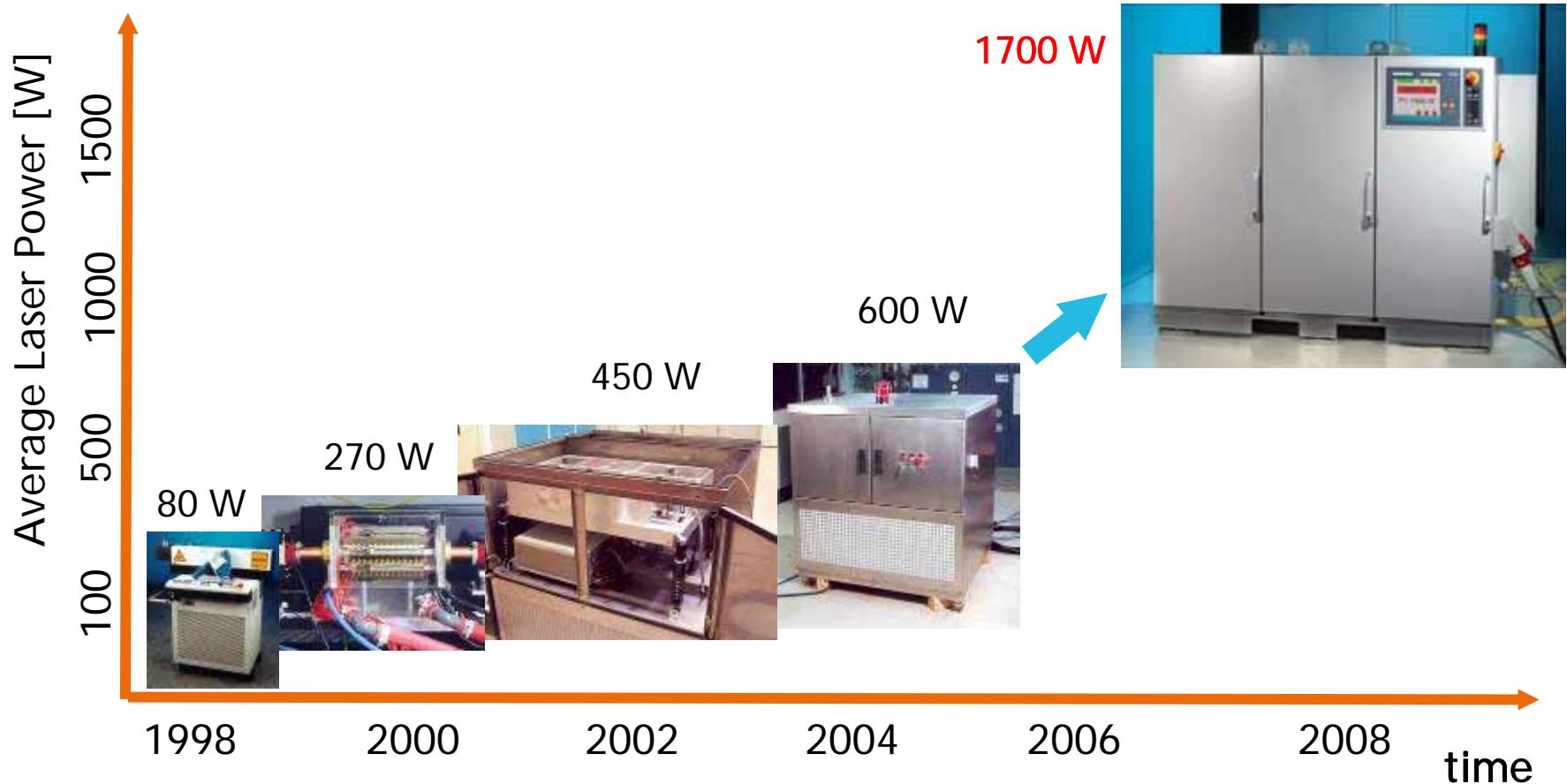
Rod Lasers and their Limitations

Innoslab – Comparison to Fiber and Thin Disk Lasers

Lamp pumped Rubin-Laser, T. H. Maiman 1960
→ side pumped cylindrical rod



Power Scaling History of Q-Switched High Power Lasers



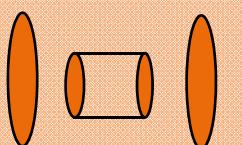
Power Scaling Fundamentals

Symmetrical oscillator with
single laser rod

$P / \text{BPP} \sim \text{const.}$

P: avg. laser power

BPP: Beam Parameter Product

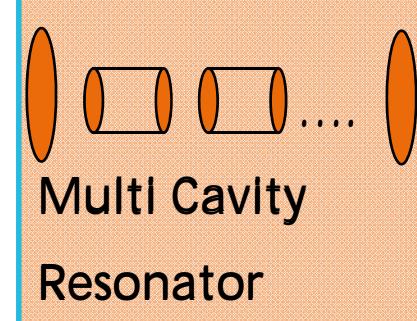


Single Cavity
Resonator

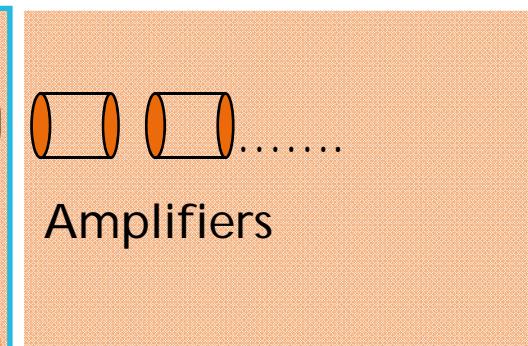
Power scaling using
symmetrical oscillator-
amplifier configuration

$N_{\text{rod}} \times P$

at const. BPP



Multi Cavity
Resonator



Amplifiers

Laser Head RSL DY HP

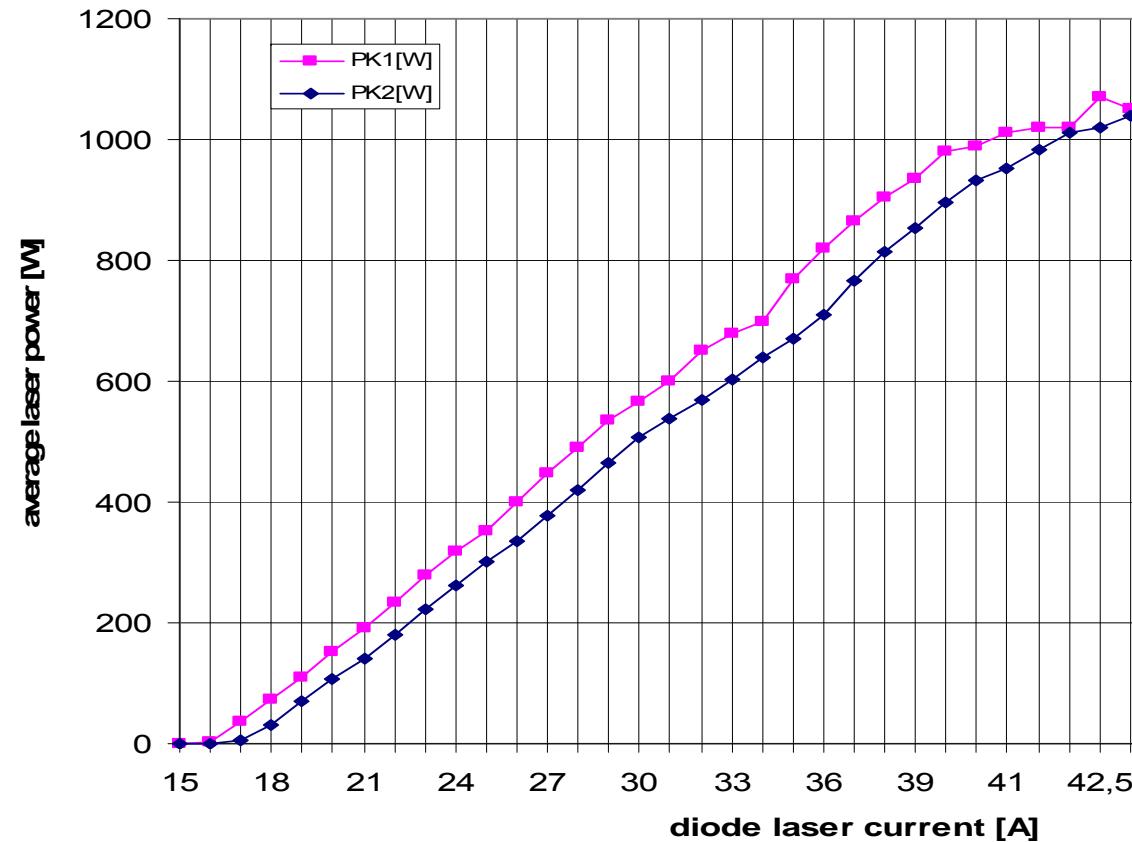
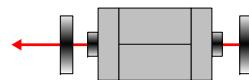
- max. CW-Pump Power:
2400 W or 4800 W
- diameter of the Nd:YAG
rod: 3 to 8 mm
- output power (lab. values)
 - < 800 W @ 12,5 mm x mrad
 - Nominal Power: 550 W
- < 1400 W @ 25 mm x mrad
 - Nominal Power: 1000 W



Single Module CW Performance - High Power Version

Symmetrical Resonator with plane mirrors

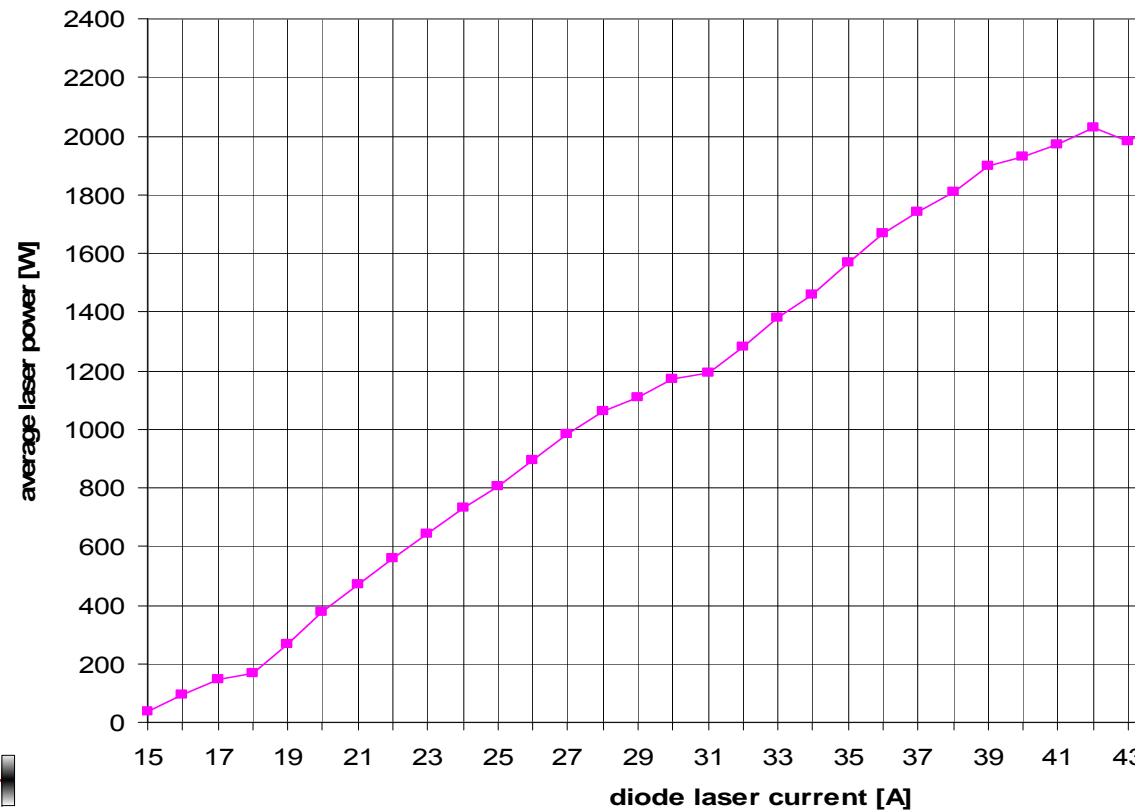
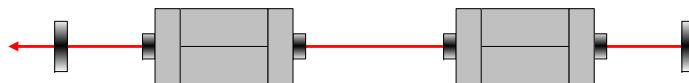
- 6.13 mm rod diameter
- Res.-Length: 500 mm
- BPP < 20 mm x mrad



