Development of a TW Level Cr:LiSAF Multipass Amplifier

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Abstract. We report here the operation, at 5 Hz, of a multipass flashlamp pumped Cr:LiSAF ultrashort pulse amplifier, presenting peak powers over 0.3 TW. This unusual high repetition rate was obtained by using two-flashlamp pumping scheme, aiming the minimization of the thermal load on the gain medium by the use of intracavity absorption filters. This cavity was used as a four-passes multipass amplifier in a hybrid Ti:Sapphire/Cr:LiSAF system. The maximum amplification factor was 150, and the compressed pulse duration was 60 fs.

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INTRODUCTION

Cr:LiSAF (Cr^{3+}:$LiSrAlF_6$) single crystals are very attractive gain media due to its spectroscopic properties[1] such as a long lifetime of the upper laser level (~67 μs) at room temperature[2], three broad absorption bands[2], a wide emission band ranging from 650 nm to 1050 nm and a high saturation fluence. Laser action was demonstrated under several pumping schemes[2-6], and pulse durations down to a few femtoseconds in Mode-Locking regime[7] were achieved.

Flashlamp-pumped Cr:LiSAF lasers[3, 8-10] have been developed reaching pulse energies up to 8.8 J and average powers up to 4.5W[8], and flashlamp pumped ultrashort pulse amplifiers[10-13] achieved peak powers up to 8.5 TW. Regrettably, the LiSAF host has poor thermal properties[14] including a low thermal conductivity and a strong temperature dependence of the laser transition lifetime due to thermal quenching[15], limiting the operation repetition rate of flashlamp-pumped Cr:LiSAF lasers below 12 Hz[8] and of TW level amplifiers under 1 Hz[10-13, 16-18]. In a gain medium in the shape of a rod, crystal cracking due to thermally induced stress was reported at 18 Hz[19].

The main heat source in a flashlamp pumped Cr:LiSAF crystal is the Stokes-Shift from the three absorption bands centered at 290 nm, 450 nm and 650 nm to the emission band at 830 nm. To reduce this thermal load on the Cr:LiSAF rod, we developed and built a two-flashlamp pumping cavity with intracavity filters that select the absorption bands being pumped, and demonstrated that this scheme allowed the laser operation at repetition rates as high as 30 Hz[20] or 30 W of average power[21], depending on the filters used. Here we report results obtained when using this pumping cavity as an ultrashort pulse amplifier in a multipass configuration.

EXPERIMENTAL SETUP

The pumping cavity houses two Xenon flashlamps, a 1.5 mol% Cr doped Cr:LiSAF rod (101.6 mm long, 6.35 mm diameter) with Brewster angled faces. Absorption filters were inserted between each lamp and the rod. Each flashlamp is individually fed by a power supply that can deliver up to 50 J of electrical energy in 65 μs. The design details are given in our previous work[20]. To operate as an ultrashort pulse amplifier, the pumping cavity was added to a CPA[22] system comprising a Ti:Sapphire main oscillator (Coherent Mira-Seed) that generates ~20 nm, 50 fs ultrashort pulses, and a Ti:Sapphire multipass amplifier (Quantronix Odin) that stretches, amplifies

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and compresses the pulses to ~1 mJ, in ~50 fs FWHM duration, at 1 kHz repetition rate. The Odin amplifier has a 1 ps/nm stretcher, and was modified to allow the extraction of the amplified, uncompressed pulses (~20 ps FWHM), that were injected into the Cr:LiSAF rod for amplification. After amplification, the amplified pulses were compressed externally by a high-energy temporal compressor matched to the Odin stretcher. The compressed pulses were then characterized by a single-shot autocorrelator (Coherent SSA).

