Observation of a repetition rate dependent thermal lens effect on a flashlamp pumped Cr:LiSAF laser

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Abstract

We report here the observation of a repetition rate dependent thermal lens effect on a flashlamp pumped Cr:LiSAF laser developed and built by us. The laser pumping cavity incorporates optical filters that select the Cr:LiSAF absorption bands being pumped, and are used to minimize thermal effects. Nevertheless, thermal effects are still present and its influence on the laser behavior was studied. Also, we demonstrated that the CDD camera used to measure the thermal lens can be employed to estimate the laser pulse energy.

Introduction

Cr:LiSAF (Cr^{3+}:$LiSrAlF_6$) single crystals exhibit optical spectroscopic properties[1] suitable for a laser medium such as a long lifetime of the upper laser level (~67 μs) at room temperature[2], three broad absorption bands[2] and a wide emission band ranging from 650 nm to 1050 nm. Laser action was demonstrated under several pumping schemes[2, 3, 4, 5], particularly in CW[6] and pulsed regimes. Pulse durations ranging from hundreds of microseconds under free-running pulsed excitation down to nanoseconds in Q-Switching and few femtoseconds in Mode-Locking regime[7] were achieved.

Flashlamp-pumped Cr:LiSAF tunable lasers[3, 8, 9,10] have been developed reaching pulse energies up to 8.8 J, but due to the poor thermal properties of the LiSAF host[11] the operation repetition rate of these lasers were always confined under 12 Hz[8]. The low thermal conductivity leads to crystal cracking due to thermally induced stress, and in the case of a gain medium in the shape of a rod, fracture was observed at 18 Hz[12]. Besides the thermal induced stress that leads to fracture, the lifetime of the Cr:LiSAF laser transition is strongly temperature dependent, dropping from ~67 μs at room temperature to half this value at 69°C, due to thermal quenching[13]. Under flashlamp pumping, the low LiSAF thermal conductivity prevents heat extraction from the laser medium, and if its temperature rises above ~25°C, the nonradiactive decay generates more heat, what in turn increases the nonradiactive decay rate, rapidly increasing the crystal temperature in a catastrophic process that reduces the energy storage capacity of the crystal and can lead to fracture.

In order to avoid thermal quenching and crystal fracture due to accumulated heat, flashlamp pumped Cr:LiSAF oscillators have been kept operating at low repetition rates. Shimada et al.[8] reported the highest repetition rate and power on a Cr:LiSAF laser to be 4.5 W at 12 Hz, and a slab geometry laser[9] scheme, that uses small thickness gain medium allowing better heat extraction, achieved pulse energies as high as 8.8 J, but at 5 Hz repetition rate.

Aiming to raise the power and repetition rate of flashlamp pumped Cr:LiSAF rod lasers, we developed and built a two-flashlamps pumping cavity that minimizes the crystal thermal load and temperature gradient by decreasing the heat reaching the gain medium and being generated inside it[14]. This is accomplished by the use of intracavity optical filters placed between each lamp and the Cr:LiSAF crystal, as shown in Figure 1, and also by matching the flashlamps pulse duration to the Cr:LiSAF higher laser level lifetime. A plane concave resonator[14] was used to study the pumping cavity performance during laser operation. The laser could be operated generating 10 kW pulses at 30 Hz and 20 W average power[14], or producing 40 kW pulses at 15 Hz repetition rate and 30 W average power[15] depending on the intracavity filters used. Although the intracavity filters reduced the thermal effects that affect the laser performance, they are still present, mainly in the form of thermal lens. Here we present measurements of the beam intensity profile and discuss its modification due to the induced thermal lens when increasing the laser repetition rate.

Experimental Setup

The pumping cavity that we have developed houses two Xe flashlamps and a 101.6 mm of length and 6.35 mm of diameter Cr:LiSAF rod with Brewster angled faces and 1.5mol% Cr doping. Each flashlamp is independently fed by a power source capable of delivering up to 50 J in ~67 μs (FWHM) pulses (the pulse duration was chosen in order to match the laser transition lifetime to decrease heat generation by pump energy lost to spontaneous emission). Details of the cavity design and power sources are given in our previous work[14]. The temperature of the gain medium inside a pumping cavity is determined by how much energy is absorbed by the medium, and the amount of that energy that is not converted into light emission (spontaneous or stimulated), and how this excess energy is extracted. The main heat source for the 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 (Figure 2). For a photon absorbed at the center of the 290 nm band resulting in an emitted photon at 830 nm, about 65% of its energy is converted into heat due to the Stokes-Shift. For photons absorbed at the center of the 430 nm and 650 nm bands, these fractions are 50% and 24%, respectively. With the purpose of controlling the heat in the rod, optical filters were inserted into the pumping cavity between the rod and each one of the flashlamps, selecting the light that is absorbed by the rod and converted into heat in the optical cycle. Also, the pumping cavity was designed in a way that the optical filters divide it in three compartments, isolating the rod from the flashlamps, allowing independent coolant flow around each component. The cooling water flows around the rod, and then refrigerates the flashlamps. Thus, heat transfer from the flashlamps to the rod by the cooling water is avoided. In Figure 1 a scheme of the pumping cavity is shown.