Dual Module CW Performance – High Power Version

Symmetrical Resonator with plane mirrors

- 6.13 mm rod diameter
- Res.-Length: 2 x 500 mm
- BPP < 20 mm x mrad



Q-Switched High Power Lasers – Actual Design

- Max. 1.7 kW avg. Power
- > 1,5 kW avg. power at workpiece
- 480 to 500 kW peak power
- 100 to 110 ns pulse duration
- 35 to 40 kHz PRF
- Max. 50 mJ pulse energy
- 400 µm Fiber delivery



Q-Switched High Power Lasers – Cleaning Applications



High speed analysis of the cleaning process

By Carsten Johnigk, ILT



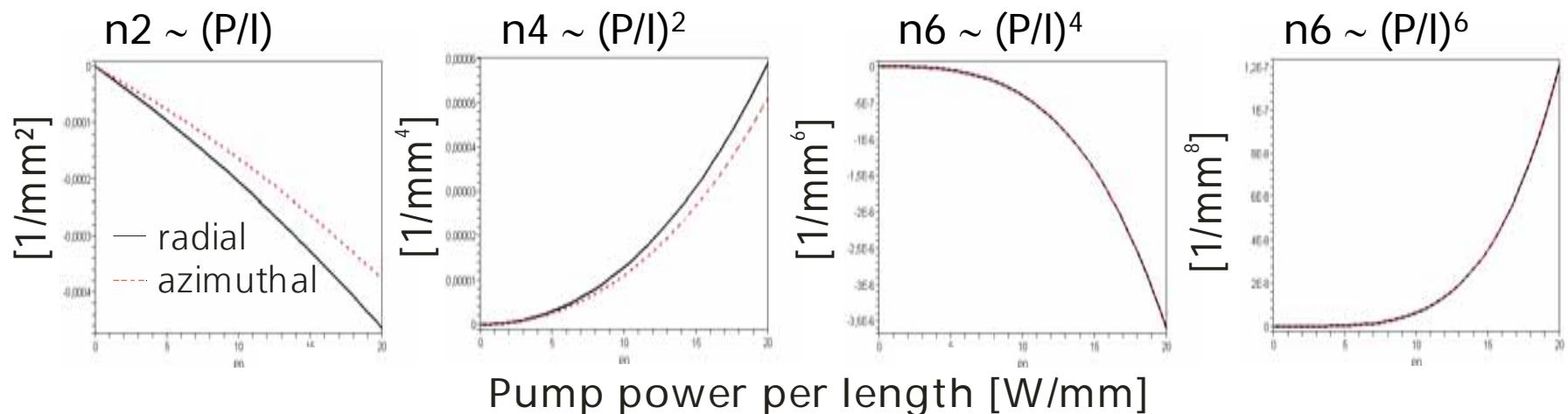
Laser cleaning with hand held 1.5 kW system (By CLEAN Laser Systems)

Selective cleaning in the automotive industry for preparation of further processing



Thermal lens

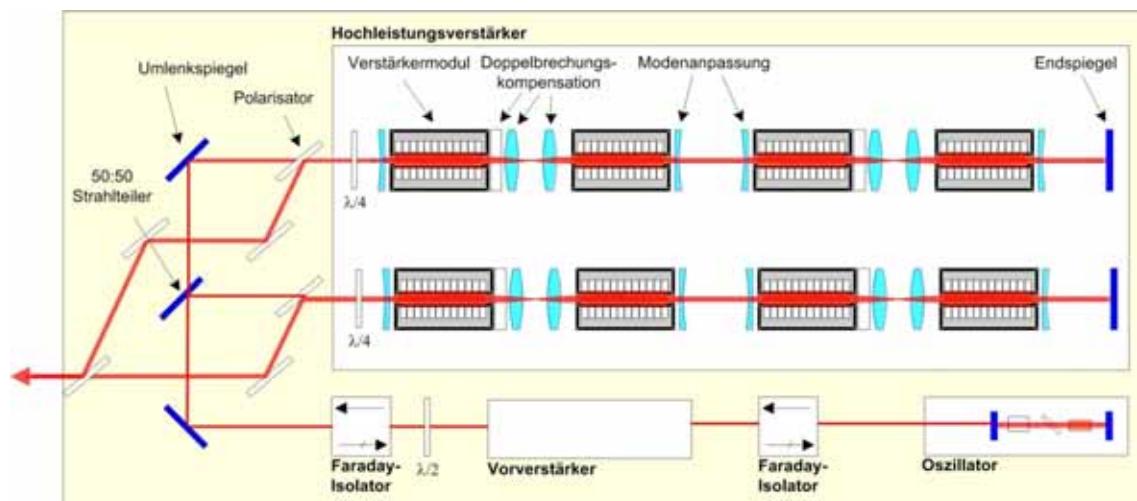
- Strong increase of aberrations with Power / Length
- Aberrations independent of rod radius



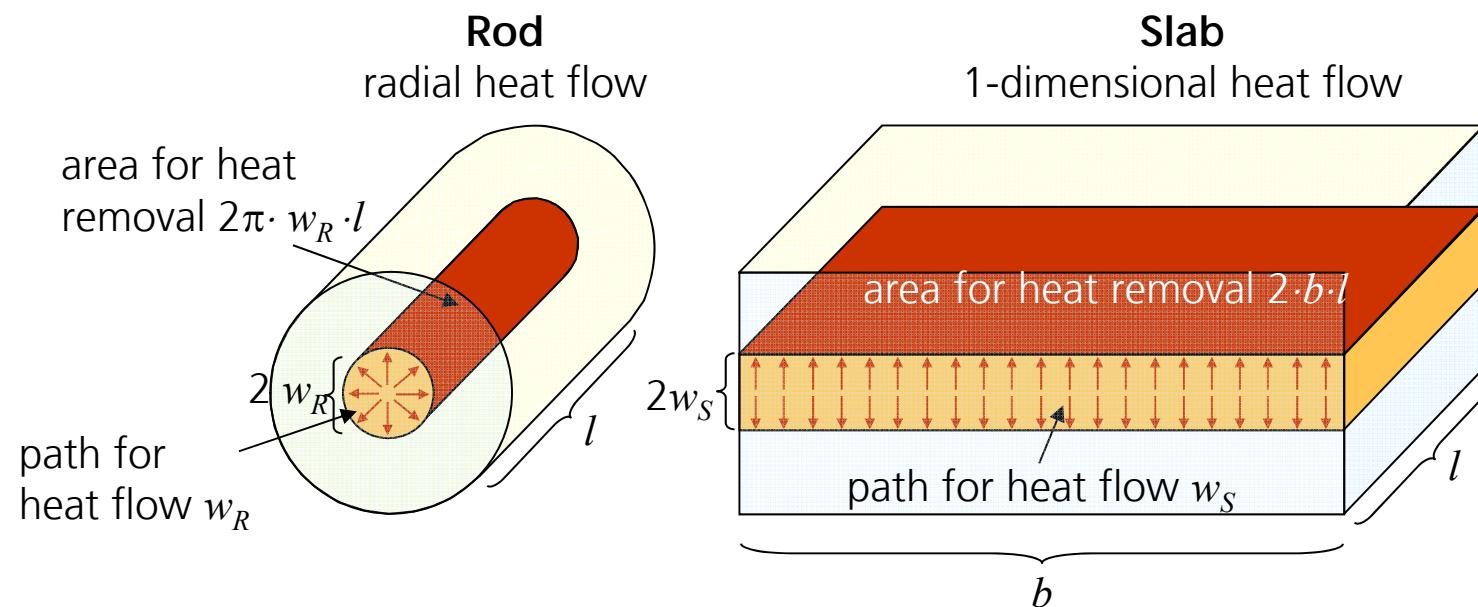
➤ Aberrations of the thermal lens limit the achievable beam quality

1.4 kW MOPA – Prototype – Delivered in 2004

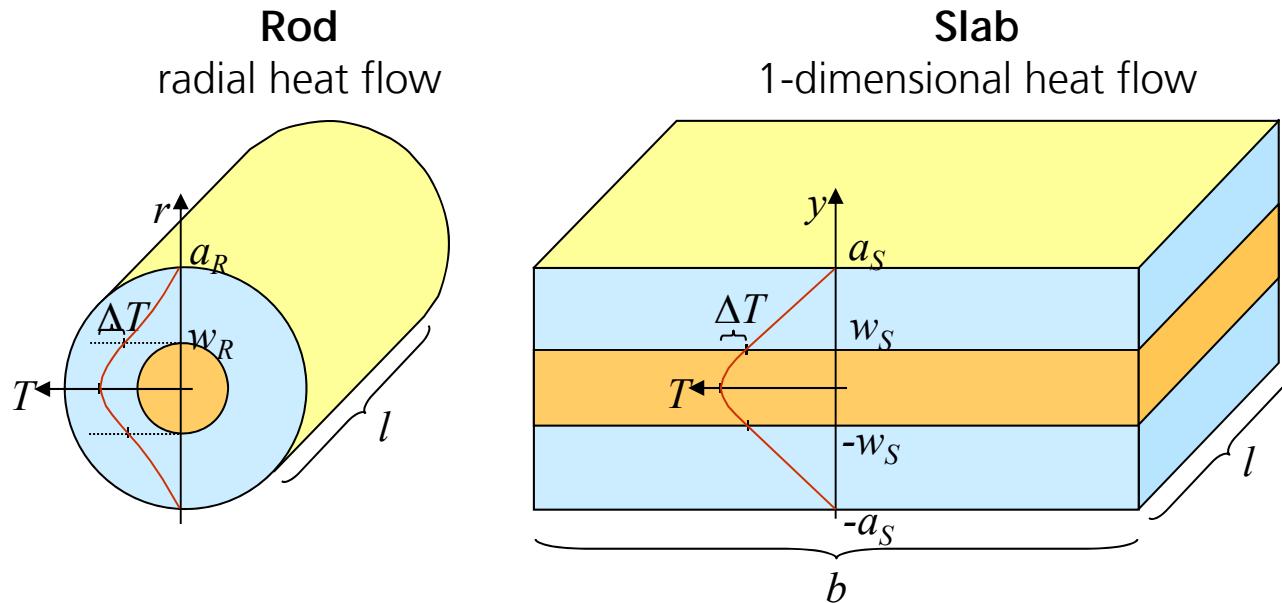
- 140 mJ
- 10 kHz
- 15 ns
- Compensation of stress induced depolarization
- Fully computer controlled
- > 1000 h of operation