RESULTS

For the initial measurements, a set of filters that allow pumping only in the 650 nm band (filter set 1 of our earlier work[21]), were used inside the pumping cavity. The Ti:Sapphire amplified, ~20 ps stretched pulses were injected into the Cr:LiSAF crystal under pumping, and the amplification $\mathcal{A}$, defined by the ratio between the pulse energies that emerge from the Cr:LiSAF under pumping and without pumping, was measured after one pass through the rod, at 1 Hz repetition rate. The results are shown in Figure 1 (filled circles), where it can be seen that the amplification grows linearly with the pumping power, indicating a low gain regime, and the maximum amplification was just over 1.5 per pass. This value, although suitable for a regenerative amplifier, is too low for a multipass configuration. To increase the gain per pass we substituted the intracavity filters by glass plates (filter set 3 of our earlier work[21]) that allowed pumping in the 650 nm and 450 nm bands, and in the wing of the 290 nm band, and the amplification results are shown as hollow squares in Figure 1. In this case, the amplification increases exponentially with the pumping energy, as expected in a high gain system, and the maximum amplification is 3.61±0.09 per pass, adequate for our multipass amplifier.

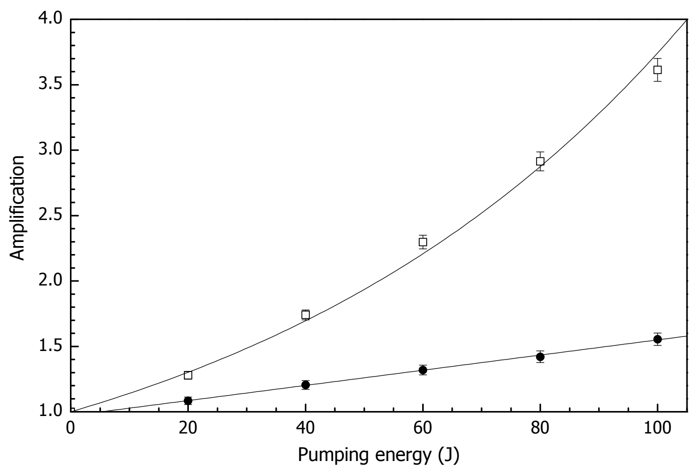

FIGURE 1. Pulse amplification dependence on the pumping energy when pumping only on the 650 nm absorption band (filled circles fitted by linear function) and on the three absorption bands (hollow squares fitted by an exponential function).

Having established the intracavity filter set that provides the gain needed for the multipass amplifier configuration, the double pass amplification at the highest pumping energy (50 J/flashlamp) was measured to be 13.4±0.7, in good agreement with the square of the single pass amplification, indicating that no additional or nonlinear losses were introduced in this second pass. We proceeded to determine the double pass amplification dependence on the repetition rate, and the 1 Hz amplification normalized results are depicted in Figure 2. This figure shows that the amplification is constant (within the experimental error) up to 5 Hz, dropping for higher repetition rates, demonstrating that our scheme to reduce the thermal load on the Cr:LiSAF rod that improved the laser performance[21] can also be used to increase the repetition rate of Cr:LiSAF flashlamp-pumped ultrashort pulse amplifiers. This amplification decrease is consistent with the behavior observed when operating the pumping cavity as a laser (inside a resonator) with filter set 3[20], and is attributed to thermal effects that diminish the population inversion and consequently decrease the stored energy available to amplify the pulses.

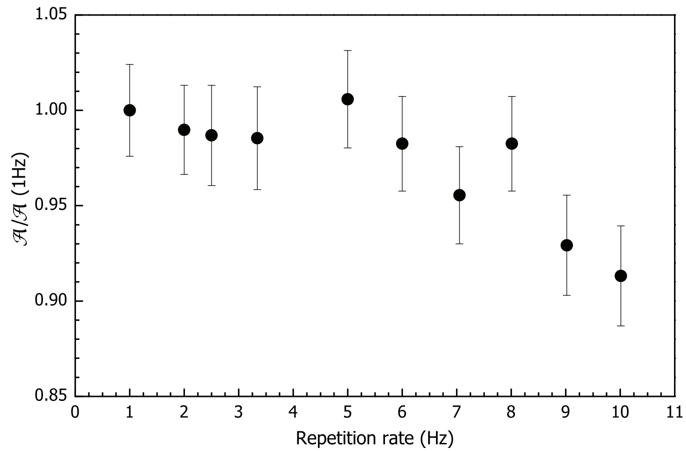

FIGURE 2. Double pass pulse amplification as a function of the repetition rate. The amplification $\mathcal{A}$ is normalized by the 1 Hz amplification $\mathcal{A}$(1 Hz).

