Experimental Cross Evaluation of Large Size Ceramic and Crystalline Yb3+:YAG Laser Gain Media Performance at High Average Power*)

Daniel ALBACH, Thierry GONCALVES-NOVO and Jean-Christophe CHANTELOUP

LULI, Ecole Polytechnique, CEA, UPMC Université Paris 06, 91128 Palaiseau, France

(Received 31 May 2012 / Accepted 22 August 2012)

Ceramic gain media are interesting candidates for large size gain media in high power diode pumped solid state lasers. We compare their performance to their crystalline counterparts used in the Lucia main amplifier. Small signal gain, wave front deformation and depolarization are of main interest.

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Keywords: ceramics, solid-state laser, Ytterbium, amplified spontaneous emission, thermal management, depolarization

DOI: 10.1585/pfr.8.3405049

1. Inroduction

Projects for laser driven fusion energy, like HiPER [1, 2], are promising candidates for future energy sources. Laser designs for such fusion drivers have to combine high energy pulses with considerable high repetition rates in the order of several Hertz. The problems to be addressed for the construction of such large size, high average power laser systems are Amplified Spontaneous Emission (ASE), thermal effects, laser induced damage and the availability of large size, high quality laser gain media. While ASE can only be minimized by the gain medium design [3], resultant effects, namely parasitic oscillations, are solved by adding a suitable cladding. One can add such an ASE absorbing cladding to ceramics with relative ease. Classic laser systems use laser quality glasses as large size gain media, which sacrifices repetition rate, while crystalline matrices show typically good thermal properties, but are difficult to grow in large size. Laser quality ceramics can be manufactured in suitable sizes and almost any shape, while maintaining most of the advantages of crystals in terms of thermal properties.

The Lucia laser system is a diode pumped laser chain delivering 10 J at 2 Hz [4, 5], which relies on Yb^{3+} doped YAG as laser crystals in an active mirror architecture with sizes of up to 60 mm in diameter. Our interest is focused towards the investigation of laser quality ceramics as potential alternatives to such large size crystals.

2. Performance of Large Size Ceramics Compared to Crystals

The ceramics under study consist in a 2 at.% Yb^{3+} doped central area with a diameter of 35 mm, which is surrounded by a 5 mm cladding of 0.25 at.% doped Cr^{4+}:YAG. The ceramic (manufactured by Konoshima, Japan) is shown in Fig. 1 together with the absorption spectra for this 7 mm thick sample for both the Yb^{3+} and Cr^{4+} doped part. We focused our interest on the performance of these ceramics in terms of small signal gain, wave front deformation and thermally induced depolarization compared to similarly doped single crystals of 60 mm diameter free of any cladding.

Figure 2 shows the small signal gain as a function of time for a pump duration of 1 ms. The pump intensity was in all cases 16 kW/cm^2 with a pump spectrum centered at 939 nm. Single-shot conditions were used to avoid the impact of thermal effects on the small signal gain. As the crystal had no external cladding, an onset of parasitic os-

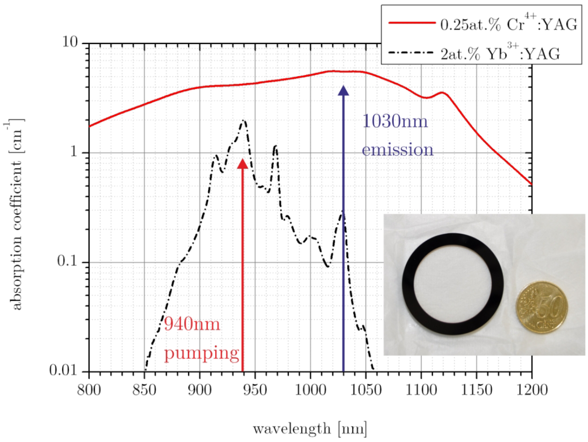

Fig. 1 Absorption coefficient of 2 at.% doped Yb^{3+}:YAG ceramic and 0.25 at.% doped Cr^{4+}:YAG ceramic at room temperature. The studied sample is scaled to a 50 Eurocent coin in the inset.