Thermal Effects – Comparison of Slab and Rod Geometry



Thermal Effects – Comparison of Slab and Rod Geometry



phase difference between middle and edge of pumped area $\Delta\phi \sim l \cdot \Delta T$

is independent of pumped area for Rod, scales with aspect ratio for Slab and determines thermal aberrations

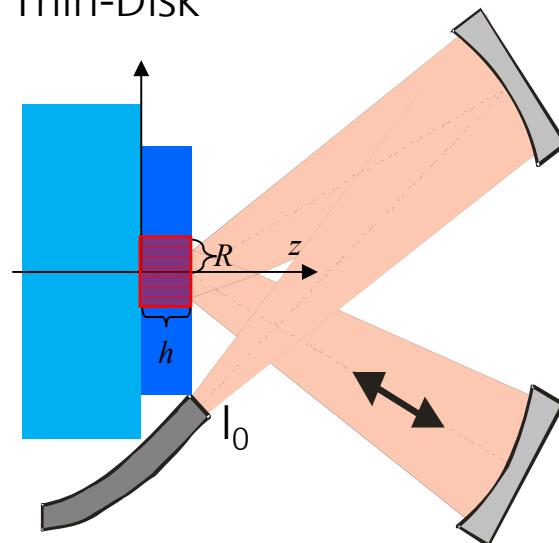
$$\Delta T_R l = \frac{P}{\lambda} \frac{1}{4\pi}$$

$$\Delta T_S l = \frac{P}{\lambda} \frac{w_S}{4b}$$

$$\frac{\Delta T_S}{\Delta T_R} = \frac{\pi}{2} \frac{2w_S}{b} = 1.6 \frac{2w_S}{b}$$

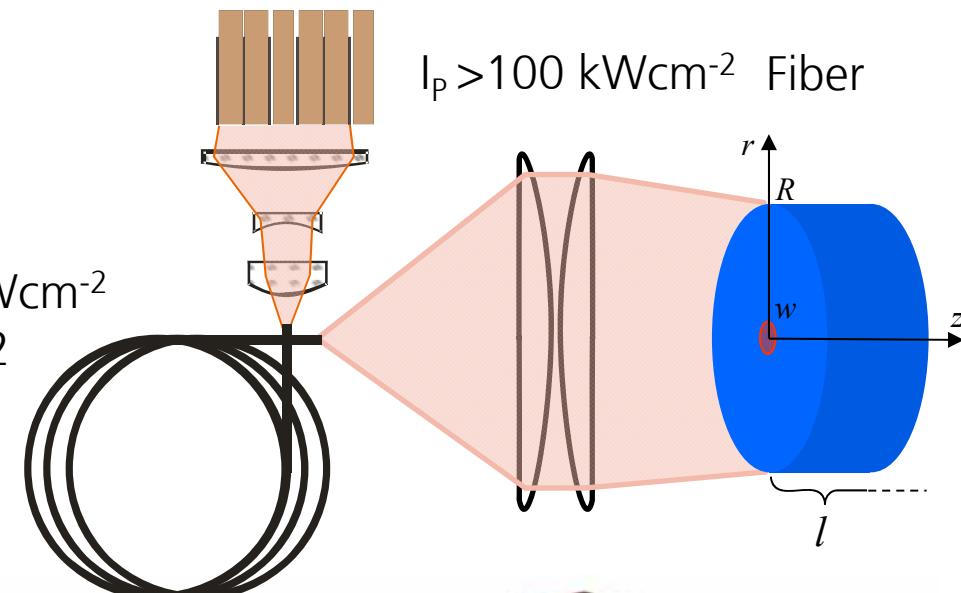
Pump Intensity (Example: Yb:YAG)

Thin-Disk

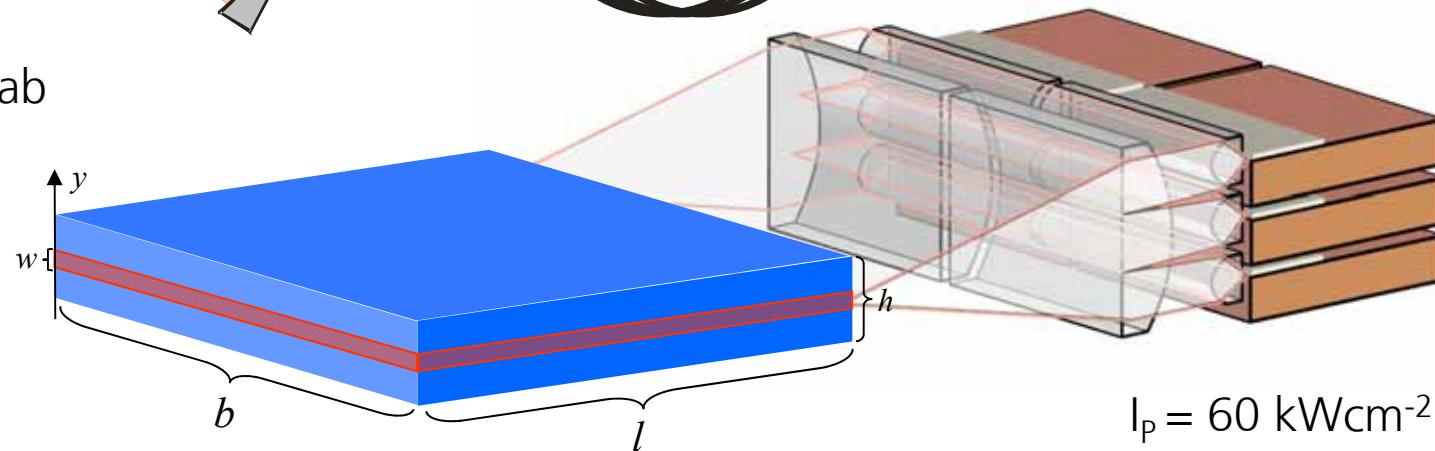


$$I_p \approx 50 \text{ kW cm}^{-2}$$
$$I_p = I_0 \cdot N/2$$
$$N = 8-32$$

$I_p > 100 \text{ kW cm}^{-2}$ Fiber



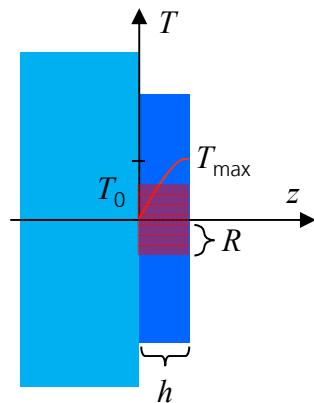
Innoslab



$$I_p = 60 \text{ kW cm}^{-2}$$

Thermal Management – Temperature Shift

Thin-Disk

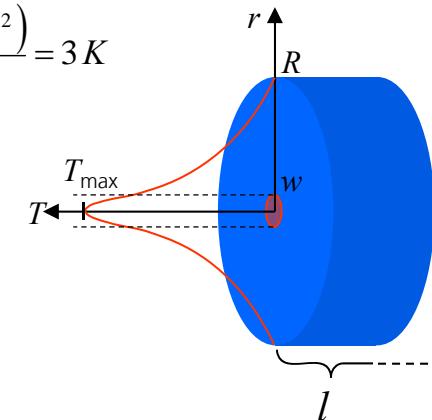


$$\Delta T_{disk} = \frac{\eta_h P_{abs}}{\lambda} \frac{h}{2\pi R^2} = 15 K$$

$$\Delta T_{fiber} = \frac{\eta_h P_{abs}}{\lambda} \frac{1 + \ln(R^2/w^2)}{4\pi l} = 3 K$$

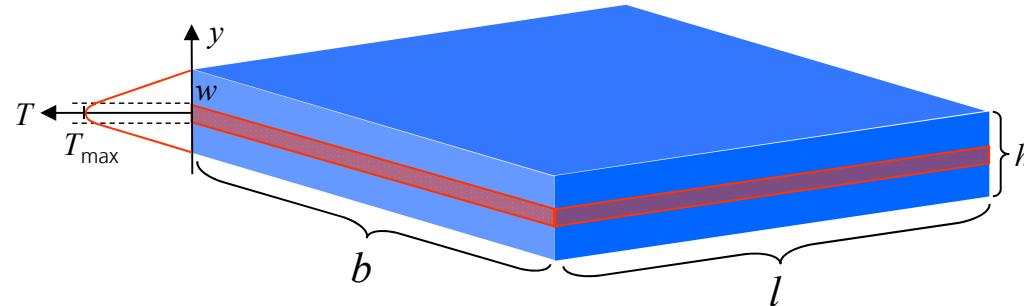
- good thermal management for all designs
- temperature depends strongly on heat contact and heat sink

Fiber



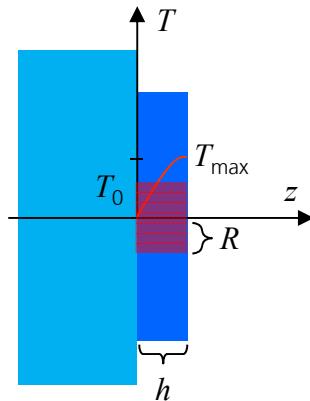
Innoslab

$$\Delta T_{slab} = \frac{\eta_h P_{abs}}{\lambda} \frac{h-w}{4lb} = 14 K$$



Thermal Management – Thermal Lensing

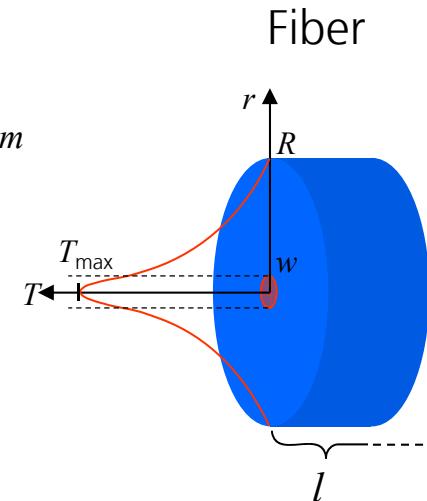
Thin-Disk



1d heat conduction
weak thermal lens
depends on pump profile

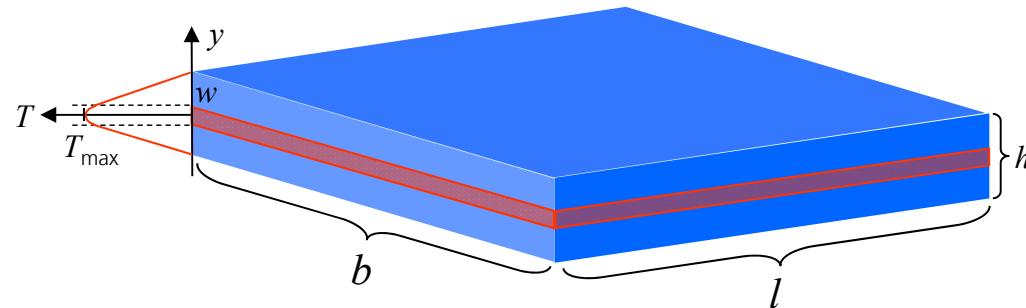
$$f_{fiber} = \frac{2\lambda \pi w^2}{\chi \eta_h P_{abs}} = 1\text{ mm}$$

thermal lens
compensated
by wave guiding



Innoslab

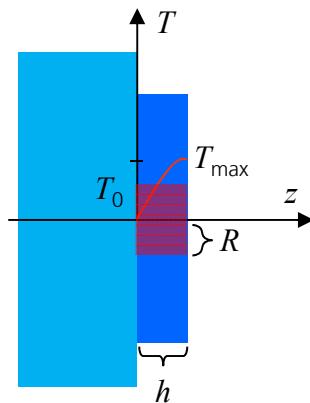
$$f_{slab} = \frac{\lambda b 2w}{\chi \eta_h P_{abs}} = 30\text{ mm}$$



