Thin Disk based MOPA – numerical modeling and experimental results

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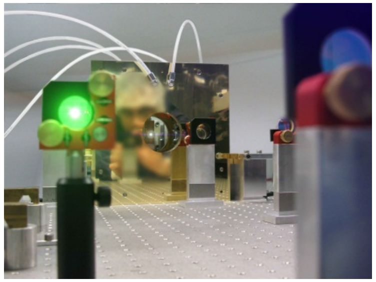
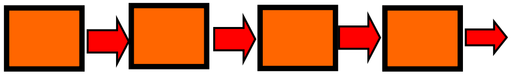
Outline



– Thin disk concept

– 200 kW MOPA concept

– Test of the concept in the lab

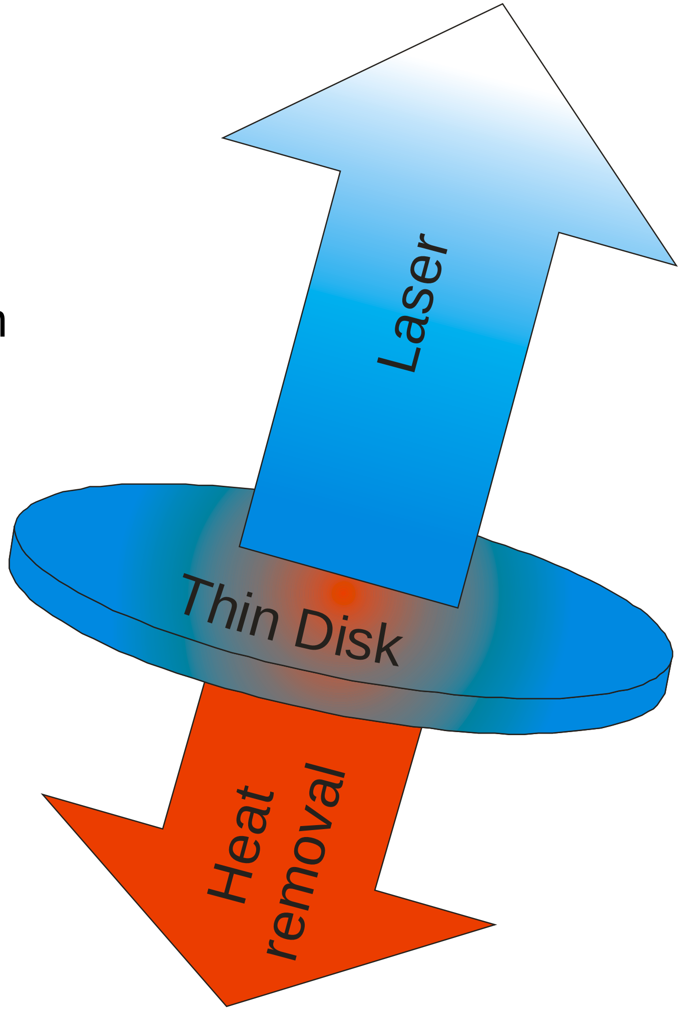


– Numerical model

– Outlook

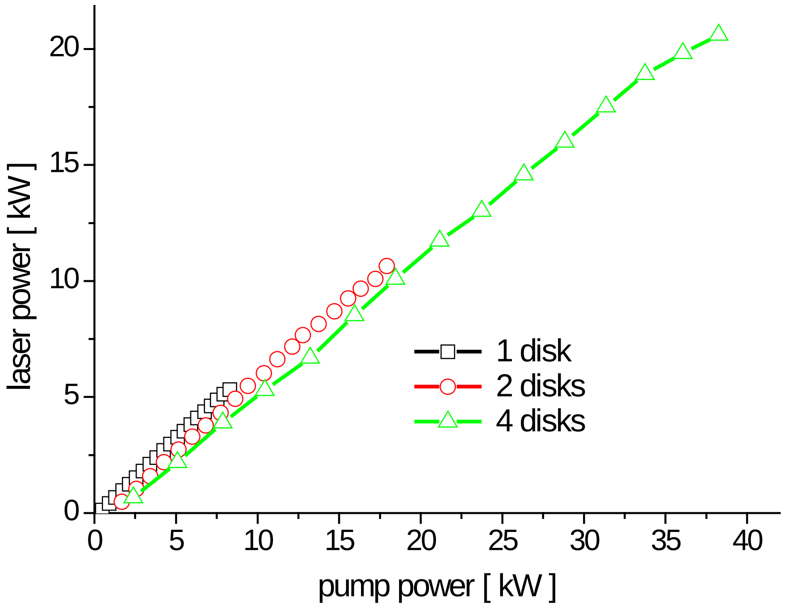
Thin Disk concept

- Core idea: thin active material, one face cooled, used as active mirror
- thickness 0.1 – 1 mm, diameter 5 – 45 mm
- Heat flow parallel to laser beam
- Minimized thermal lens
- High output power and high efficiency simultaneously
- Power / energy scaling
  by scaling of pump spot area
  (power / energy densities and temperatures constant)
- variety of active materials