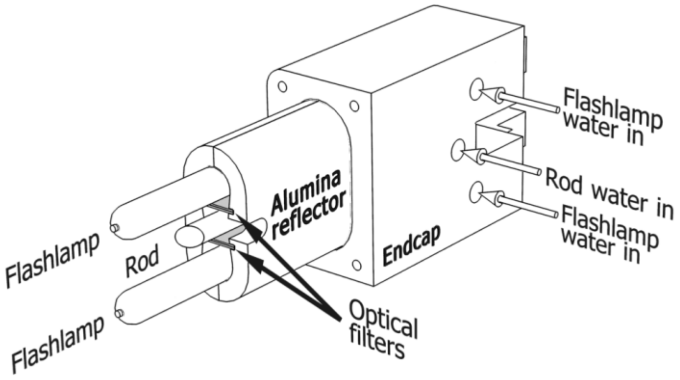

Figure 1. Scheme of the pumping cavity without an endcap. The different cooling water entrances for cooling the crystal and flashlamps are indicated; the optical filters, located between each flashlamp and the crystal, divide the pumping cavity into three independent cooling chambers.

Three different filter sets, whose transmission spectra are shown in Figure 2, were used. The filter set 1 allows pumping only on the lower energy band, while filter sets 2 and three transmit light to pump the other two absorption bands.

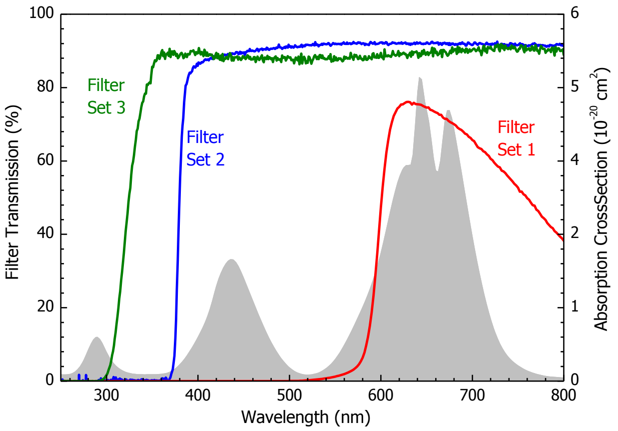

Figure 2. Transmission spectra of the intracavity filters sets used (lines, left scale), and Cr:LiSAF absorption cross section parallel to the c-axis (shaded, right scale).

To study the thermal effects dependence on the on the laser repetition rate, the pumping cavity was placed inside a plane-concave resonator and the laser pulse energy dependence on the repetition rate was measured for the filter set 2, for various pumping energies. To measure the beam intensity profile dependence on the repetition rate, a CCD camera was used (Newport LBP Series Laser Beam Profiler).

Results and Discussions

In Figure 3 the laser pulse energy dependence on the repetition rate is shown for filter set 2 placed inside the pumping cavity. Among the three filter sets used, this one generates 30 W of average power at 15 Hz, at the highest pumping energy[15] (100 J). At this repetition rate the pulse energy drops 20% of its value at 1 Hz, indicating the presence of thermal effects. In our previous work[15], we investigated if this energy drop results from the thermal quenching of the Cr:LiSAF upper laser lever[13], and we observed no dependence of the upper laser level lifetime on the repetition rate, indicating that another mechanism is responsible for the energy reduction. Figure 4 depicts the Cr:LiSAF laser transversal beam section measured with the CCD camera for 1 Hz and 15 Hz repetition rates. In this figure is easily seen that the beam spot size and shape show a strong dependence on the repetition rate. As the repetition rate increases, the beam became more confined to the central region of the rod, indicating a converging lens behavior. This is typical of thermal lenses[16] that arise when a temperature gradient is crated inside the gain medium as a consequence of the heat generated within the rod and the heat extraction by the cooling fluid.