1d heat conduction
cylindrical thermal lens

Thermal Management – Scaling to Higher Power

Thin-Disk



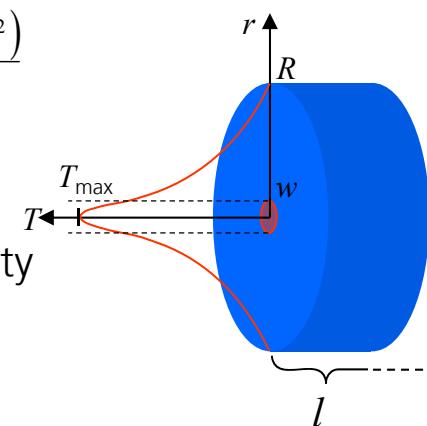
$$\Delta T_{disk} = \frac{\eta_h P_{abs}}{\lambda} \frac{h}{2\pi R^2}$$

Scaling: increase R
limited by ASE

$$\Delta T_{fiber} = \frac{\eta_h P_{abs}}{\lambda} \frac{1 + \ln(R^2/w^2)}{4\pi l}$$

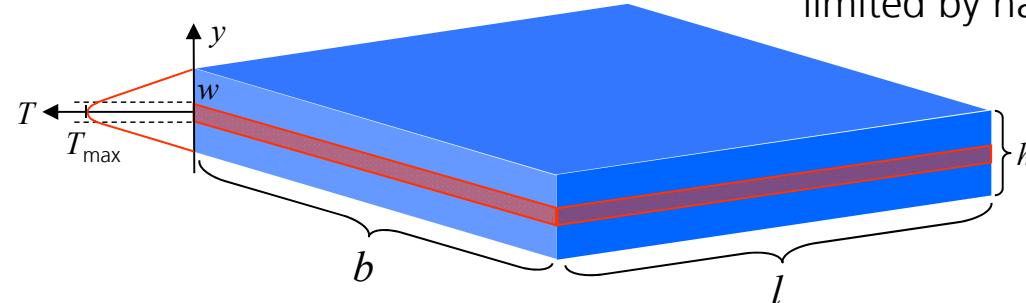
Scaling: increase l
limited by nonlinearity

Fiber



Innoslab

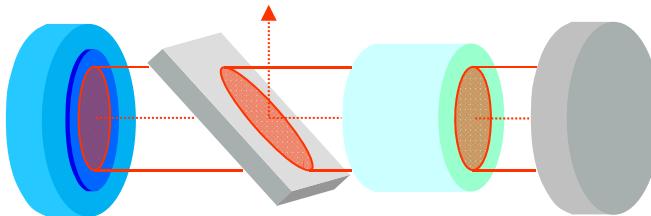
$$\Delta T_{slab} = \frac{\eta_h P_{abs}}{\lambda} \frac{h-w}{4lb}$$



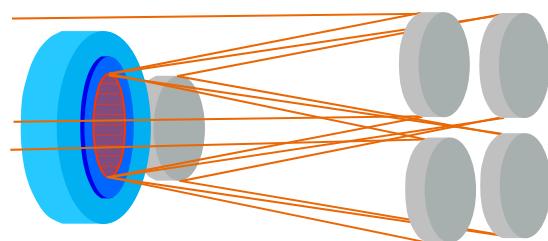
Scaling: increase b
limited by handling

Gain

Thin-Disk Amplifier

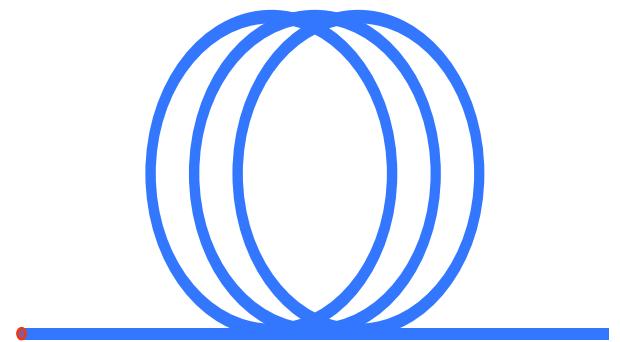


Regenerative
 $G \approx N \cdot 1.1$
 $G = 10^6 \dots 10^8$



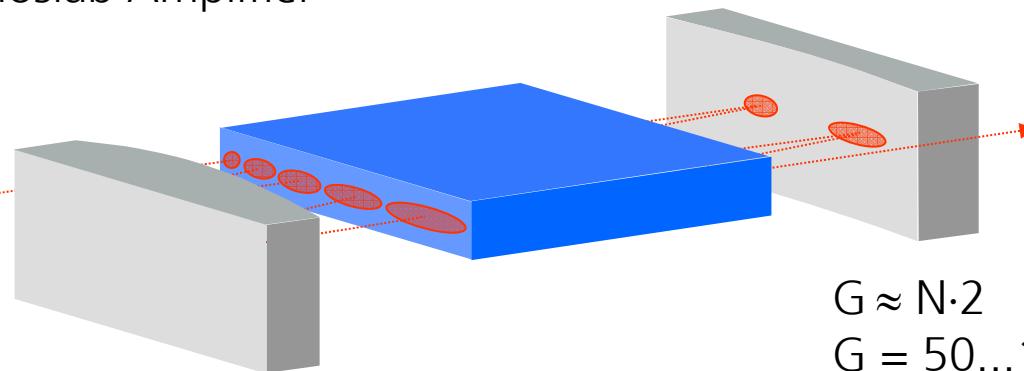
Multi-Pass
 $G \approx N \cdot 1.2$
 $G = 2 \dots 10$

Fiber Amplifier



$G = 10 \dots 1000$

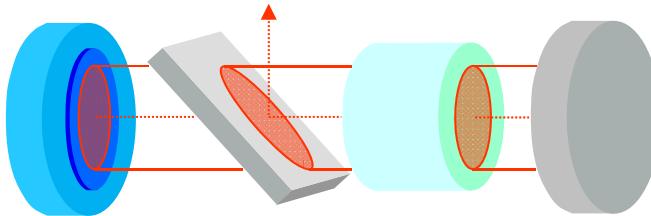
Innoslab Amplifier



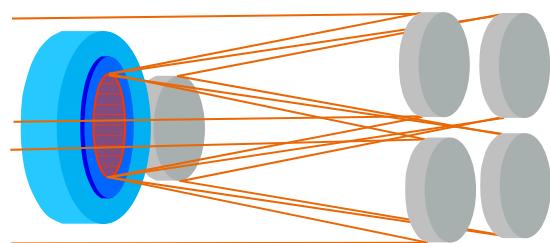
$G \approx N \cdot 2$
 $G = 50 \dots 1000$

Efficiency

Thin-Disk Amplifier

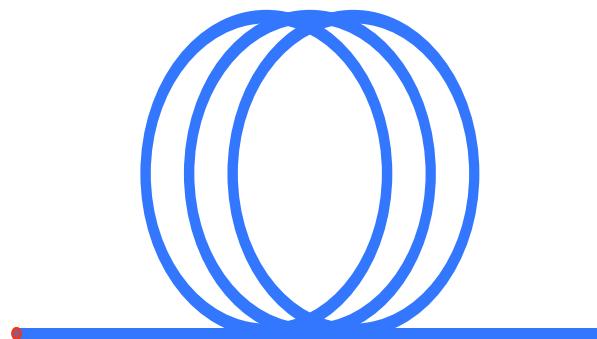


Regenerative
 $\eta_{\text{opt-opt}} \approx 40\%$



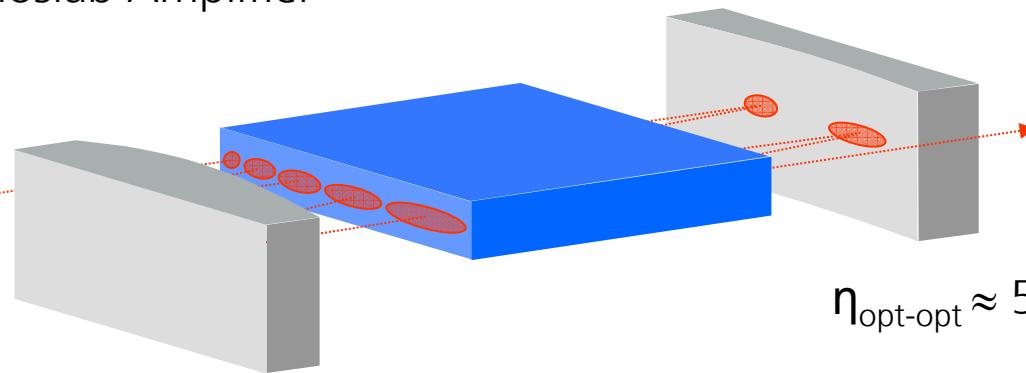
Multi-Pass
 $\eta_{\text{opt-opt}} \approx 10-50\%$