DLR

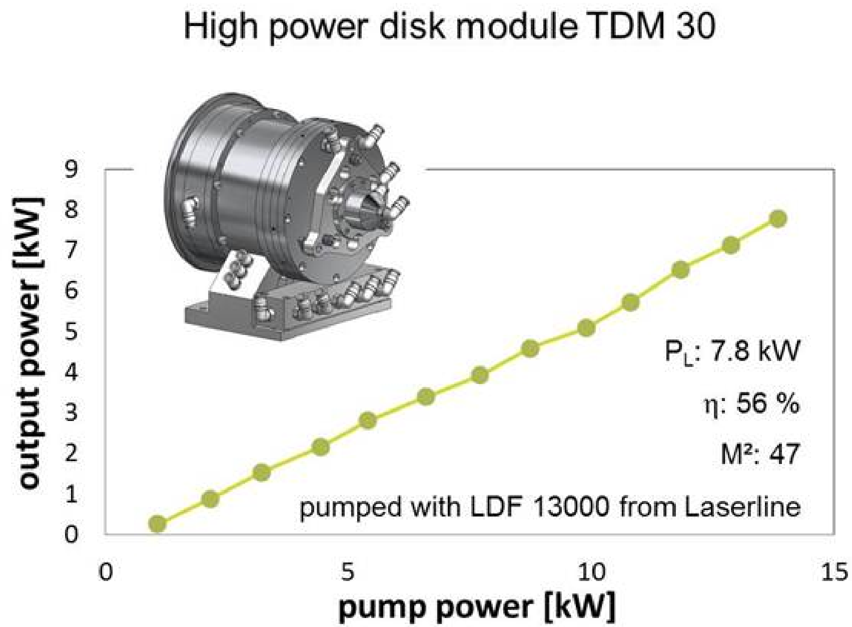
Power scalability



5.3 kW out of one disk /
20 kW with four disks

extracted volume power density > 600 kW/cm³

Courtesy TRUMPF Laser Schramberg

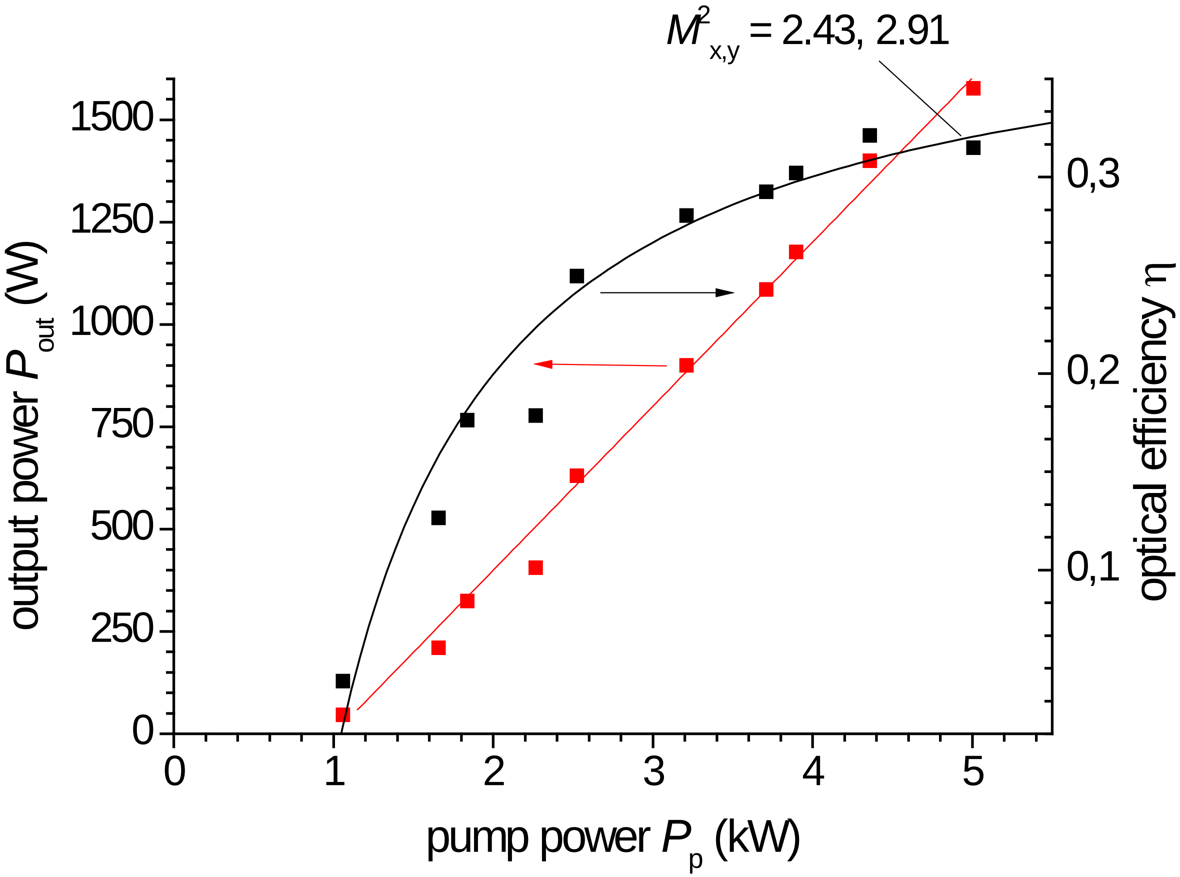


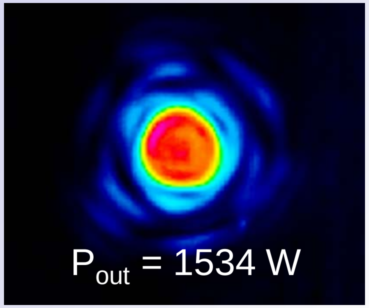
New high power disk module, common development of ITP and industrial partner

Courtesy Dausinger und Giesen GmbH

