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# High power diode pumped $\text{Yb}^{3+}:\text{CaGdAlO}_4$ laser

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**Abstract:** We study the performance of  $\text{Yb}^{3+}:\text{CaGdAlO}_4$  under 100 W diode pumping with a standard laser design. We also investigate the laser properties of  $\text{Yb}^{3+}:\text{CaGdAlO}_4$  for different doping in order to optimize the absorption and wavelength tunability.

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OCIS codes: 140.5680 Rare earth, solid state laser, 140.3480 Laser, diode-pumped, 140.4050 Mode-locked lasers

## 1- Introduction

$\text{Yb}^{3+}:\text{CaGdAlO}_4$  [1] has been recently demonstrated to be very interesting for the development of next generation diode-pumped short-pulsed modelocked lasers. In fact, this crystal demonstrated two very promising properties. First, it has, to our best knowledge, the broadest and the flattest emission band of the Yb-doped materials. This allowed the generation of 47 fs pulses at a low average power of 38 mW [2]. Second, a recently presented model [3] allowed us to evaluate the thermal conductivity of undoped  $\text{CaGdAlO}_4$  at  $11.4 \text{ W K}^{-1} \text{ m}^{-1}$  and we measured the 2 at. % Yb:CALGO thermal conductivity to be 6.9 and  $6.3 \text{ W K}^{-1} \text{ m}^{-1}$  along the  $a$  and  $c$  axis, respectively. This high thermal conductivity allows high-power pumping. Based on this result, we demonstrated the generation of 68 fs pulses with an average power of 520 mW for 15 W of pumping power[4]. Nevertheless, these works raised new interrogations on this crystal. First, is the ultimate pumping power for this crystal in the tens of Watts range? What is the thermal lens in this crystal? And more generally, what are the thermo-optical properties of this crystal? Second, because we observed that the absorption of the 2%-doped crystal is not optimal to maximize laser efficiency, more heavily doped crystals were grown. But, would the very exceptional spectral properties of Yb:CALGO be the same for highly-doped crystals? We try to answer these questions in this report.

## 2- Thermal behaviour of $\text{Yb}^{3+}:\text{CaGdAlO}_4$ under 100 W pumping

In order to access simultaneously to the temperature distribution (thermal camera 8-12  $\mu\text{m}$ ) and the thermal lens of the Yb:CALGO under lasing and not lasing conditions with an *in situ* longitudinal high power diode pumping, we developed the specific setup described on figure 1.

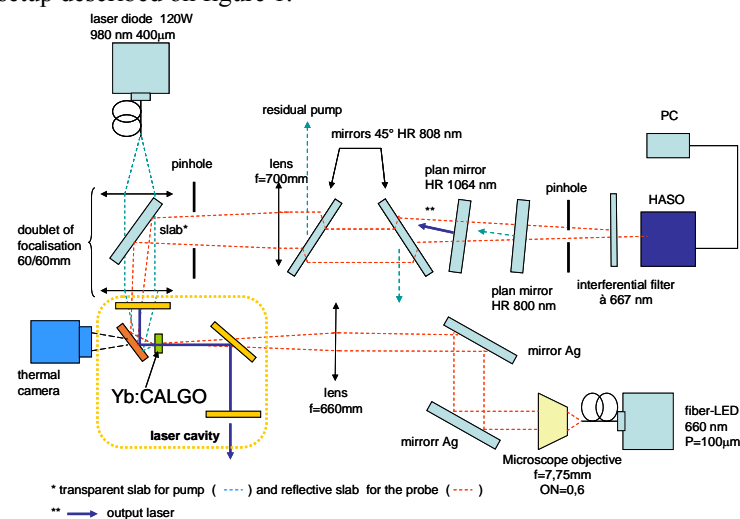


Fig 1. Experimental setup for measurements of the thermal cartography and the thermal lens under lasing and no lasing condition.

The diode emits up to 120 W at 980 nm on a 400- $\mu\text{m}$  diameter fiber-coupled output. The incident power on the 2%-doped Yb:CALGO is 86 W which corresponds to an absorption of 30 W without laser and 42 W with laser operation. Under these conditions the thermal lenses measured are  $f=37$  cm without laser and  $f=25$  cm with laser. As shown in fig. 2, the wavefront (wf) is almost no distorted. These results are very interesting because it shows that even at very high power the Yb:CALGO almost does not affect the cavity stability since the thermal lenses are relatively weak..