Fiber Amplifier



$\eta_{\text{opt-opt}} \approx 65\%$

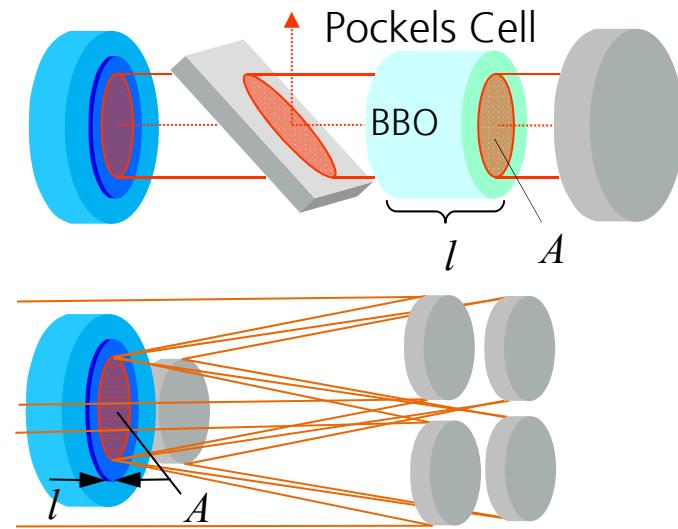
Innoslab Amplifier



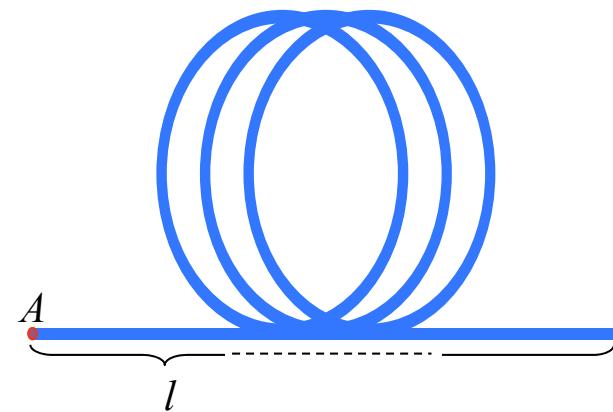
$\eta_{\text{opt-opt}} \approx 50\%$

B-Integral

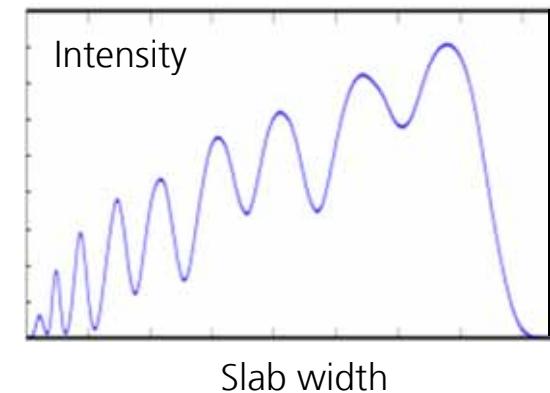
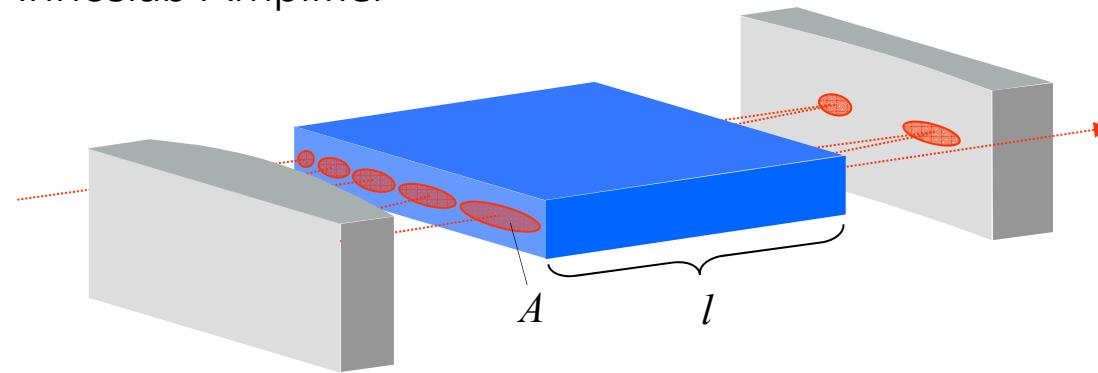
Thin-Disk Amplifier



Fiber Amplifier

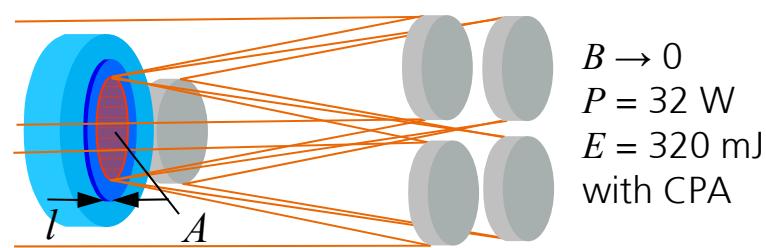
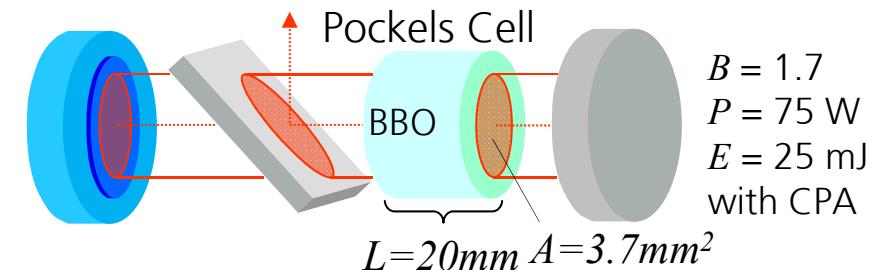


Innoslab Amplifier

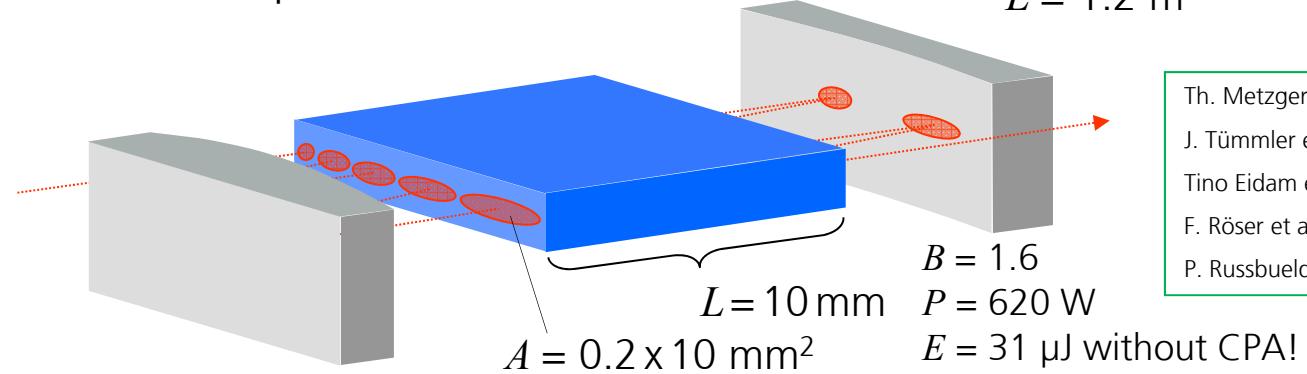


B-Integral – Examples $\tau < 1\text{ps}$

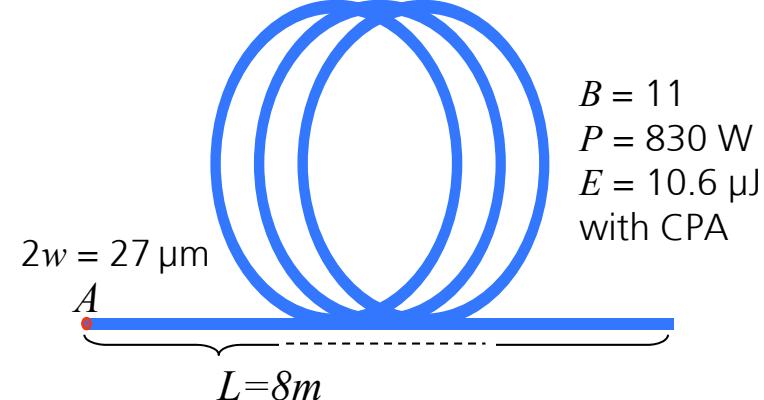
Thin-Disk Amplifier



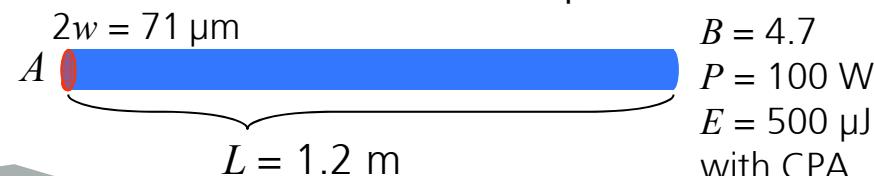
Innoslab Amplifier



Fiber Amplifier



Fiber Rod Amplifier

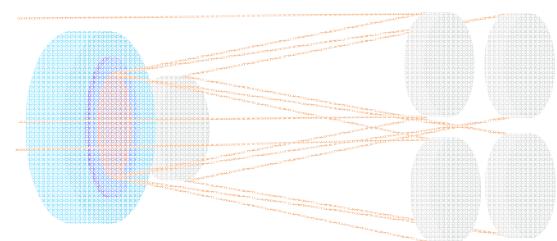
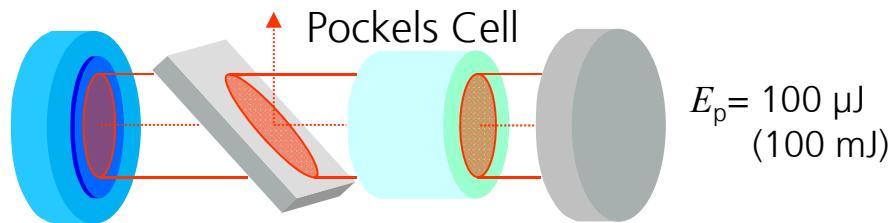


- Th. Metzger et al., Opt. Lett. 34, 2123-2125 (2009)
- J. Tümmler et al., Opt. Lett. 34, 1378-1380 (2009)
- Tino Eidam et al., Opt. Expr. 35, 94-96 (2010)
- F. Röser et al., Opt. Lett. 32, 3495-3497 (2007)
- P. Russbueldt et al., Opt. Expr. 17 12230ff (2009)

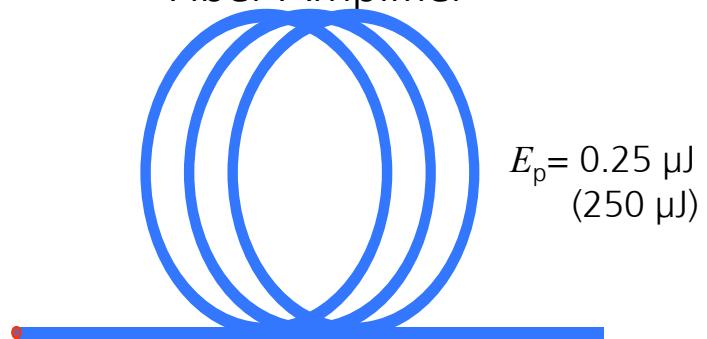
Pulse Energy Limitation at $P = 100 \text{ W}$

$\tau = 1 \text{ ps (CPA, 1 ns)}$

Thin-Disk Amplifier



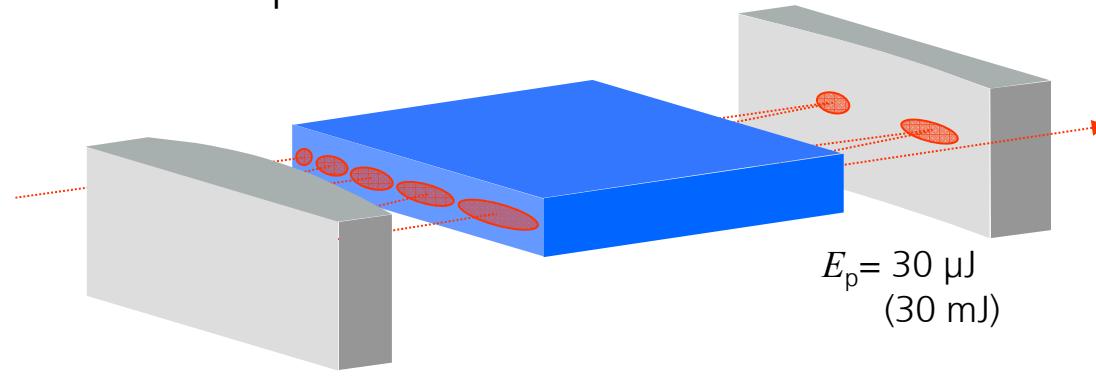
Fiber Amplifier



Fiber Rod Amplifier

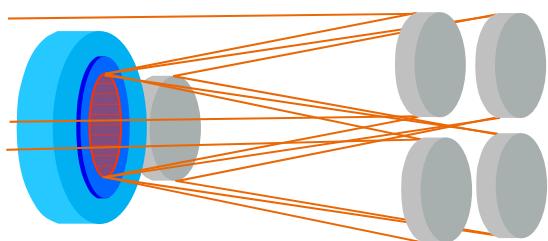
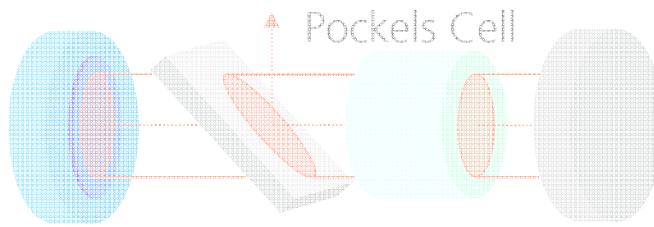