Even with a gain over 3, in order to amplify the pulses to obtain peak powers in the TW region, an amplification by a factor over 100 is needed to compensate for the system losses, mainly in the compressor, and to obtain this gain, four passes through the Cr:LiSAF crystal are necessary. The small diameter/length ratio of the Cr:LiSAF rod determines a small acceptance angle for the laser beam passages, resulting in long distances between the rod and the mirror that define the multipass amplifier geometry. The rod Brewster angled faces reduce the acceptance angle even more due to the enlargement of the beam in the plane of incidence, in the horizontal plane in our design. To minimize this problem, we decided to restrain the four passes to the vertical plane, orthogonally to the plane of incidence defined by the Brewster faces, as schematized in Figure 3. The mirror M_2 is located at 9 cm from one of the Cr:LiSAF faces, and mirrors M_3 and M_4 are 90 cm from the other face; the vertical separation between mirrors M_3 and M_4 is 4 mm.

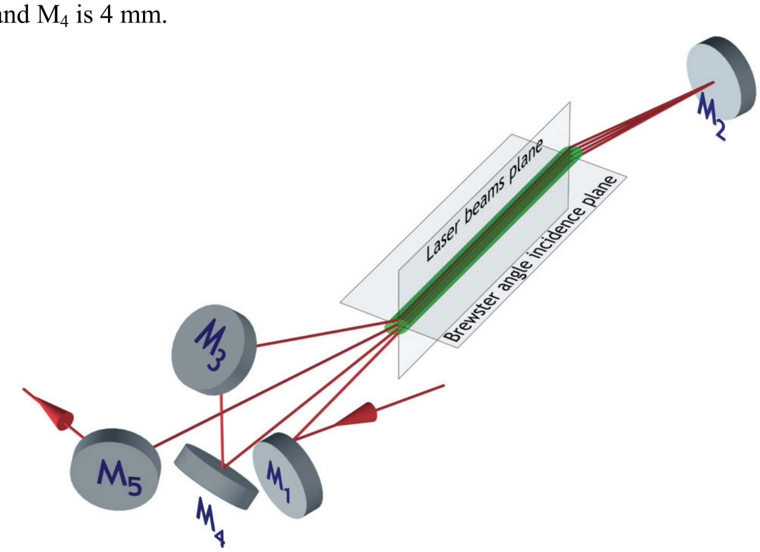

FIGURE 3. Scheme of the four-passes Cr:LiSAF amplifier geometry (the refraction angles of the beams entering and leaving the rod are not real, and the distances are not to scale). The mJ level pulses are injected in the amplifier by mirror M_1 in an ascendant trajectory, then mirrors M_2, M_3 and M_4 define the subsequent passes; after the fourth pass the pulses pass between mirrors M_3 and M_4 to mirror M_5 and to the compressor.

The amplification dependence on the pumping energy for the four-passes configuration was measured at 5 Hz repetition rate, since the amplification is the same as at 1 Hz (Figure 2), and the results are shown in the upper graph in Figure 4 as filled circles; the right scale presents the pulses measured energy after compression. In the same graph, the hollow squares represent the fourth power of the single-pass amplification results shown in Figure 1, and a good agreement is observed, except for the data at the highest pumping energy (100 J). This deviation occurs because at this higher pumping, the amplified pulse damaged the Cr:LiSAF rod and mirror M_2. Nevertheless it was possible to measure the energy (30 mJ) and pulse duration (60 fs FWHM, on the single-shot autocorrelator) at the maximum pumping energy, resulting in a pulse with 0.5 TW of peak power, that damaged the gain medium. The subsequent energy measurements provided the last point shown in Figure 4. For the temporal measurements, the distance between the compressor gratings was adjusted to minimize the pulsewidth at the single-shot autocorrelator when there was no pumping in the rod (unitary amplification), and was kept for the amplification measurements. The lower graph in Figure 4 depicts the temporal pulsewidth (FWHM) measured along with an exponential function fitted to the five initial points. The last point, in gray, represents the value of the fitted function at the highest pumping energy with an estimated error ten times greater than measured at the lower pumping energies, and was used to estimate the peak power at 100 J pumping. Even after the damage, the peak power obtained at the higher pumping energy exceeded 0.3 TW, at 5 Hz repetition rate. Previous results of similar peak power for this crystal were always limited to 1 Hz. The 20% increase in the pulsewidth at the higher pumping indicates that the B integral of our amplifier is small, and once the gratings distance was not increased after the initial optimization, the pulses can be shortened, generating higher peak powers at 5 Hz repetition rate.