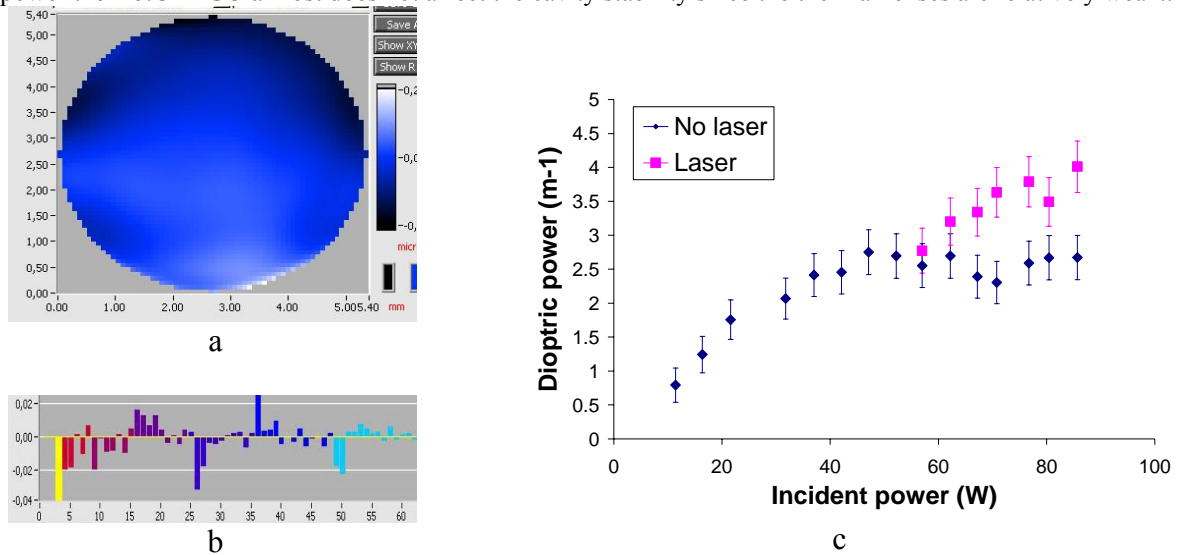


Fig 2. thermal lens measurement: a) distorted wavefront ( $P_i=83$  W), b) decomposition of this wf on the Zernike polynoms, c) thermal lens vs power.

A temperature mapping of the surface of the crystal has also been done using this system. The results are plotted in fig. 3. First, the crystal was set in a copper mount with contacts on 3 sides (bottom, left and right). Fig. 3a clearly indicates the lack of thermal dissipation on the fourth face. In these conditions we observed a global temperature elevation of 105 °C for 83 W of incident pump power and a temperature gradient in the crystal of 20 °C. This relatively small increase of temperature clearly confirms the excellent conductivity of this crystal and contributes to the small thermal lens.

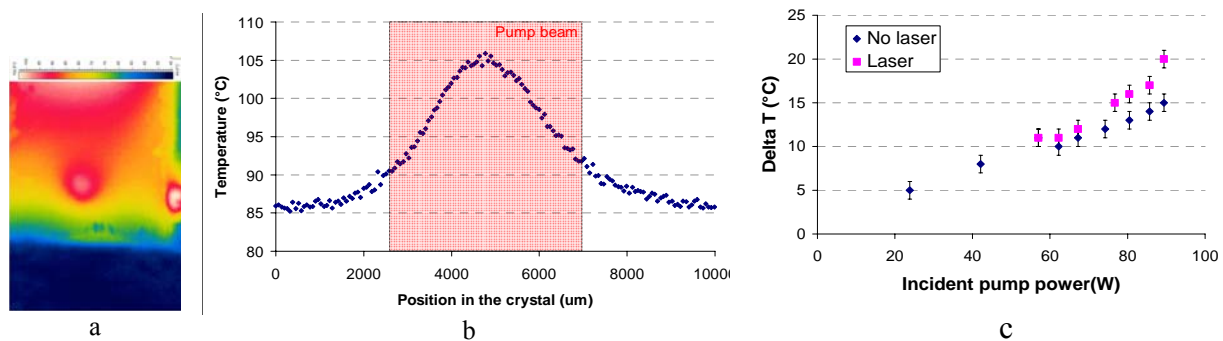


Fig 3. Thermography: a) temperature image ( $P_i=83$  W), b) extracted profile, c) temperature gradient vs power.