Innoslab Amplifier



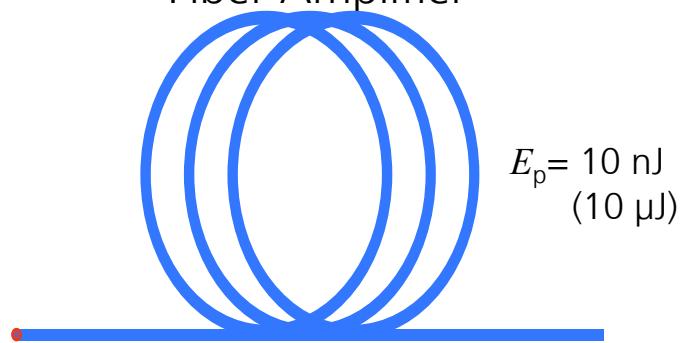
Pulse Energy Limitation at $P = 1000 \text{ W}$ $\tau = 1 \text{ ps (CPA, 1 ns)}$

Thin-Disk Amplifier



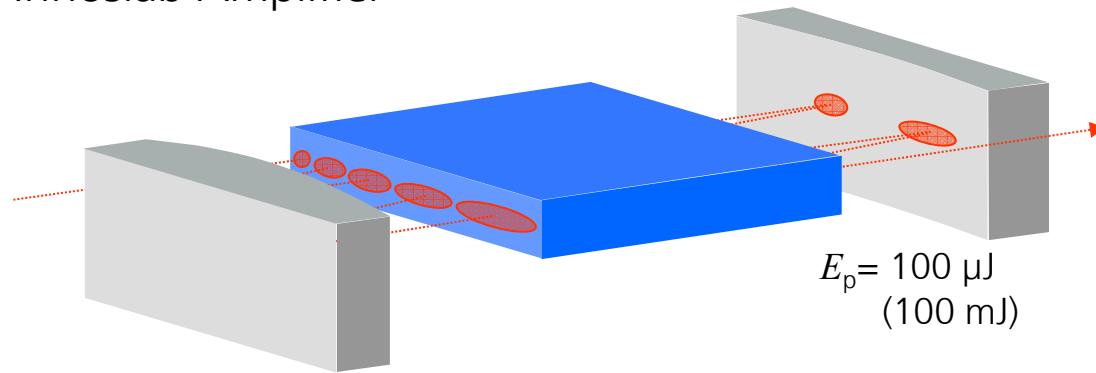
$$E_p = 1-2 \text{ J} \\ (1-2 \text{ J})$$

Fiber Amplifier



Fiber Rod Amplifier

Innoslab Amplifier



$$E_p = 100 \mu\text{J} \\ (100 \text{ mJ})$$

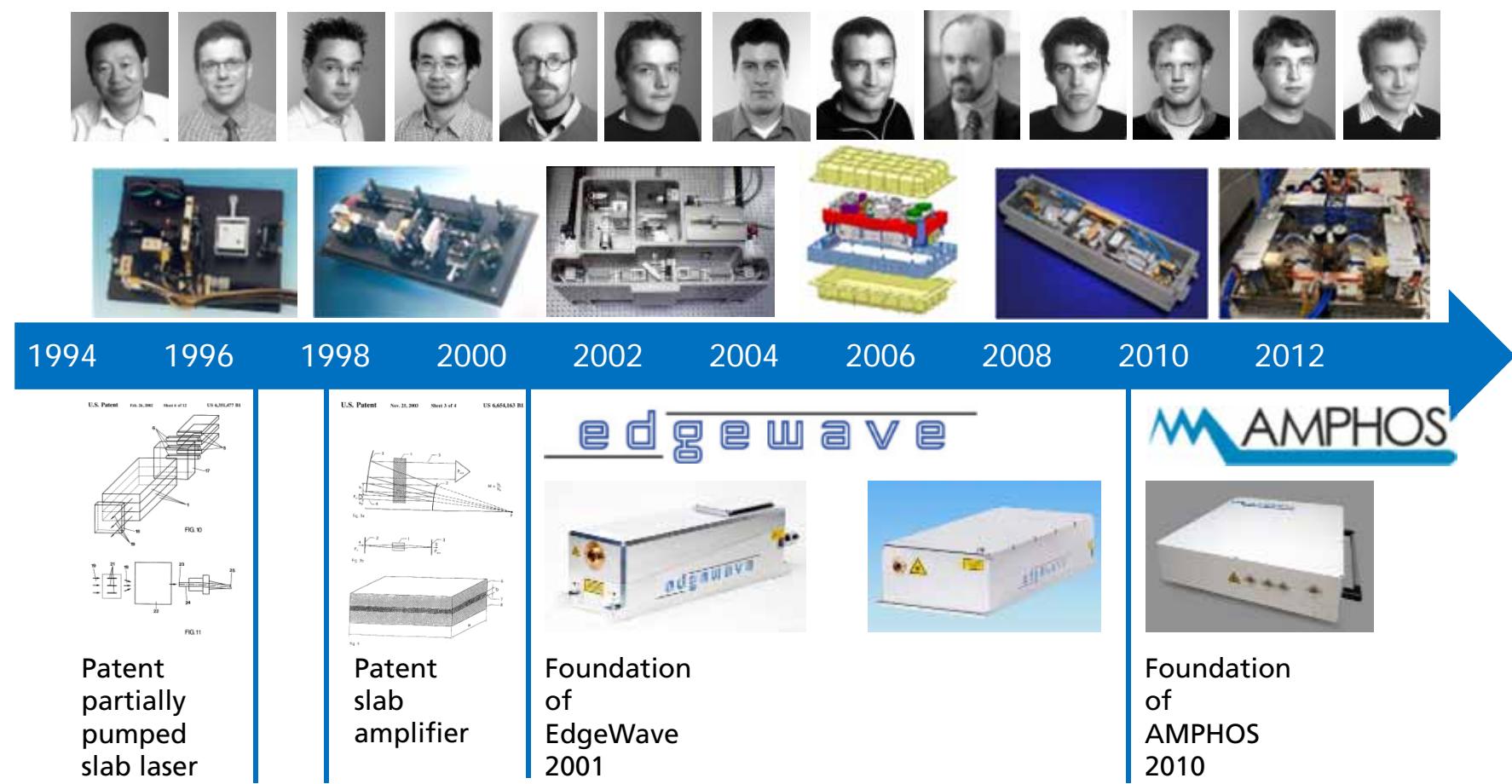
High Power Amplifier Concepts

	Fiber	Innoslab	Thin-disk	
			regenerative	multi-pass
Average power (fundamental mode)	> 5 kW	> 1 kW	< 0.1 kW	>1 kW
Mode area	< 0.004 mm ²	0.1mm ² \Rightarrow 2 mm ²	1-10 mm ²	>10 mm ²
Amplification factor	> 60 dB	30 dB	> 60 dB	<10 dB
Nonlinearity @100W $B/(P_{peak}/P)$	1·10 ⁻³	2·10 ⁻⁵	5·10 ⁻⁶	10 ⁻¹⁰
Pulse energy (CPA)	1 mJ	100 mJ	100 mJ	1 J
Repetition rate	>10 kHz	>10 kHz	10-500 kHz	>10 kHz

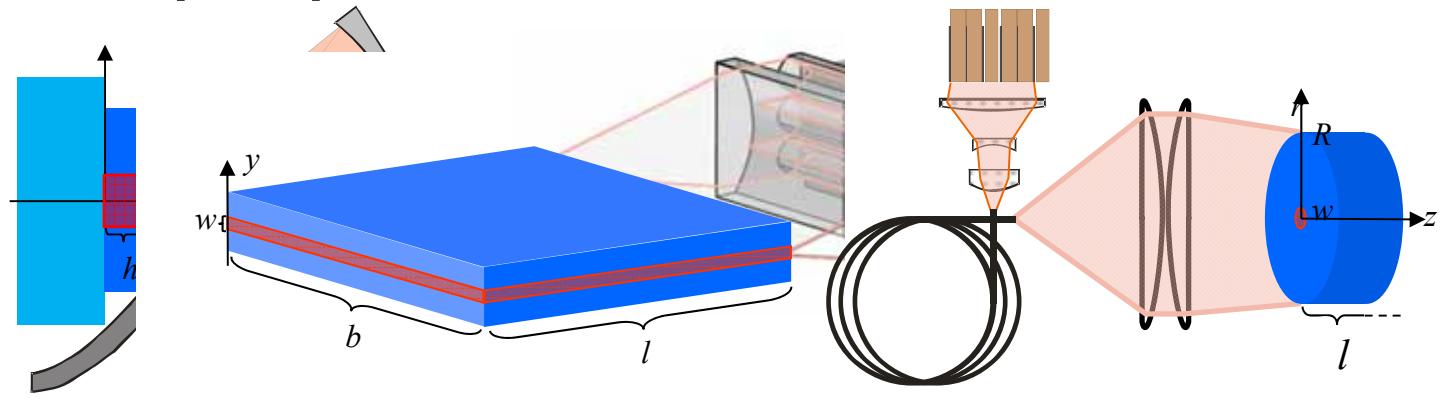
High Power Amplifier – combination of all designs!

	Fiber	Innoslab	Thin-disk	multi-pass
Average power (fundamental mode)	< 100 W	100-1000 W		>1 kW
Mode area	< 0.004 mm ²	0.1mm ² \Rightarrow 2 mm ²		>10 mm ²
Amplification factor	> 60 dB	30 dB		<10 dB
Nonlinearity @100W $B/(P_{peak}/P)$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-5}$		10^{-10}
Pulse energy (CPA)	1 mJ	100 mJ		1 J
Repetition rate	>10 kHz	>10 kHz		>10 kHz