Concept of Neutral Gain Modules *

V-shaped resonator with 2 Relay NGMs and AO





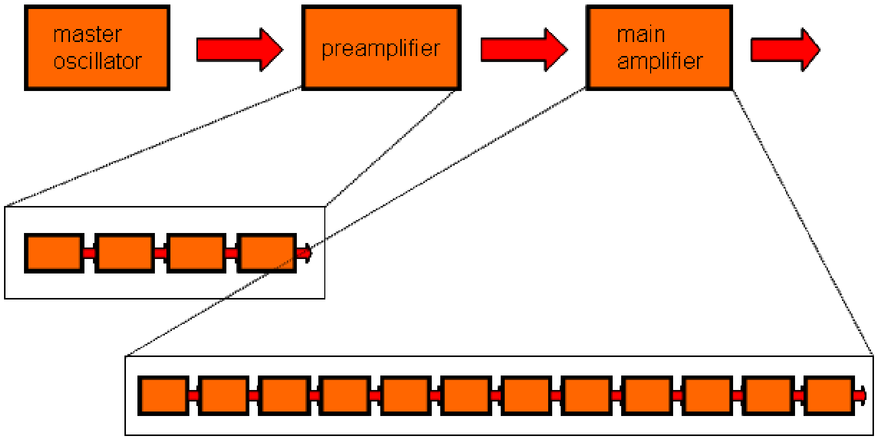
$$B = 21 \frac{\mathrm{GW}}{\mathrm{cm}^2\,\mathrm{sr}}$$

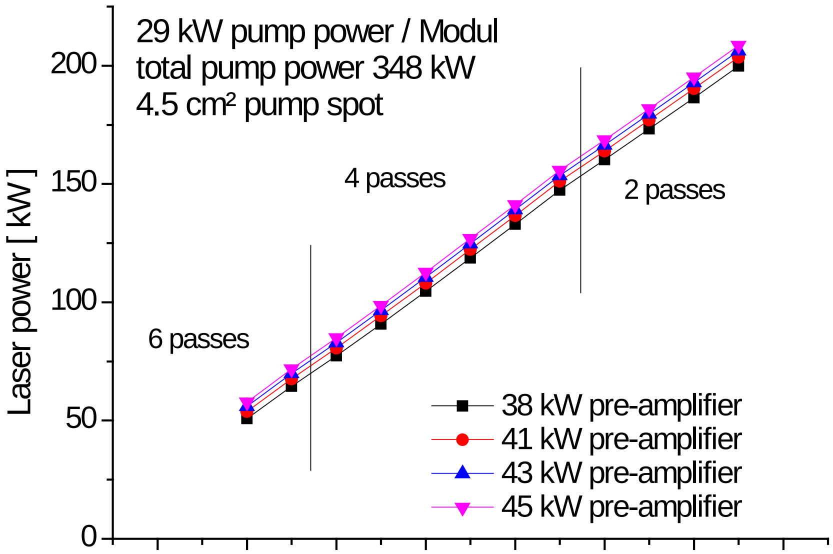
diffraction limited:

$$P_{out} = 1.5\ \mathrm{kW}$$
$$M^2 = 1$$
$$\rightarrow B = 141 \frac{\mathrm{GW}}{\mathrm{cm}^2\,\mathrm{sr}}$$

