A simple technique to evaluate the thermal lens strength of a laser material

Daniel Esser, Dieter Preussler

CSIR NATIONAL LASER CENTRE (NLC)

LRI
Laser Research Institute

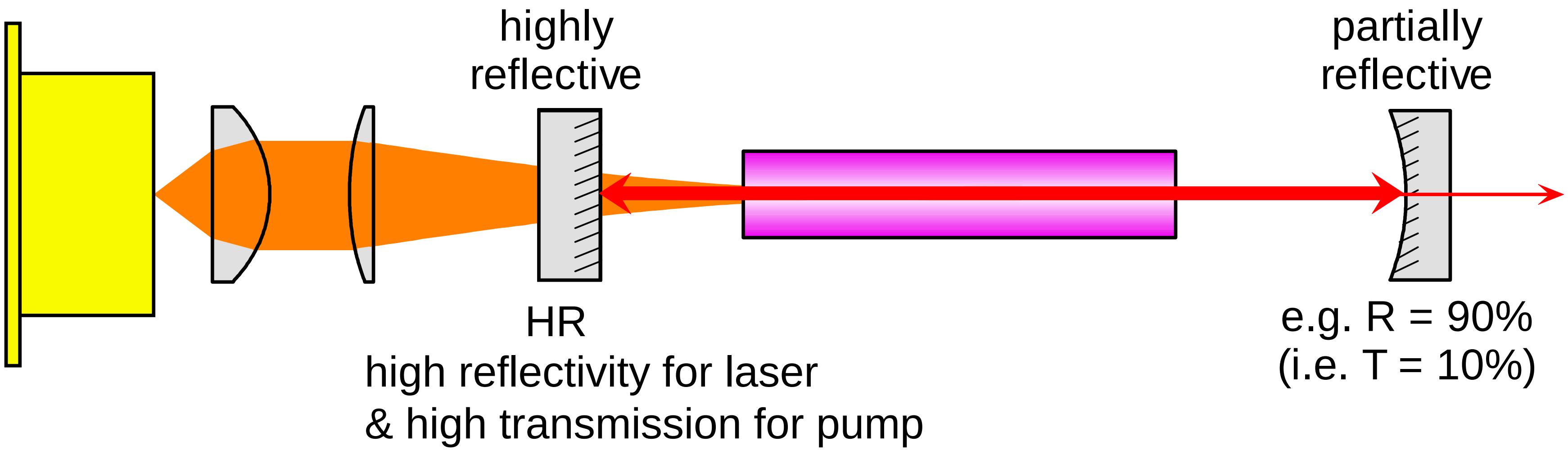
Christoph Bollig

Outline

- Thermal lenses in solid-state lasers
- Methodology to measure a thermal lens
- Experimental setup
- Results
- Conclusions

Thermal lenses

Diode-end-pumped solid-state laser



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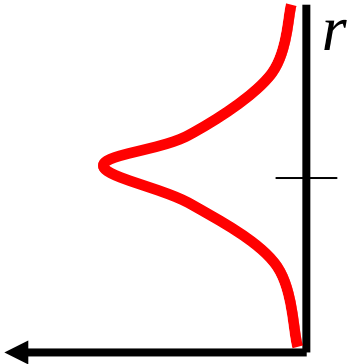
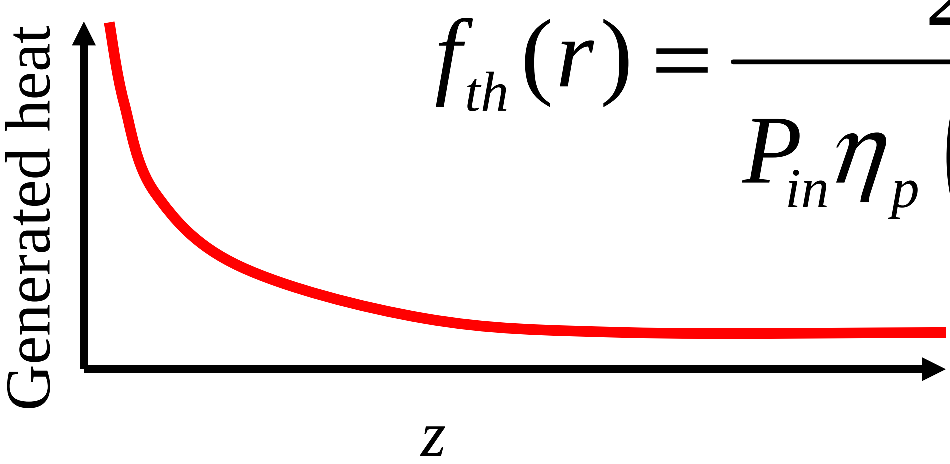
Thermal lenses