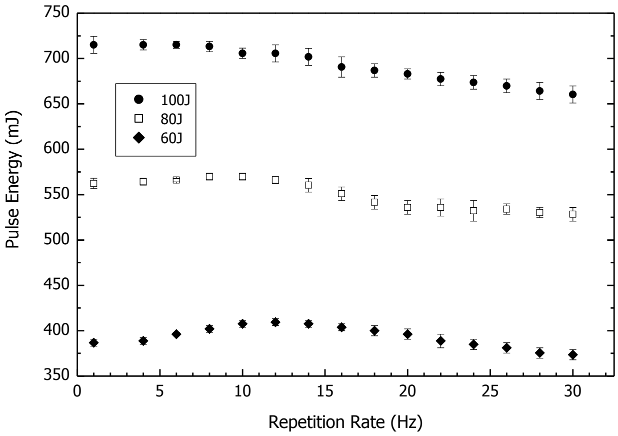

Figure 3. Pulse energy dependence on the repetition rate for filter set 1. Under 100 J pumping, at 30 Hz repetition rate, the measured pulse energy was 660 mJ, resulting in 19.8 W of average power.

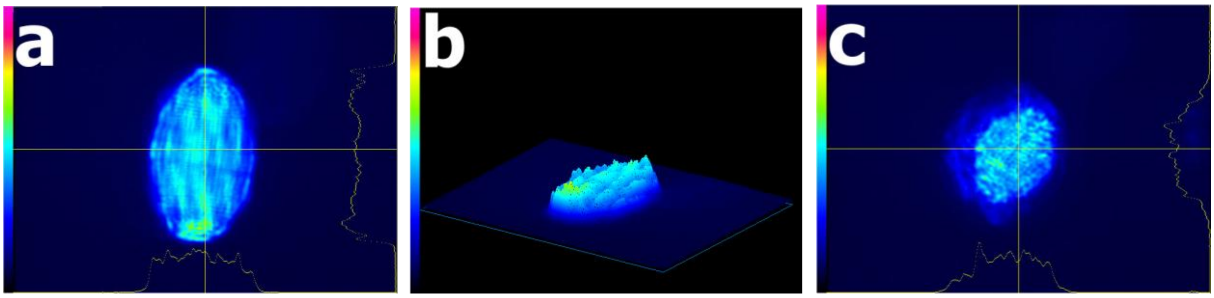

Figure 4. Cr:LiSAF laser transversal beam section false color (bar on the left is intensity scale) CCD image for: a) 1 Hz repetition rate; b) 1 Hz (same as fig. 4a), 3D view; c) 15 Hz repetition rate. On the lower and right margins of each figure the intensity profile along the lines is plotted.

To check if the CCD data can be used to estimate the pulse energy, we calculated the effective volume of the beam spot measured by the CCD (see Figure 4b), since it is expected to be proportional to the pulse energy; this effective volume is calculated by summing the value of each image pixel. In Figure 5 we present the plot of this volume versus the energy measured by an energy detector after attenuation by a beam-splitter (the volumes were normalized by the higher measured value). These measurements were performed for the laser operating in the range from 1 Hz to 15 Hz. This plot shows that there is a linear relation between the volume calculated and the energy measured, validating this method of measuring the pulse energy.

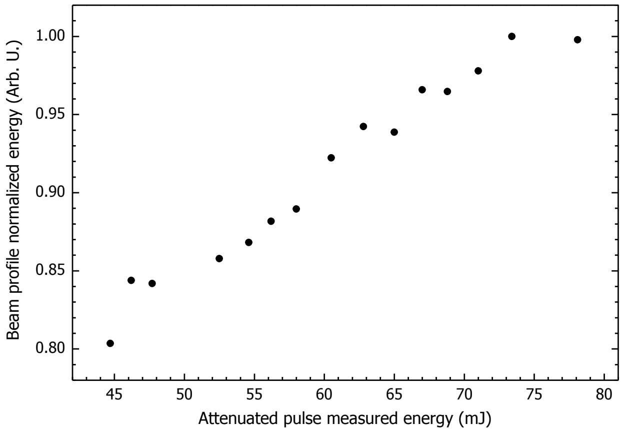

Figure 5. Plot of the beam profile normalized calculated energy versus the pulse measured (attenuated) energy. The plot linearity shows that the CCD data can be used, within a good approximation, to estimate the pulse energy.

Conclusions

Using a CCD camera we observed that the beam profile in our flashlamp pumped Cr:LiSAF laser exhibits a strong dependence on the operating repetition rate. This dependence is expressed in a beam transversal compression as the repetition rate increases.

Also, we demonstrated that the CCD camera images of the beam profile can be used to estimate the beam energy since it was shown that the calculated volume of the acquired image is proportional to the beam energy.

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