Flashlamp pumped Cr:LiSAF laser thermal effects dependence on the pumping spectrum filtering

Ricardo Elgul Samad, Sonia Licia Baldochi, Gesse Eduardo Calvo Nogueira and Nilson Dias Vieira Jr.

Centro de Lasers e Aplicações – IPEN/CNEN-SP
Av. Prof. Lineu Prestes 2242, 05508-000, São Paulo, Brazil
resamad@gmail.com   resamad@ipen.br

Abstract

We report the performance of a flashlamp-pumped Cr:LiSAF laser developed and built by us. The pumping cavity incorporates filters that select the flashlamps' emission spectrum to match the absorption bands of the gain medium, allowing control of the amount of nonradiactive decay heat contribution of the optical cycle, minimizing thermal effects on the laser operation. We were able to conclude that the laser efficiency is affected by resonator configuration changes due to thermal lens effects, and not to thermal quenching of the Cr:LiSAF luminescence.

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 limited up to 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. To study the pumping cavity performance during laser operation, it was placed inside a plane concave resonator[14]. 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. Here we describe some laser performance results obtained for three different intracavity filter sets, and discuss observed thermal effects arising 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.

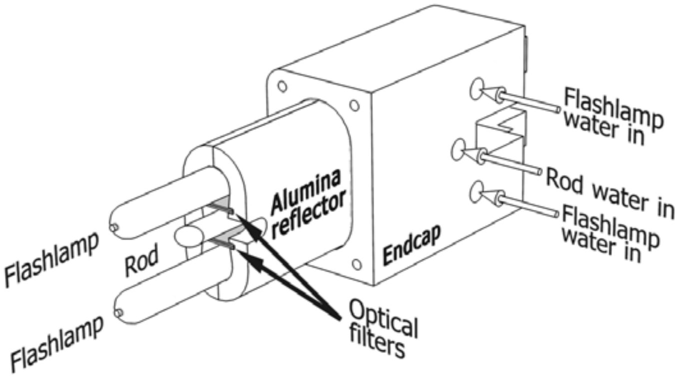

Figure 1. Scheme of the pumping cavity without an endcap. The different cooling water entrances for cooling the crystal and flashlamps are indicated; the optical filters, located between each flashlamp and the crystal, divide the pumping cavity into three independent cooling chambers.

To study the effect of filtering the pumping spectrum, the pumping cavity was placed inside a plane-concave resonator and the laser pulse energy dependence on the repetition rate was measured for three different filter sets whose transmission spectra are shown in Figure 2. The filter set 1 allows pumping only on the lower energy band, while filter sets 2 and three transmit light to pump the other bands.

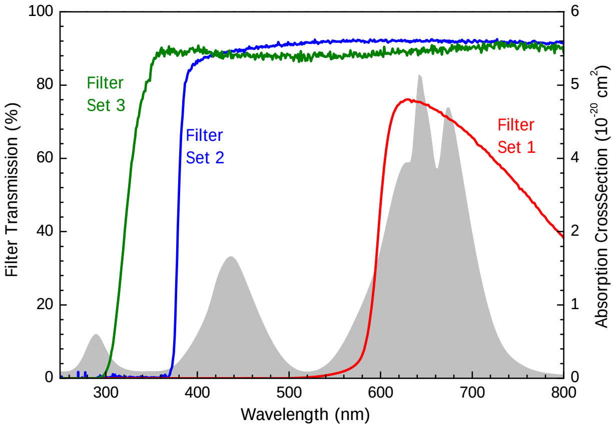

Figure 2. Transmission spectra of the intracavity filters sets used (lines, left scale), and Cr:LiSAF absorption cross section parallel to the c-axis (shaded, right scale).