* J. Mende et. al., Concept of Neutral Gain Modules for Power Scaling of Thin-Disc Lasers, Applied Physics B, 97 (2), 2009

Master oscillator / power amplifier (MOPA)





- Pump spot diameter, pump power and power densities similar to actual commercially used systems!

- Control of beam quality more simple than in resonator (lower power densities, linear accumulation of phase distortions, no feedback)

MOPA system aspects

System requirements:

– 200 kW output – 500 kW diode power / 1 MW electrical power

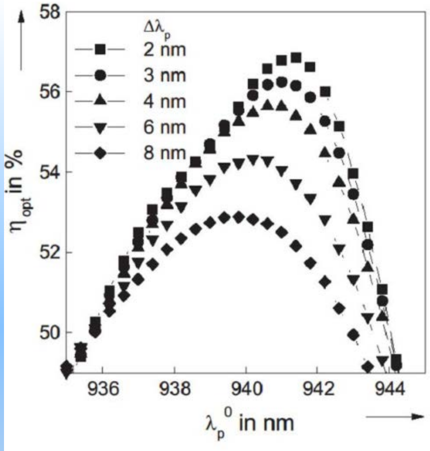
– Engagement ~ 50 s

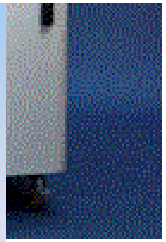
– rechargeable battery pack: 400 – 600 kJ/kg

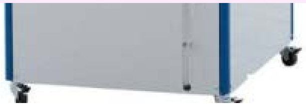
– 2 m³ of water (temperature rise ~ 5 K, i.e. wavelength shift 1.5 nm)

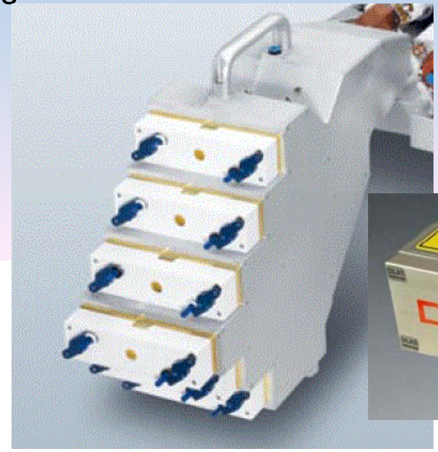
– (fibre coupled) pump modules: 1 kW / kg, 1 MW / m³