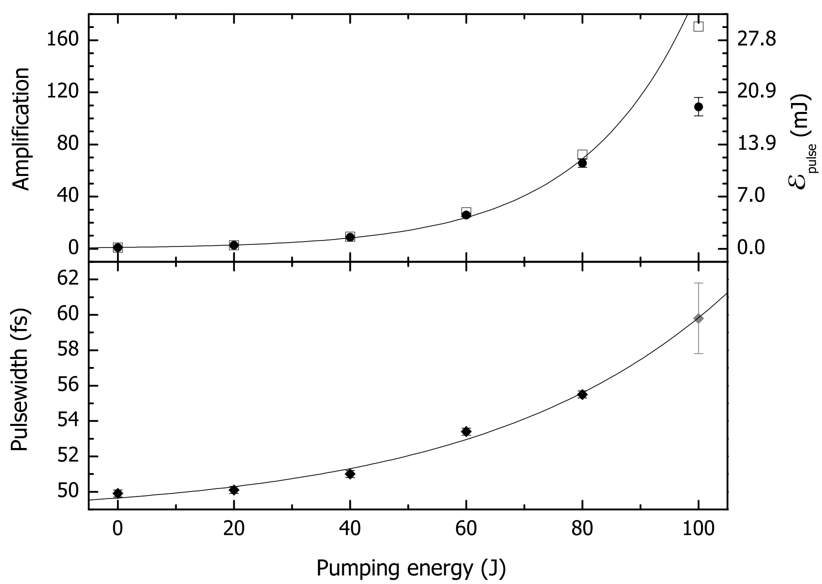

FIGURE 4. Upper graph: the filled circles represent the four passes amplification dependence on the pumping energy, and the empty squares are the fourth power of the single pass amplification from Figure 1, with the right scale indicating the pulse energy. The lower graph shows the amplified pulses temporal pulsewidth (FWHM) after compression.

Measuring the damage size in the Cr:LiSAF rod and in mirror M_2, the damage threshold was estimated to be around 0.3 J/cm^2, about one order of magnitude below the usual damage threshold. This result, together with the damage shape, indicates that the beam had hot-spots with very high local intensities that damaged the optical components. Further investigation allowed determining that these hot spots were due to misalignments in the whole amplification chain, and a careful alignment aimed to improve the beam transversal profile will eliminate them.

CONCLUSIONS

We developed a Cr:LiSAF pumping cavity with reduced thermal load in the crystal rod, that could be operated as a laser or as an ultrashort pulse amplifier. Amplification over 150 was obtained, generating pulses at 5 Hz repetition rate with peak powers over 0.3 TW, the highest obtained by a laser system in the southern hemisphere. At 0.5 TW peak power the gain medium was damaged as a consequence of the presence of hot-spots in the beam. At the present time we are working to improve the beam transversal energy distribution, eliminating hot-spots, and also to stretch the pulses to larger pulsewidths, what will allow amplification to higher energies and peak powers to the 1 TW region. Using the presented configuration, higher repetition rates could be obtained at the expense of less amplification per pass (Figure 2). At the present time we have substituted the gain medium and are using intracavity filters (filter set 2 from our earlier work[21]) that will provide a slightly smaller gain, but are expected to allow the generation of high peak power pulses at 10 Hz repetition rate.

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