$$n(r,\phi,z) = n_0 + \Delta n_{temp}(r,\phi,z) + \Delta n_{stress}(r,\phi,z)$$



$$f_{th}(r) = \frac{2\pi K_c r^2}{P_{in}\eta_p \left({}^{\mathrm{d}n}\!/\!{}_{\mathrm{d}T} \right) s(r)}$$

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Thermal lenses

Why the thermal lens needs to be considered:

- Increases the loss inside the resonator

  $\longrightarrow$ Reduce the output power of the laser

$$P_{out} = \frac{T}{\delta}\eta\left(P_{in} - P_{th}\right)$$

- Influences resonator mode size

  $\longrightarrow$ Reduce the mode-matching efficiency

  $\longrightarrow$ Can cause the resonator to become unstable

Thermal lenses

Need to know the thermal lens:

$$f_{th}(r) = \frac{2\pi K_c r^2}{P_{in}\eta_p \left(\mathrm{d}n / \mathrm{d}T \right) s(r)}$$

$$s(r) = \frac{2\pi}{P_{in}} \int_0^r r' I_p(r') dr'$$

$$I_p(r) = \frac{2P_{in}}{\pi \omega_p^2} e^{\left(-2r^2/\omega_p^2\right)}$$

$$K_c = \frac{1}{T} \frac{A}{\gamma^2 \varepsilon^3} T_{mp}^{3/2} \rho^{2/3} M^{1/3} n^{-1/3} \mu^{-3/2}$$

T : temperature;

A : numerical constant;

γ : Gruneisen material constant;

ε : covalency of the material;

T_{mp} : melting point temperature;

ρ : material density;

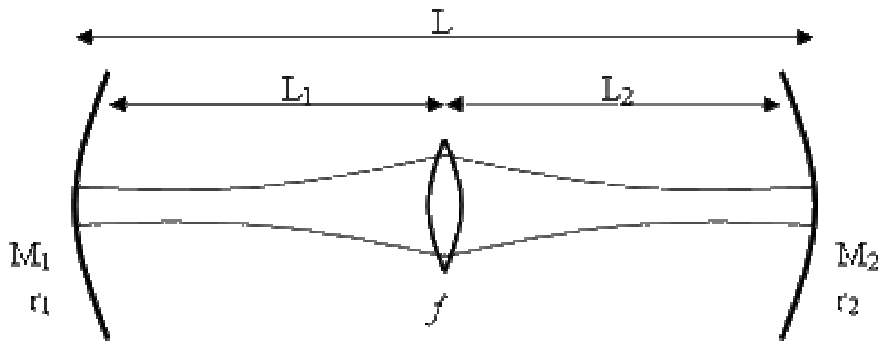
M : molar mass;

n : number of atoms per formula unit;

μ : reduced mass.

Thermal lenses

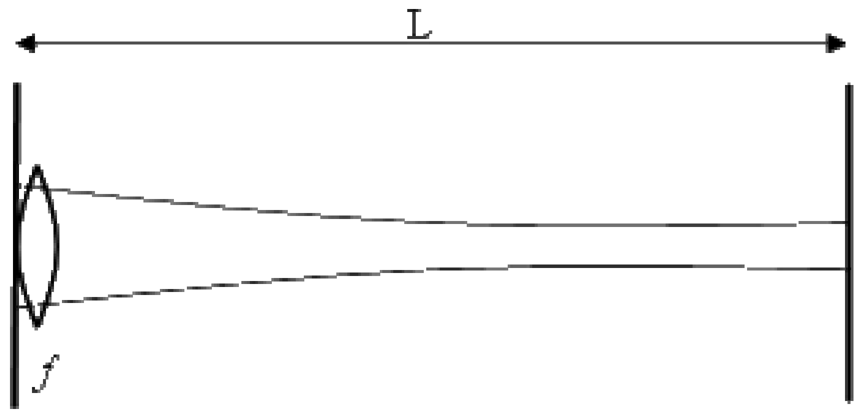
~~Need to know~~ Measure the thermal lens:



$$g_1 = 1 - \frac{L_2}{f} - \frac{L_0}{R_1} \text{ and } g_2 = 1 - \frac{L_1}{f} - \frac{L_0}{R_2}$$

$$L_0 = L_1 + L_2 - \frac{L_1 L_2}{f}$$

$$0 < g_1 g_2 < 1$$



Unstable when *f* → L

$$\omega_1^2 = \frac{\lambda L}{\pi} \sqrt{\frac{g_2}{g_1(1 - g_1 g_2)}}$$

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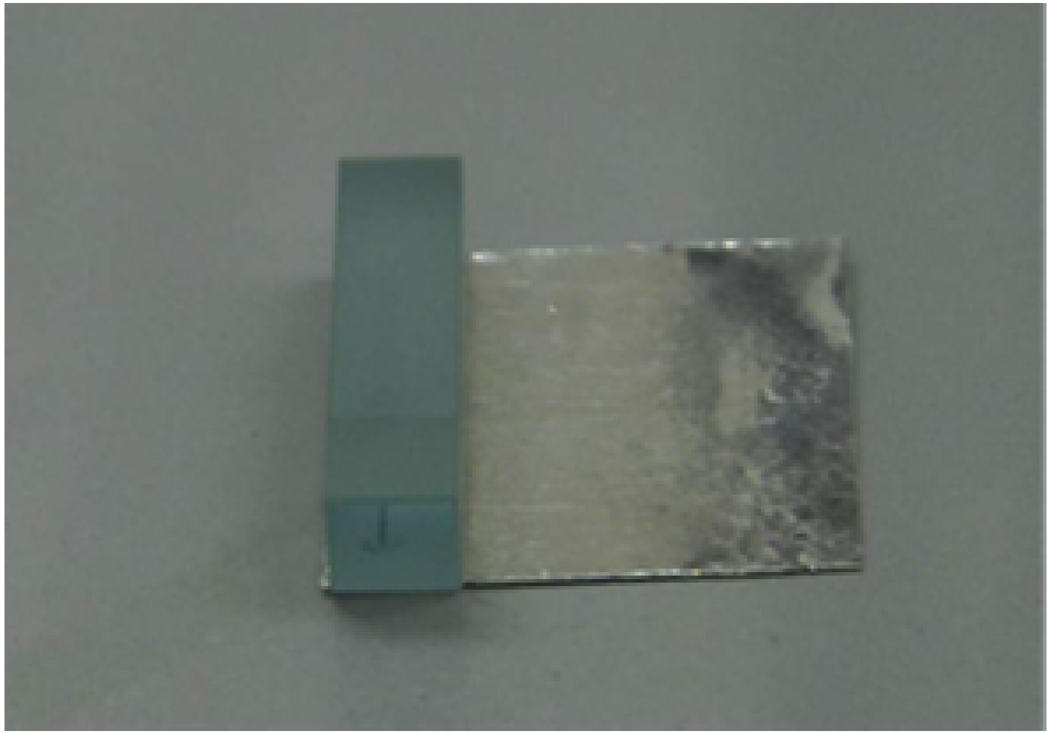
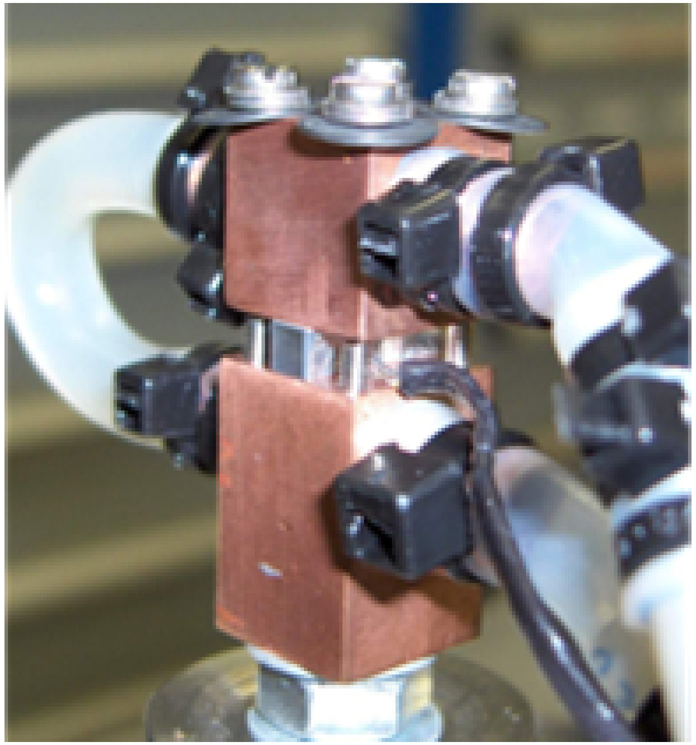
Experimental method