< 4000 kg & < 4 m³ for 500 kW pump power

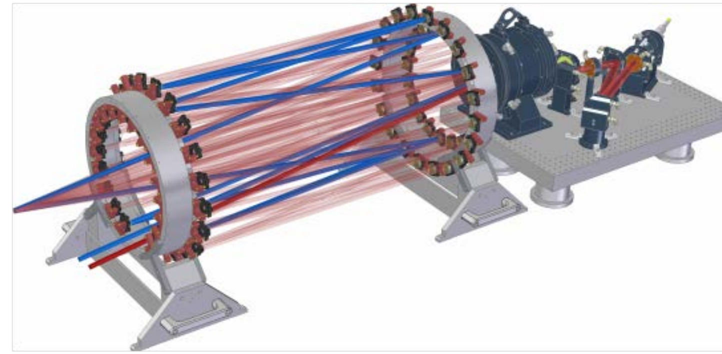








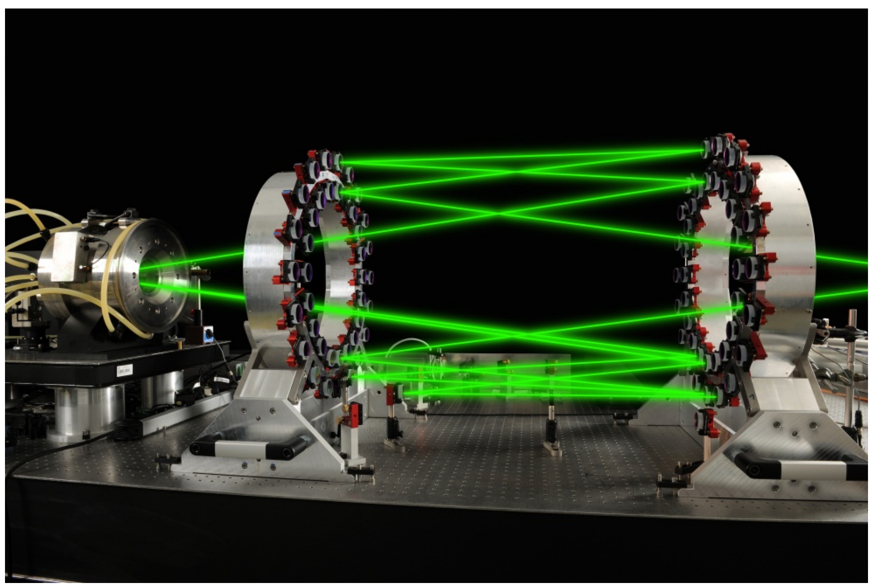
Test of MOPA concept



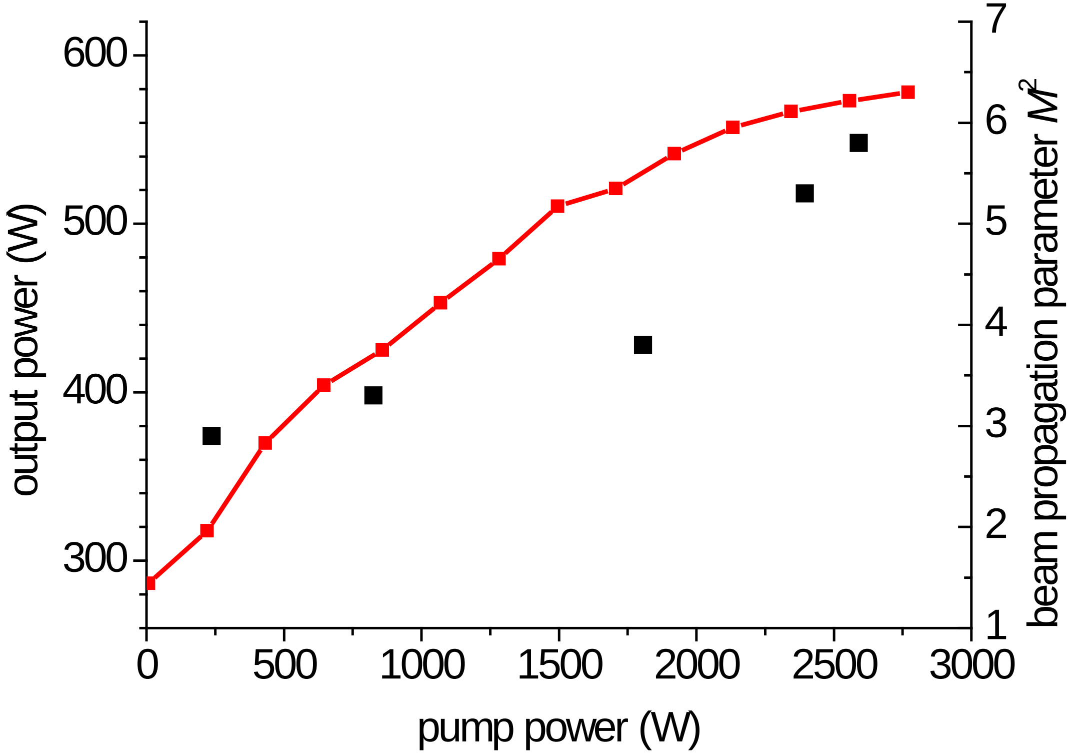
master oscillator → $5\%\ I_{sat}$ → multipass amplifier → $25\%\ I_{sat}$ → multipass amplifier → $48\%\ I_{sat}$ → multipass amplifier →

Stable resonator
~ 1.5 kW
M² < 3

> 15 kW output



Test of MOPA concept



10.5% Yb:YAG, 140 µm thick

24 pump passes

20 amplification passes

1.2 cm pump spot diameter

Oscillator 360 W, M^2 ~ 3

Loss analysis:

~ 0.7% round trip loss

Latest tests with increased oscillator power: 2070 W

Test of MOPA concept - numerical modeling

$$\dot{N}_2 = Q - S - \frac{N_2}{\tau} \equiv 0$$

fundamental rate equation

$$S = \frac{\lambda_{osc}}{2\pi\hbar c}\frac{P_{osc}}{\pi r_{osc}^2 h}\left(\exp\left(m_{amp}\gamma_{osc}h\right)-1\right)$$

$$Q = \frac{\lambda_p}{2\pi\hbar c}\frac{P_{pump}}{\pi r_{pump}^2 h}\left(1-\exp\left(-m_p\alpha_p h\right)\right)$$

$$P_{out} = P_{osc}\exp\left(m_{amp}\gamma_{osc}h\right)$$

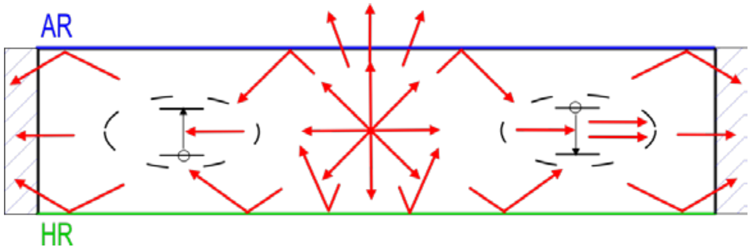
output power

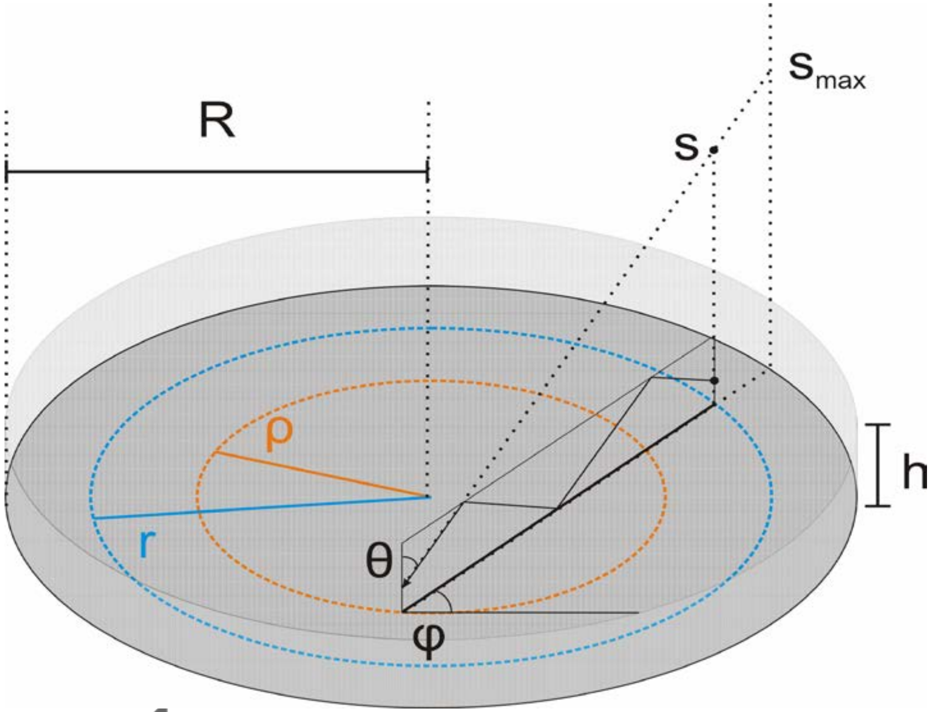
$$\alpha_p = \sigma_{abs}(T)N_0 - \sigma_{abs}(T)\left(1+f_{em}(T)\right)N_2 \quad \gamma_{osc} = \sigma_{em}(T)\left(1+f_{abs}(T)\right)N_2 - \sigma_{em}(T)f_{abs}(T)N_0$$

$$f_{abs}(T) = {Z_2}/{Z_1}\exp\left({2\pi\hbar c_{vac}}/{\lambda k_B T}\right) \qquad f_{em}(T) = {Z_1}/{Z_2}\exp\left({-2\pi\hbar c_{vac}}/{\lambda_p k_B T}\right)$$

Amplified spontaneous emission (ASE)

$$\dot{N}_2 = Q - S - \frac{N_2}{\tau} - \iint \gamma_\lambda \Phi_{\lambda,\Omega} \, d\lambda \, d\Omega$$