Innoslab Platform – History



Scaling of End-pumped Solid-State Lasers



Thin-Disk

Power scaling by area

improved thermal management by 1D heat flow

Innoslab

width

aspect ratio

Fiber

length

wave guiding

Relative to rod

pump passes

multiple

single / double

fractional

beam crosssection

+

○

-

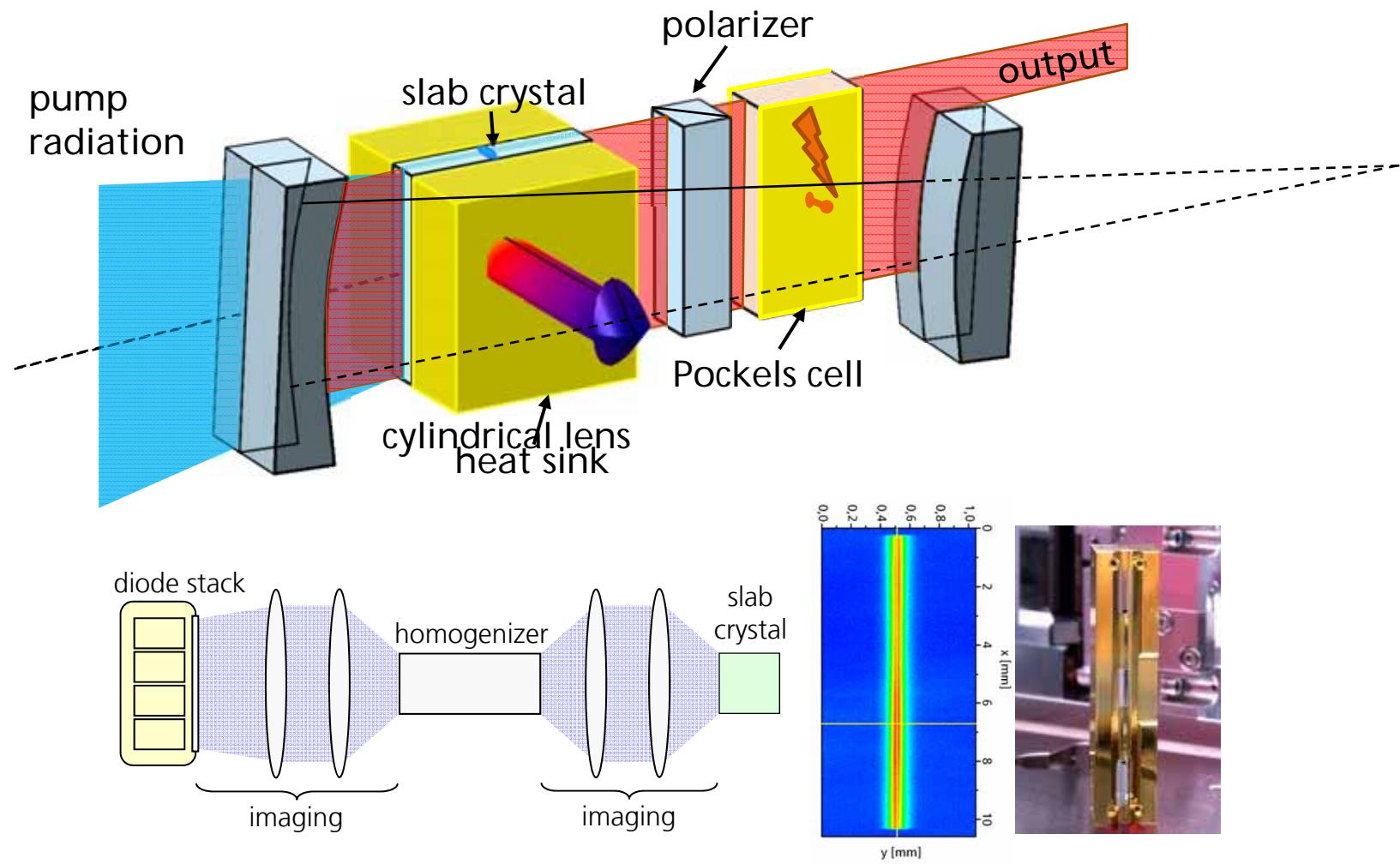
single-pass gain

-

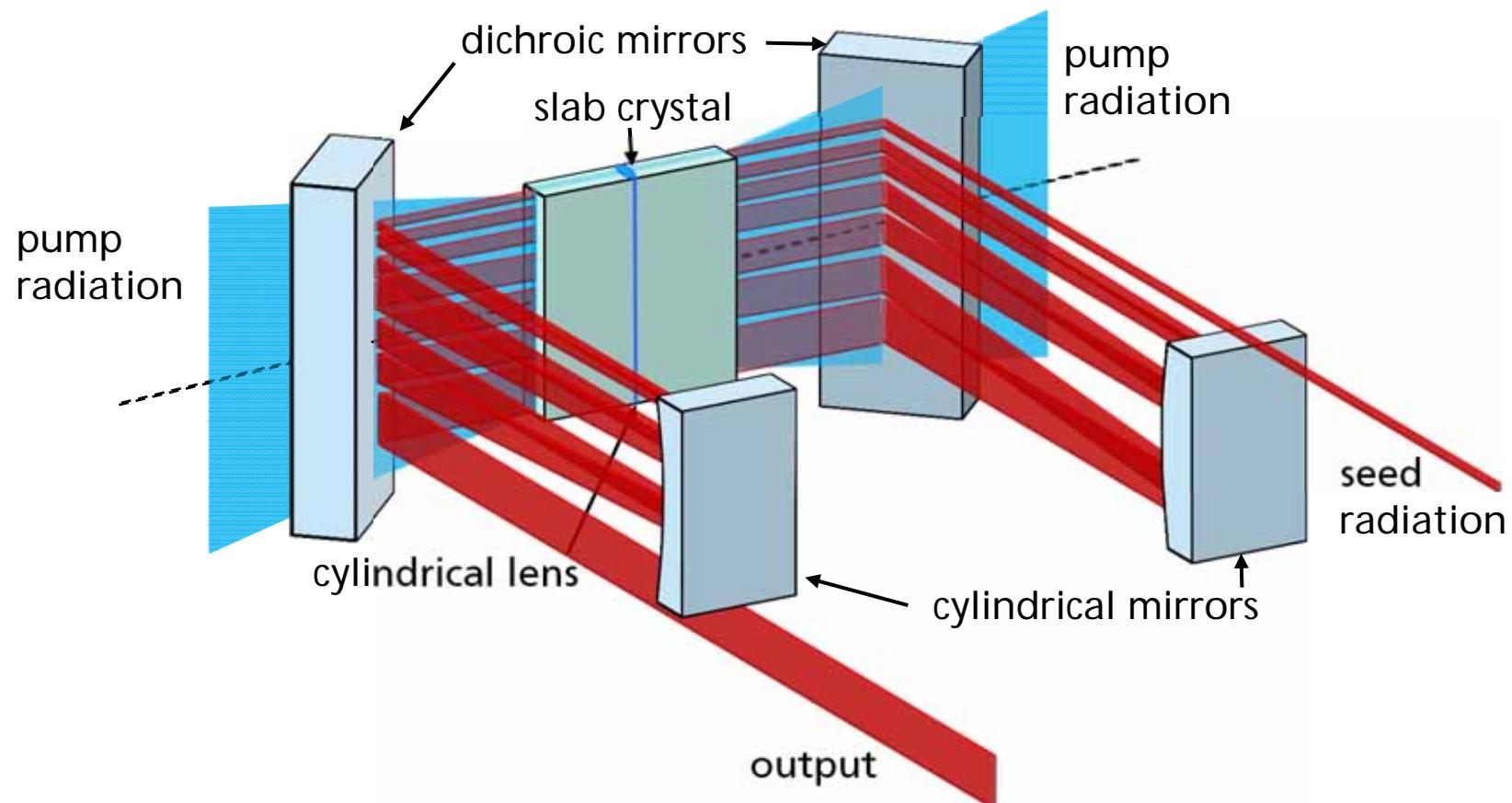
○

+

Innoslab Oscillator



Innoslab Amplifier



Innoslab Laser Records

Highest
average power
 $< 10\text{ns}$ laser

Highest
average power
sub-ns laser for
X-ray generation

First laser matching
the spectral purity
requirements
for
 CO_2 LIDAR

Highest
average power
ps-laser

Highest
average power
fs-laser

Most brilliant
visible laser

Edgewave – Innoslab Lasers with ns and ps Pulse Duration

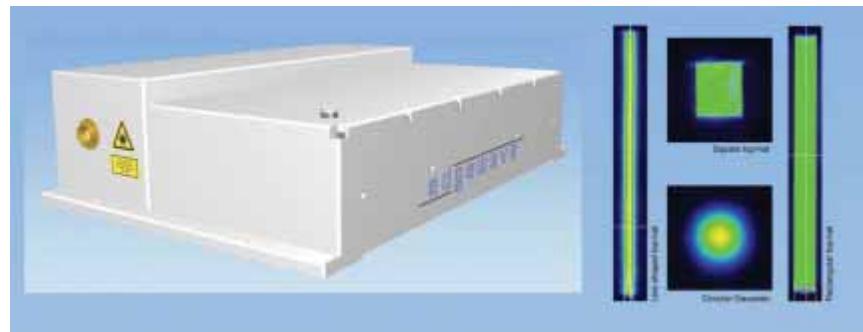
■ Q-switched lasers

- Pulse duration 4 – 10 ns
- Repetition rate < 100 kHz
- Pulse energy < 60 mJ
- Beam quality M² < 2
- avg.power@1064nm < 600 W
- avg.power@532nm < 200 W
- avg.power@355nm < 50 W
- avg.power@266nm < 20 W

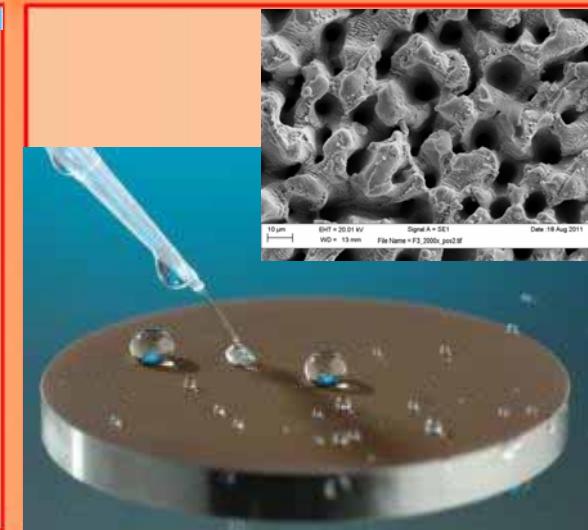
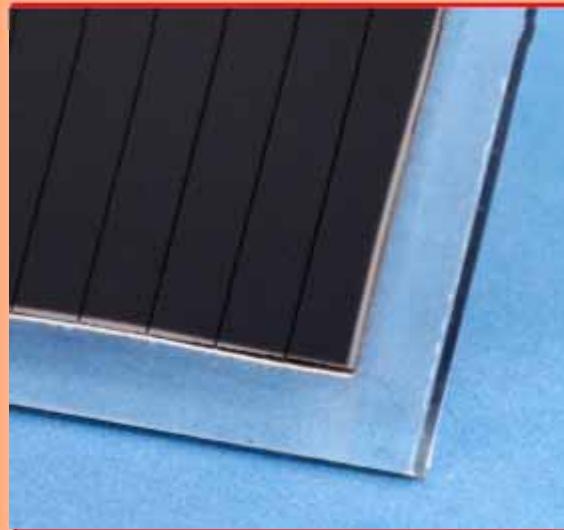
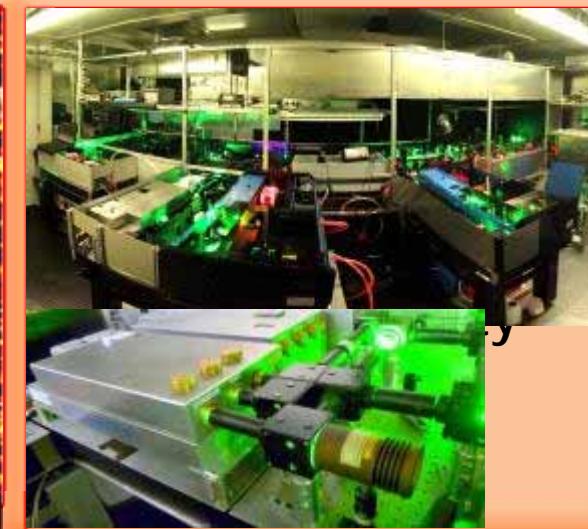
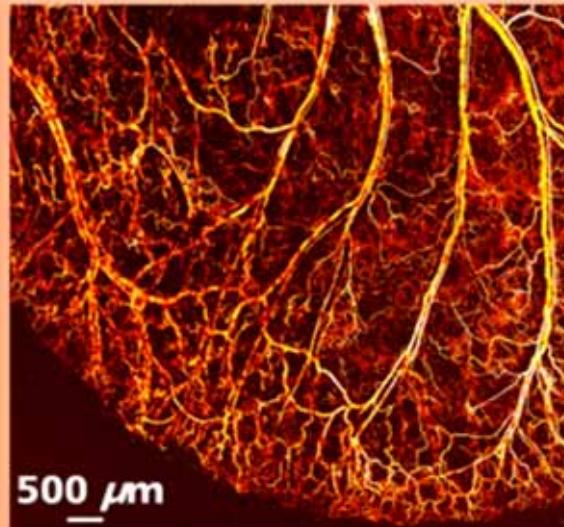
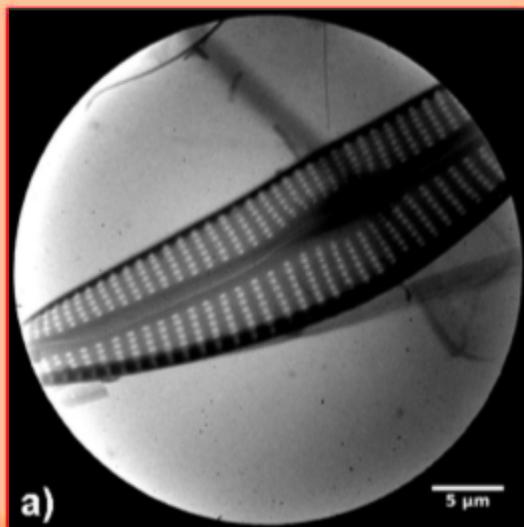