Results and Discussions

In Figure 3 the laser pulse energy dependence on the repetition rate is shown for filter set 1 placed inside the pumping cavity. Among the three filter sets used, this one generates the least amount of heat inside the crystal, minimizing thermal effects. This minimization results in laser operation with small pulse energy variation as the repetition rate increases, what can also be observed in Figure 3. This variation is under 3% (around the average value) at 60 J pumping energy, and is a drop of 8% (from 715 mJ to 660 mJ) at the 100 J pumping. Besides, Figure 3 shows that the laser could be operated at 20 W average power at 30 Hz repetition rate[14], that is and increase of almost 5 times in the average power compared to the previous flashlamp-pumped Cr:LiSAF rod lasers (4.5 W at 12 Hz[8]).

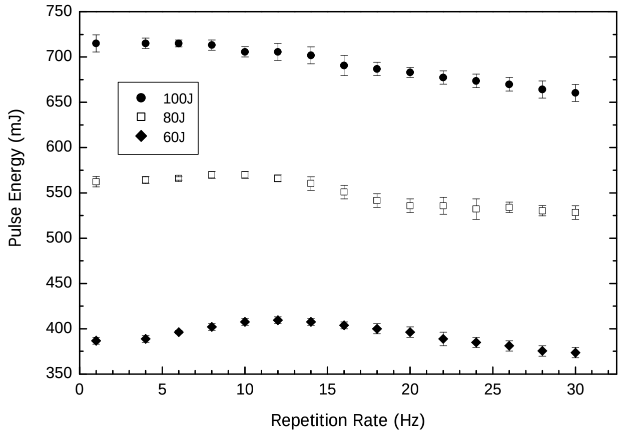

Figure 3. Pulse energy dependence on the repetition rate for filter set 1. Under 100 J pumping, at 30 Hz repetition rate, the measured pulse energy was 660 mJ, resulting in 19.8 W of average power.

Using filter sets 2 and 3, the laser gain increased, and generated pulses with more than 2.5 J of energy at 1 Hz. For both filter sets, at the higher pumping energy (100 J) a pulse energy drop over 20% was observed with the repetition rate increase. In Figure 4 the normalized pulse energy decrease measured for the three filter sets is shown. It is clearly seen that the pulse energy drops for the three filer sets, but the energy decrease as a function of the repetition rate has a strong dependence on the absorption bands being pumped. When pumping only the 650 nm band (filter set 1), the laser operated at 30 Hz with only an 8% drop relative to 1 Hz; pumping the 650 nm and 450 nm bands, there is a 23% energy drop at 15 Hz, and the pumping in the three absorption bands causes a 20% energy drop at 8 Hz repetition rate. This results confirm that thermal effects upon the Cr:LiSAF laser performance are strongly dependent on the excitation spectrum filtering. The maximum average power generated by the laser when using filter set 2 was 30 W at 15 Hz, and 16 W at 8 Hz repetition rate with filter set 3[15].

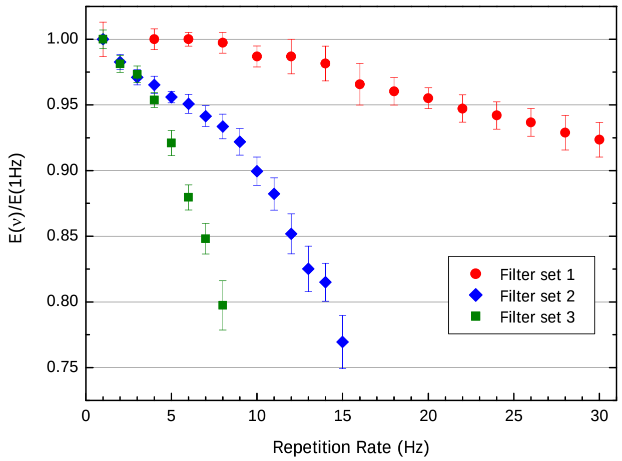

Figure 4. normalized pulse energy decrease as a function of the laser repetition rate for the three filter sets used. The pulse energy is normalized by the 1 Hz value.