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author's e-mail: daniel.albach@polytechnique.edu

*) This article is based on the presentation at the Conference on Inertial Fusion Energy '12.

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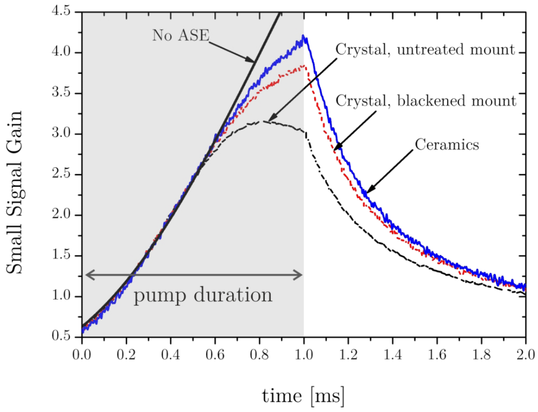

Fig. 2 Small signal gain as a function of time for a large size crystal with untreated and blackened gain medium mount as well as in the ceramic case under similar pumping conditions.

cillations cannot easily be suppressed. The shape of the mount as well as its surface structure revealed a critical role [6], as shown in the two different curves in Fig. 2. Leaving the gain medium mount, made out of untreated stainless steel, parasitic oscillations set in at ≈ 600 µs after the pump action starts (black curve). Coating this mount with black nickel partially solves this problem as the reflectivity drops significantly [6] (red curve), reducing the feedback from the gain medium mount. However, only the strong absorption of the ceramic cladding ensures a complete suppression of parasitic oscillations under single-shot condition blue curve).

Wave front distortions play an important role as it, for instance, significantly changes the intensity distribution on transport optics. In order to compare the Yb^{3+} doped ceramics to the crystals currently used in the Lucia laser system, we relied on an analysis set-up using a four wave lateral shearing interferometer (Phasics SID4) as a wave front sensor and a 1064 nm probe beam with an observation pupil of 22 mm in diameter. Figure 3 compares theoretical [7] and experimental results for the 60 mm diameter crystals and the 45 mm diameter ceramics with cladding.

The pump spot was 32 mm and the observation pupil 22 mm in diameter. One can observe in each case a negative focal length, as it is expected in the active mirror architecture. In the case of the large size crystal, only half of the diameter is covered by the pump spot and consequently a strong positive thermal lens compensates for the negative mechanical lens. For the ceramic, a reduced thermal conductivity and the additional heat deposition into the cladding by ASE leads to a stronger overall negative lens effect.

As focal lengths become rather short, compensation is needed if higher average intensities are requested (i.e. higher repetition rates). In a multiple pass extraction scheme, wave front compensation, by e.g. a deformable mirror, might be necessary.

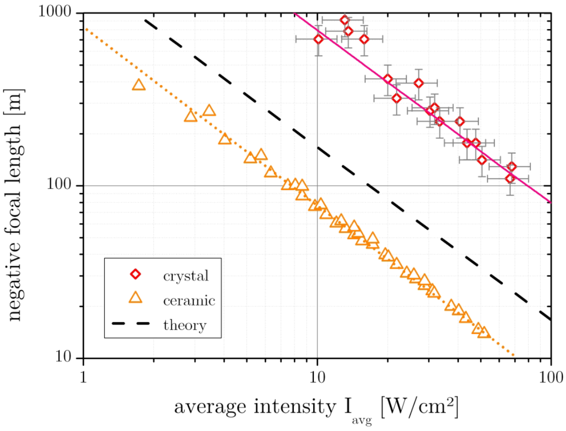

Fig. 3 Negative focal length as a function of the average pump intensity for both ceramic and crystal. The theoretical curve is displayed as well. One observes approximately one order of magnitude difference due to the lateral temperature distribution.