### 3- Laser operation of Yb<sup>3+</sup>:CaGdAlO<sub>4</sub> under 100 W pumping

A simple V-cavity has been developed with this crystal in order to test its laser performances. The setup is described in figure 4.

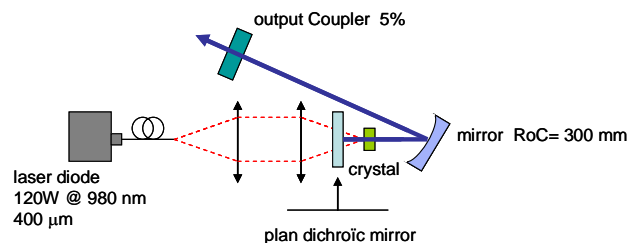


Fig 4. Experimental setup of the high power laser.

The laser power versus incident pump power is plotted in figure 5. We obtained up to 15 W output power in this configuration. The measurement of the absorbed pump power clearly indicates that only half of the incident power is absorbed in the 2%-doped Yb:CALGO under laser condition and only one third with no lasing (due to the saturation of absorption in this condition). This absorption measurement indicates that the 2-% doping is probably too low.

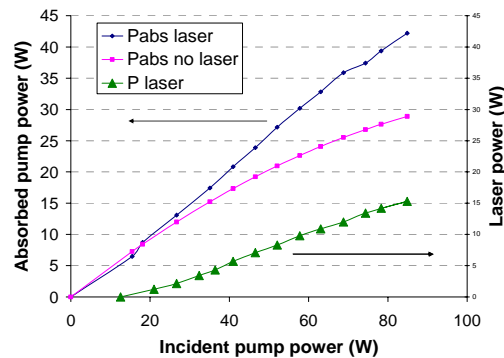


Fig 5. Laser power and absorbed powers vs incident pump power.

#### 4- Higher doped crystals

We decided to investigate different doped crystals in order to optimize the absorption. Our main concern was then the emission band. In fact, since the very particular emission band flatness of Yb:CALGO is provided by two exactly compensated crystallographic sites, this exact compensation is *a priori* not obvious for all doping ranges. We made some experiments to compare the emission spectra using a (low power) tunable laser with 2, 3.5, and 5-% doped crystals (fig. 6). Since no obvious differences appear in the tunability spectra for higher doping, one could expect to have similar performance in femtosecond regime than with the 2% doped crystal.

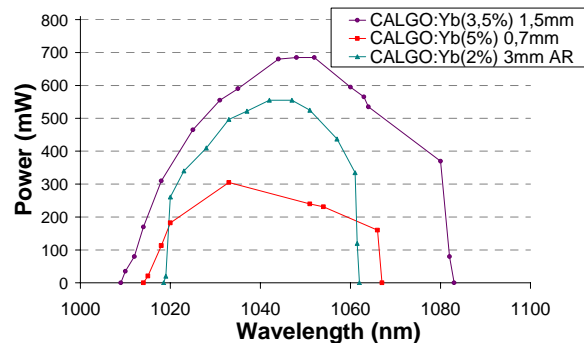


Fig 6.laser tunability for different crystal doping concentrations.

#### 5- Conclusion

In conclusion, we have demonstrated laser operation of Yb:CALGO pumped with 100W of pump power. We obtained 15 W of laser operation for 42 W absorbed power. We also investigated both temperature elevation and thermal lens in these conditions. Both results corroborate the excellent thermal behavior of Yb:CALGO. The 2-% Yb:CALGO demonstrates the exceptional quality of combining good thermal properties with a large emission and ultra-flat bandwidth. In order to optimize the absorbed power in a future work, we also investigated in a preliminary phase the spectral tunability for different higher doping concentrations.

#### 6- References

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