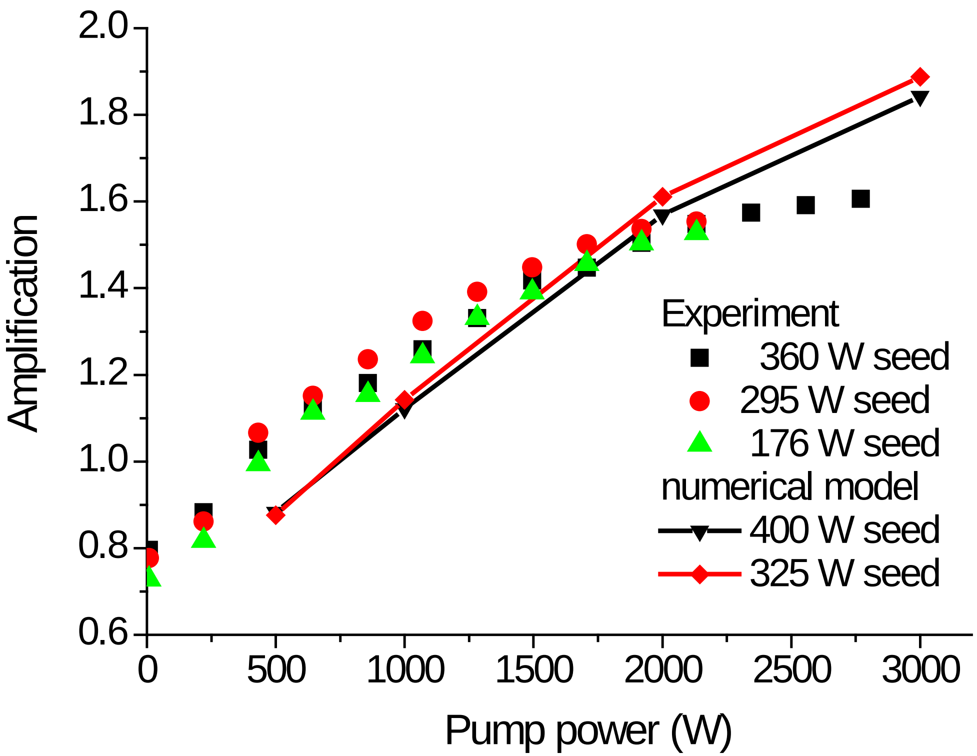


Photon flux density from a volume element at position $\vec{s}$

$$d\Phi_\lambda(\vec{s}) = \beta_\lambda \frac{N_2(\vec{s})}{\tau} \frac{1}{4\pi s^2} G_\lambda(\vec{s}) \, dV$$

Requirement for model:
No back reflection from outer edges, e.g. by **absorbing cladding**