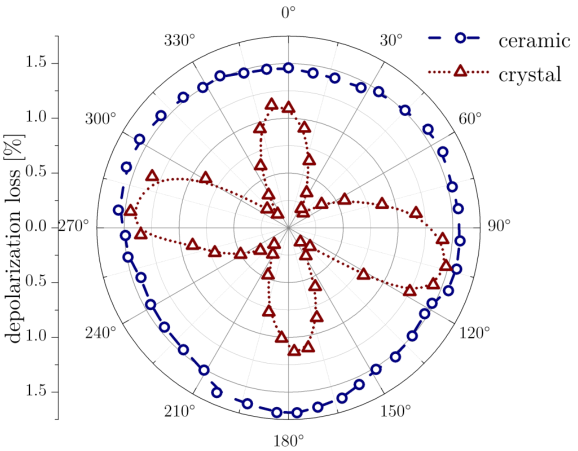

Fig. 4 Depolarization loss as a function of gain medium rotation for an average pump intensity of 40 W/cm^2. The rotation is performed around an axis normal to the surface.

The third performance parameter discussed in this context is the thermally induced depolarization. All laser crystals are oriented in the same way. The [001] axis is inclined by 12° from the perpendicular surface normal. Ceramics show stress induced birefringence similar to [111] oriented crystals [8] as when they are observed under an angle of 0°. There is no distinction for specific orientation of the gain medium in the ceramic case.

The dependency of the depolarization loss in one pass in active mirror configuration for the crystal and ceramic case is shown in Fig. 4 for a time averaged pump intensity of 40 W/cm^2. The angle of incidence is 24° (13° refracted angle). The detection limit for the crossed polarizer setup is the order of 0.02%. While the ceramic sample stayed constant during rotation, a strong modulation of the depolarization loss is observed for the crystalline sam-

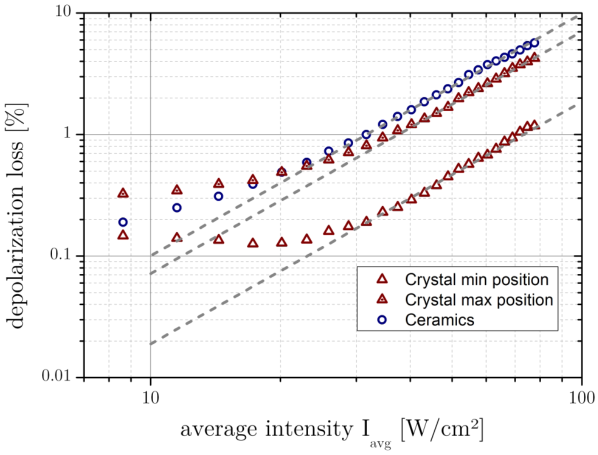

Fig. 5 Depolarization loss for the crystal minimum and maximum orientations together with the ceramic gain medium case. A distinctive I^2 scaling is found.

ple. Experimental values vary between 1.5% and 0.25%. The higher depolarization loss for the ceramic can be explained by the additional heat source in the ASE absorbing cladding.

Figure 5 displays the power scaling of depolarization losses with the average pump intensity I for the crystal in minimum and maximum loss orientations together with the ceramic case. While for low average intensities the losses are dominated by intrinsic effects, like mounting and sample quality, a distinctive scaling with I^2 is found. This scaling behavior is very similar to the deformation as shown in Fig. 3. This clearly restates the close relationship to the thermally induced sample deformation as source for the stress, hence the depolarization.

3. Conclusion

Yb^{3+}:YAG ceramics and crystals key laser characteristics are cross evaluated with the Lucia room temperature operated main amplifier. The presence of the Cr^{4+} doped YAG peripheral cladding layer of the ceramics is very likely to play a major role to the 10% increase observed in small signal gain. It also leads to a different heat load distribution within the disk, therefore increasing by an order of magnitude the thermal lens effect. This observation indicates the importance of cladding thermal management for foreseen cosintered ceramic based amplifiers [9].

Under typical operating conditions (several tens of W/cm^2 pump intensity) depolarization losses are in the order of 1% in one pass. Energetic performances are currently being performed to be followed by a multiple pass extraction campaign devoted at pursing this cross evaluation study of the two gain media at disposal for high energy/high average power laser chains.

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