- Determine the focal power of the thermal lens created in $Nd:YVO_4$ and $Nd:GdVO_4$
- Set up flat-flat resonator
- Set up cooling and optical pump as it would be in laser
- Measure the output power and beam quality as a function of resonator length, or as a function of pump power
- Pump source: 2 x 30 W Jenoptik fibre-coupled laser diodes, 500/550, 0.22 N.A.

Experimental method



(a)



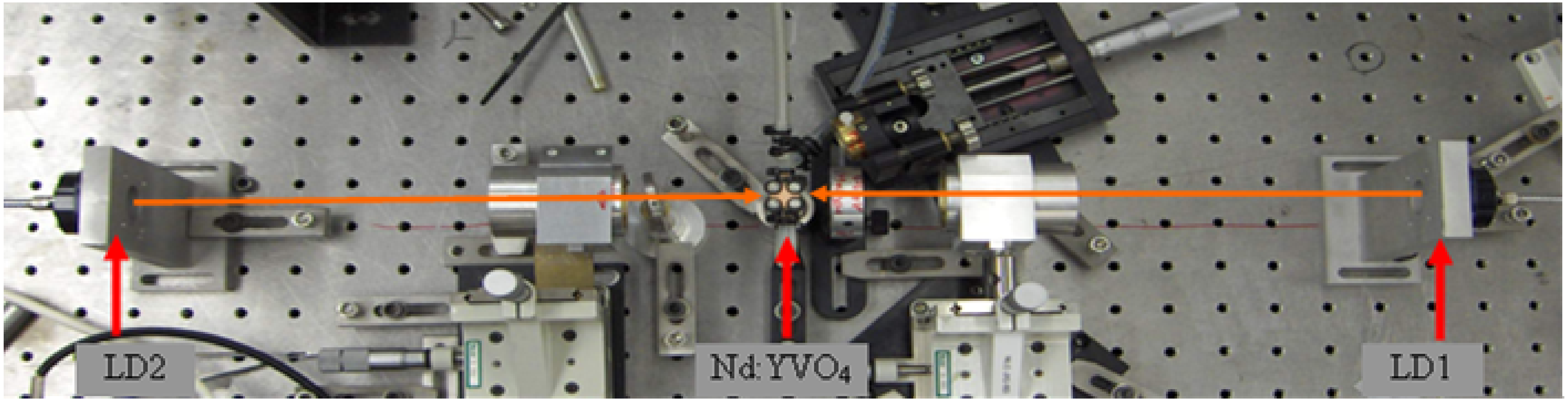
(b)

Nd:YVO_4 and Nd:$GdVO_4$

3 x 3 x 12 mm

0.27 % (at.)