Test of MOPA concept



10.5% Yb:YAG, 140 µm thick

24 pump passes

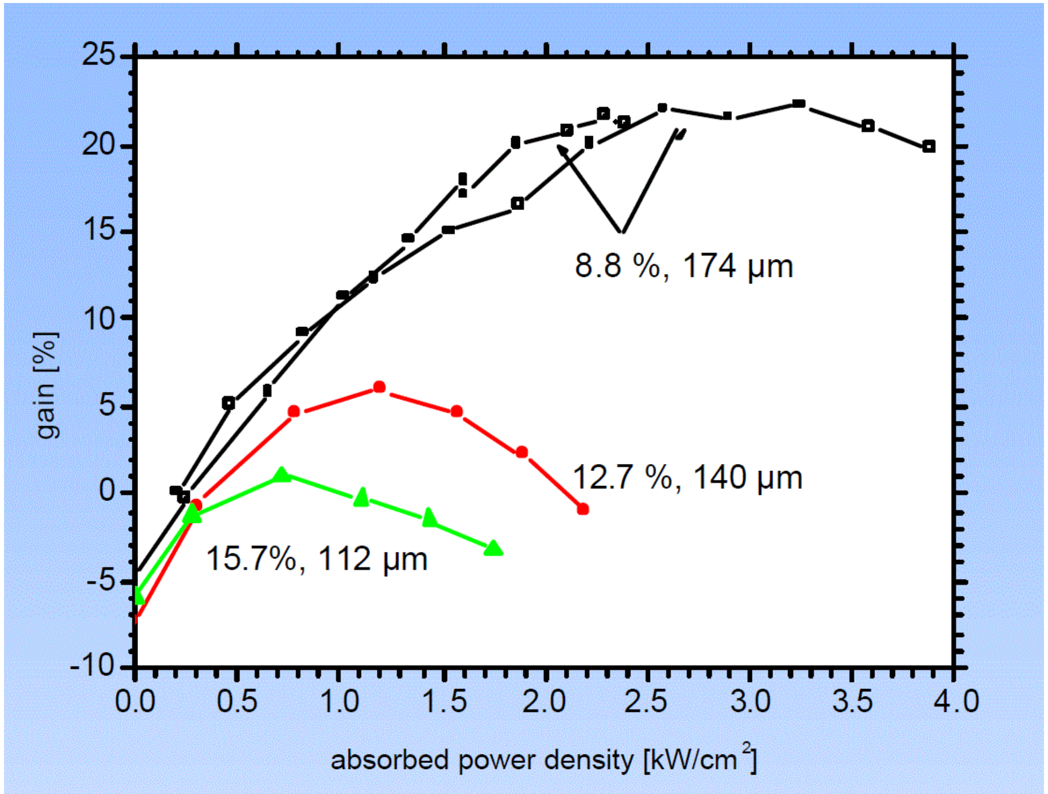
20 amplification passes

1.2 cm pump spot diameter

Pump spectra from experiment

Temperatures calculated using established model

Influence of doping concentration on achievable gain

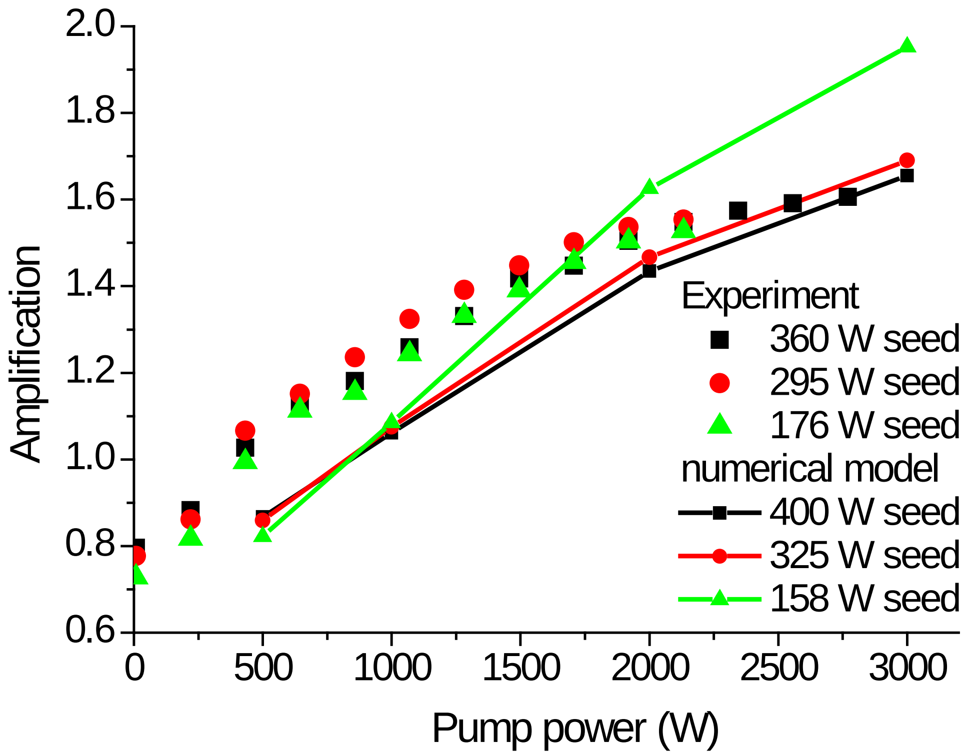


M. Larionov et al., *Nonlinear Decay of the Excited State in Yb:YAG*, ASSP 2005, Vienna

- doping-dependent, non linear loss
- additional heat generation
- intrinsic effect?
- generation of charge transfer band?
- enhanced by impurities!

Test of MOPA concept – modified rate equation

$$\dot{N}_2 = Q - \frac{N_2}{\tau} - \gamma_{osc}\Phi_r - \iint \gamma_\lambda \Phi_{\lambda,\Omega} d\lambda d\Omega - k_\Sigma N_2^2$$



10.5% Yb:YAG, 140 µm thick

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Temperatures calculated using established model

k_Σ = 64 · 10^{-20} cm^{-3}

Summary & Outlook

- Thin Disk based Master Oscillator Power suitable for 200 kW with actual available components
- Auxiliary components (power, cooling) strongly dependent on engagement scenario
- Concept experimentally proven (~ 2 kW)

- Demonstration of > 5 kW, $M^2 < 10$ planned for May / June 2013 with external partner
- Demonstration of ~ 5 kW, $M^2 < 5$ end of 2013 with improved multipass setup