■ ps lasers

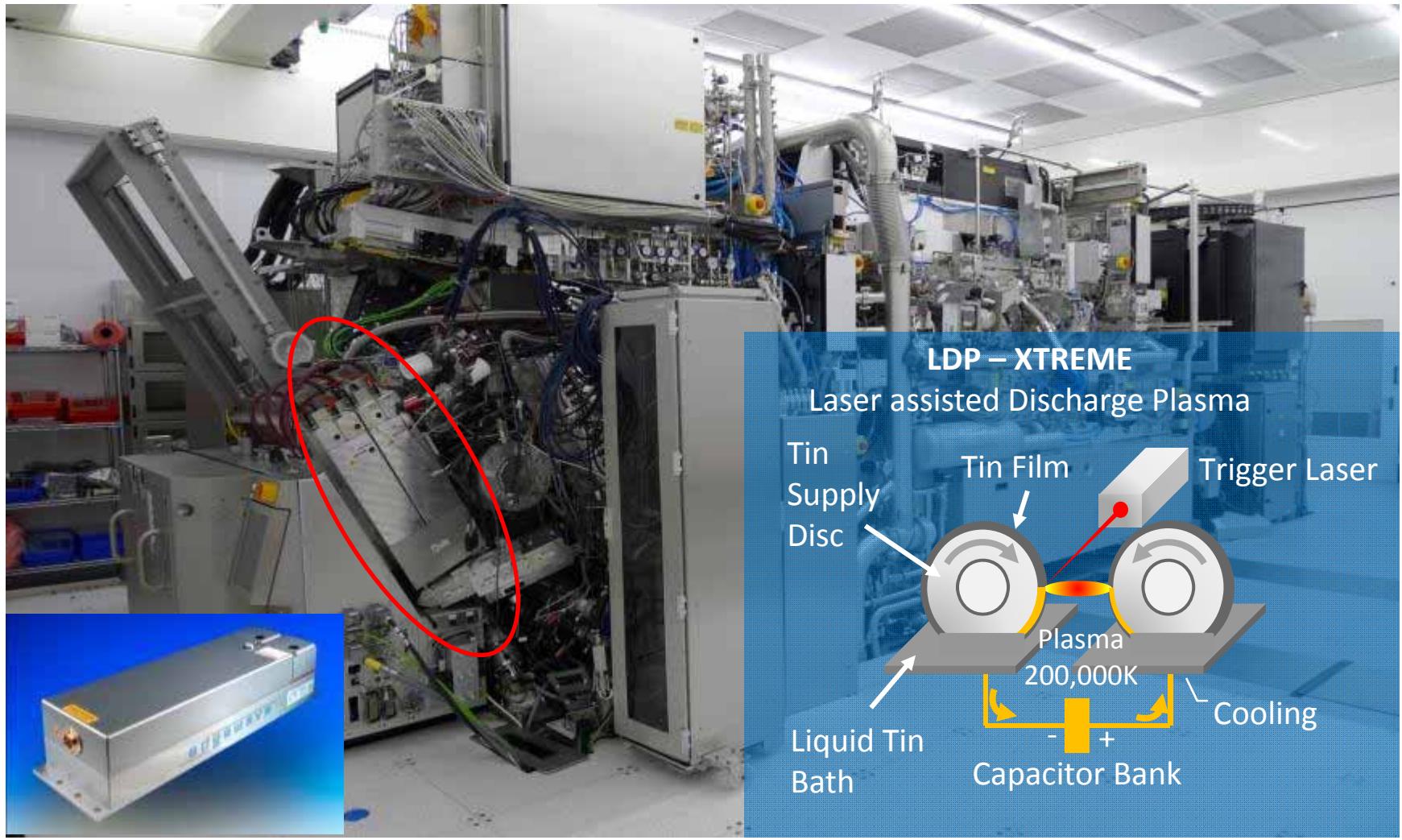
- Pulse duration 10 ps
- Beam quality M² < 2
- avg.power@1064nm < 400 W
- avg.power@532nm < 180 W



Applications - Innoslab Laser



Applications – ns Innoslab: 13.5 nm EUV generation

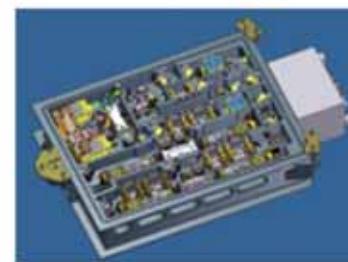


Application – Innoslab based LIDAR lasers



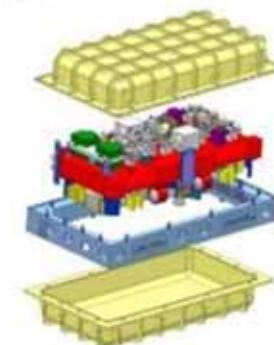
LIDAR for Pipeline Leakage Detection

- Methane



Monitoring of greenhouse gases

- Methane
- CO₂
- Water Vapour



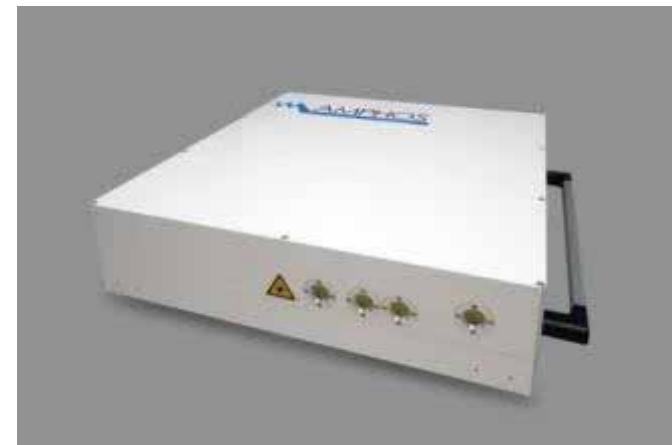
Satellite based LIDAR – platform

- ESA: [FULAS](#)
- DLR: [MERLIN](#)

AMPHOS - Yb:Innoslab lasers

■ Flexible ns operation

■ Pulse duration	2 ns ... 100 ns
■ Time structure	flexible (< 50 MHz)
■ Pulse energy	< 20 mJ
■ Average power	< 250 W



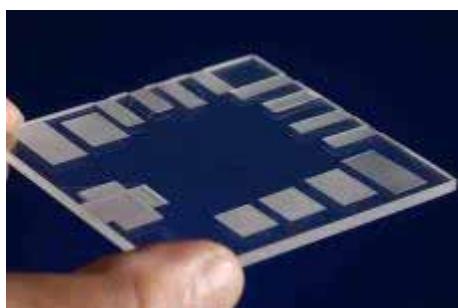
■ fs operation

■ Pulse duration	500 fs ... 10 ps
■ Repetition rate	500 kHz – 50 MHz
■ Pulse energy	50 .. 500 µJ
■ Beam quality M ²	< 1.5
■ avg.power	400 W (up to 1 kW)

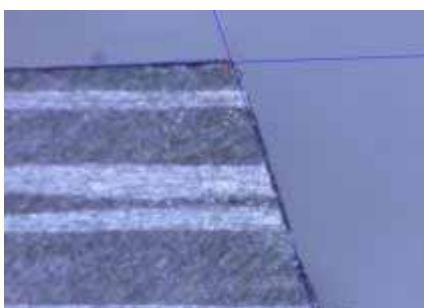


Application - Materials Processing with fs Pulses - High Average Power Translates into Processing Speed

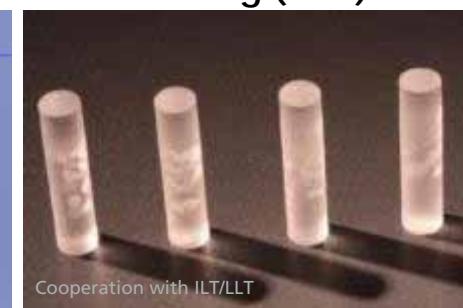
Fused Silica



CFRP



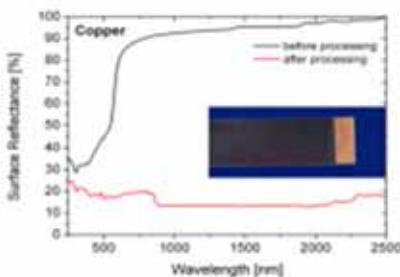
In Volume Selective
Laser Etching (ISLE)



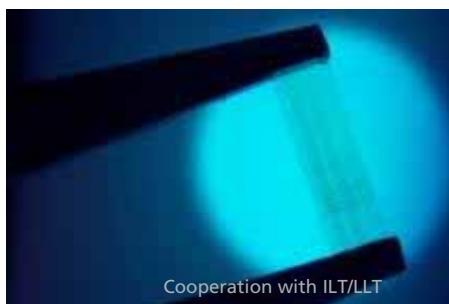
Compound Wafer



Blackening of Metals



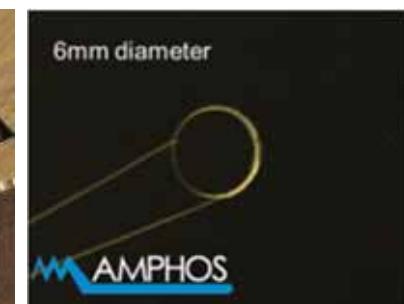
Waveguide Structures



Processing of Metal



Heat treated glass



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

Summary and Outlook INNOSLAB

- The Innoslab is a platform with outstanding performance for short and ultra-short pulsed lasers of high average output power
- Power / Energy Scaling
 - Energy scaling to 500 mJ in progress
 - **5kW avg. power** seem feasible
- Shorter pulses
 - 600fs → **300fs** by new crystal material
 - Sub 300fs by compression
 - Sub 100fs by OPCPA
- Compact design
 - **„Pizza box“ size 500W** Laser Amplifier
 - Planar Mounting Technology