Experimental outlay



Diode-end-pumped from both ends

Pump diameter: 750 μm

Folded flat-flat resonator:

length from crystal to OC: 123mm

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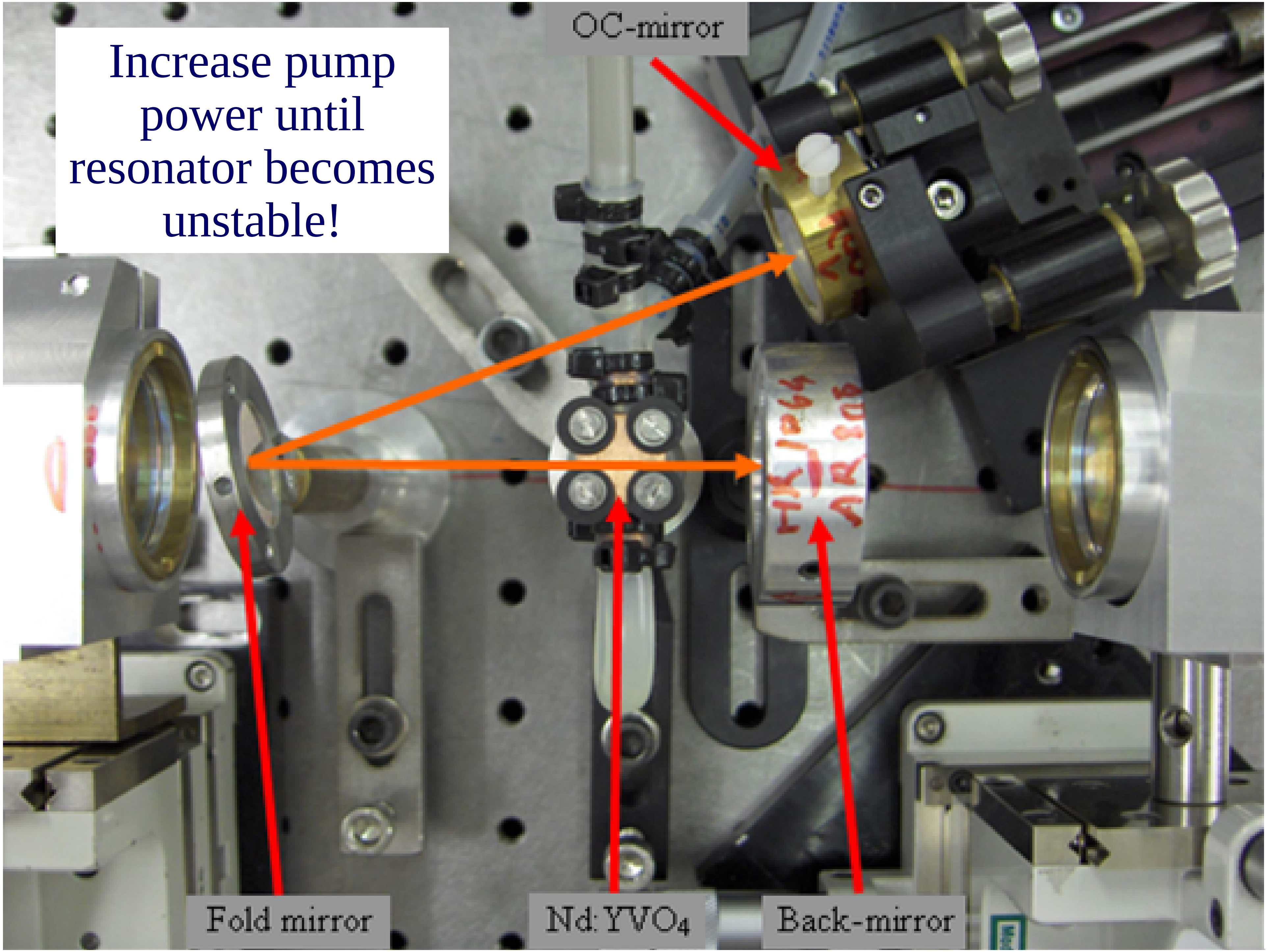
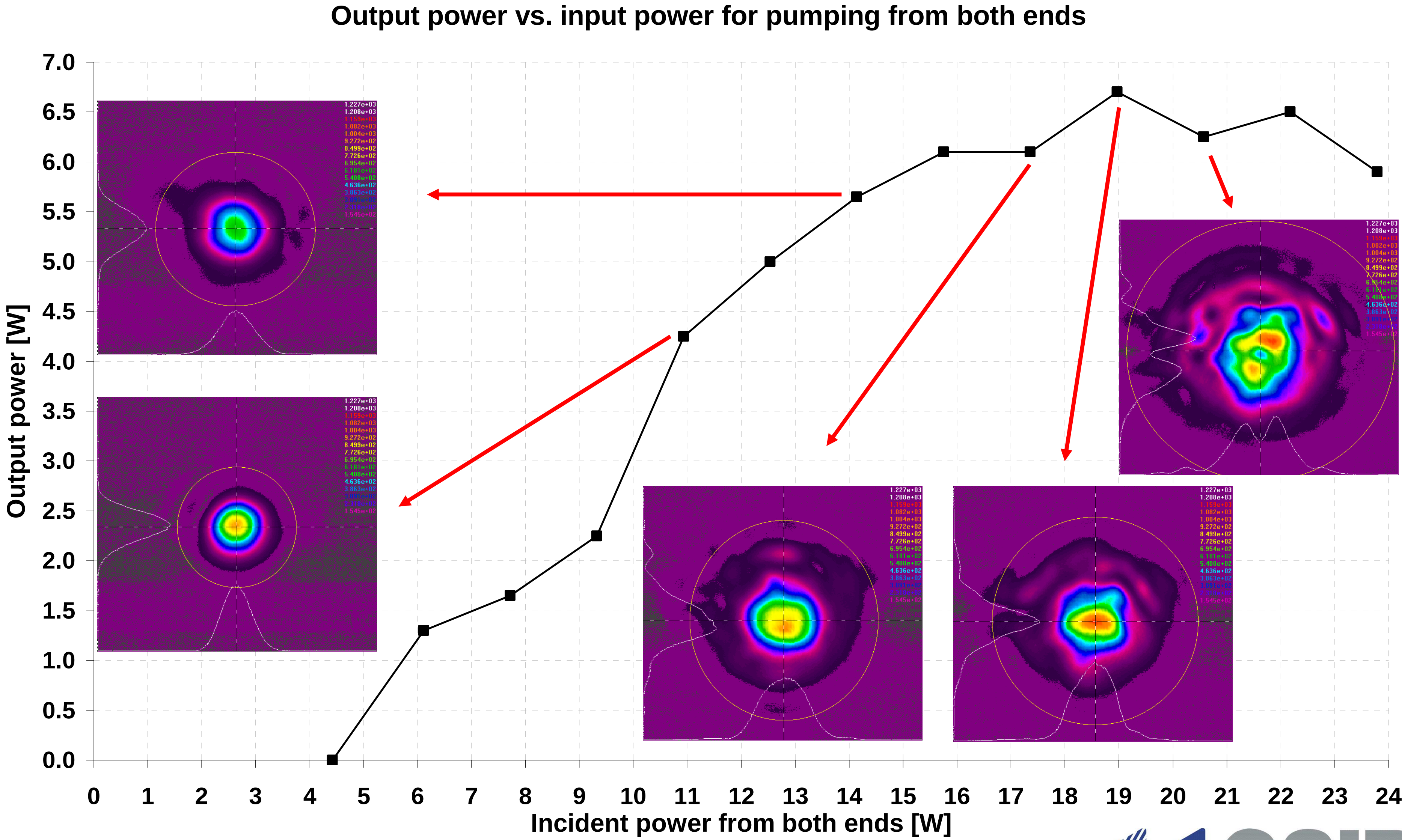
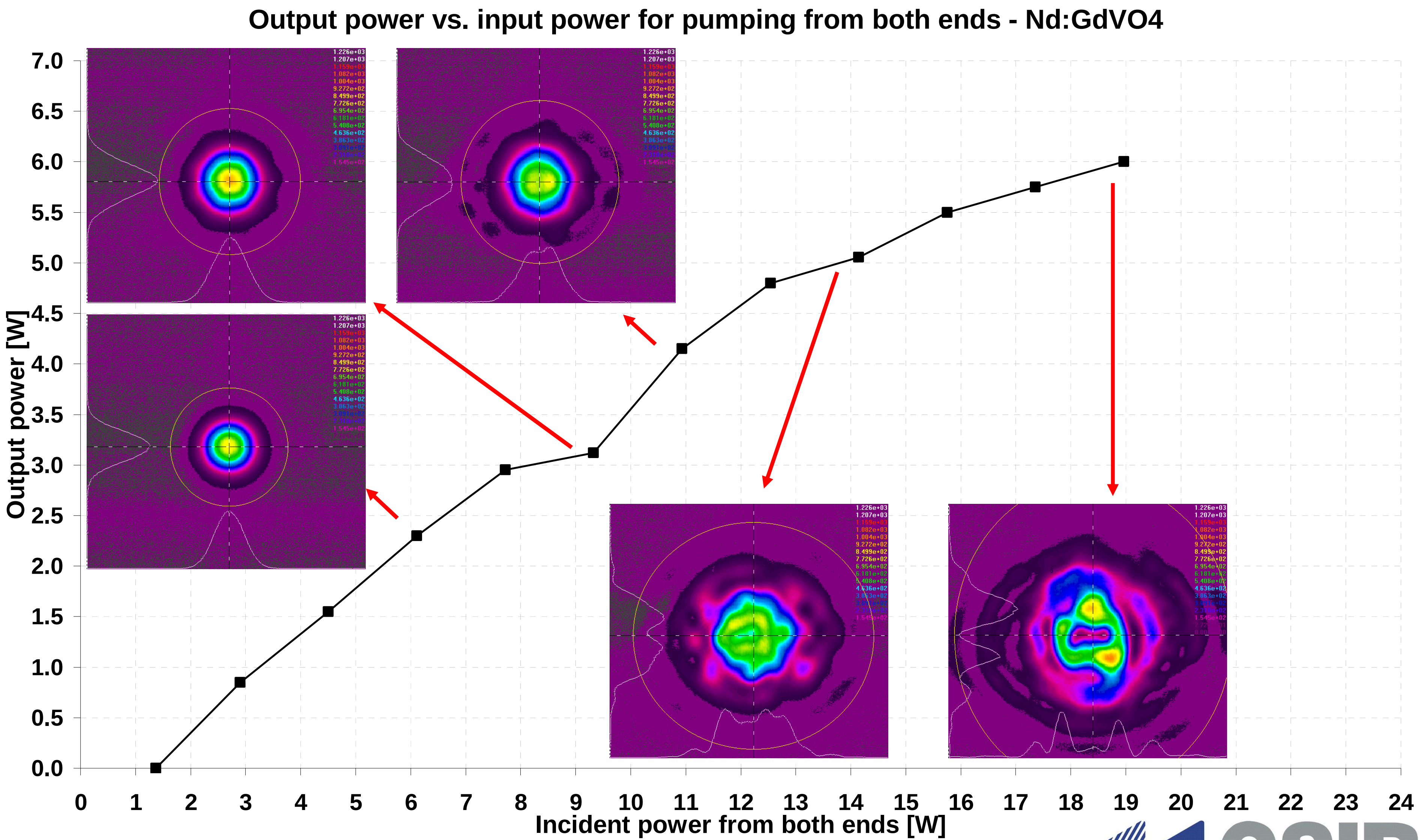

Increase pump power until resonator becomes unstable!
OC-mirror
Fold mirror
Nd:YVO4
Back-mirror

Experimental results: $Nd:YVO_4$



Experimental results: Nd:$GdVO_4$



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Experimental results

- Nd:YVO_4
  - Higher threshold
  - TEM_{00} unstable at ~ 16 W incident power
  - Thermal lens approx. 123 mm

- Nd:$GdVO_4$
  - Lower threshold
  - TEM_{00} unstable at ~ 14 W incident power
  - Thermal lens approx. 123 mm

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Conclusions

- A simple technique to measure the thermal lens
  - Same pumping conditions as real laser
  - Same cooling configuration as real laser
- Comparative experiment made
  - $Nd:YVO_4$ has smaller thermal lens than $Nd:GdVO_4$
  - $Nd:GdVO_4$ has higher absorption efficiency
- $Nd:YVO_4$ implemented in a commercial laser

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