To verify if the energy drop shown in Figure 4 results from thermal quenching of the Cr:LiSAF upper laser level, we simultaneously measured the temporal profile of the flashlamps emission and of the Cr:LiSAF spontaneous emission for filter set 2, and used the rate equation to fit the Cr:LiSAF lifetime to the spontaneous emission curve, as described in our earlier work[14]. This was done for various pumping energies and repetition rates, and the results are shown in Figure 5, where can be seen that the Cr:LiSAF lifetime drops as the pumping energy increases, but does not depend on the repetition rate. These results indicate that the energy drop shown in Figure 4 is not a consequence of thermal quenching of Cr:LiSAF luminescence, and probably results from variations on the flashlamps efficiency and a thermal lens effect that modify the resonator, lowering its overall efficiency. The lifetime decrease with the pumping energy rise most certainly results from excited state absorption processes[15] that reduce the upper laser level population, and also from a local heating caused by the

Stokes-shift, that is instantaneous (tens of picoseconds) and takes place in the Cr ions neighborhood. In the repetition rates investigated, this heat is removed by the cooling system, minimizing its accumulation between pulses, leaving heat enough to create a small thermal lens but not to quench the Cr ion lifetime.

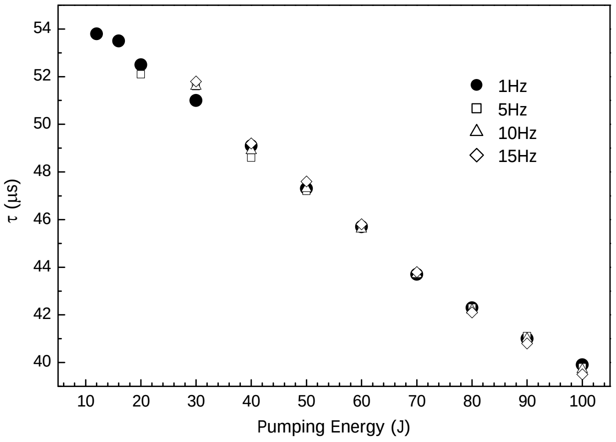

Figure 5. Upper laser level transition lifetime as a function of the pumping energy, showing that the lifetime is not influenced by the repetition rate.

Conclusions

We developed and built a Cr:LiSAF pumping cavity that allowed laser operation in various regimes depending on the intracavity filters used. These regimes made possible the operation of the laser at repetition rates up to 30 Hz, or average powers up to 30 W, the highest reported for a Cr:LiSAF rod gain medium. Additionally, we studied the gain medium behavior as a function of the pumping repetition rate, demonstrated the existence of thermal effects due to Stokes shift that decrease the laser overall efficiency and lower the pulse energy, but ruled out Cr:LiSAF luminescence quenching as the cause of this drop. Pumping the Cr:LiSAF 290 nm absorption band increases the laser energy by _10% compared with pumping only the other two bands, but the trade-off is a greater efficiency drop at higher repetition rates.

Acknowledgements

The authors thank Dr. Wagner de Rossi for helpful discussions and Fundação de Amparo à Pesquisa do Estado de São Paulo for financial support.

---

1) Payne S. A., Chase L. L. and Wilke G. D., *J. Luminescence* **44**, 167-176 (1989).
2) S. A. Payne, L. L. Chase, L. K. Smith, W. L. Kway and H. W. Newkirk, *J. Appl. Phys* **66**, 1051-1065 (1989).
3) M. Stalder, B. H. T. Chai and M. Bass, *Appl. Phys. Lett.* **58**, 216-218 (1991).
4) R. Scheps, J. F. Myers, H. B. Serreze, A. Rosenberg, R. C. Morris and M. Long, *Opt. Lett.* **16**, 820-822 (1991)
5) B. Agate B, A. J. Kemp, C. T. A. Brown and W. Sibbett, *Opt. Express* **10**, 824-831 (2002).
6) M. Ihara, M. Tsunekane, N. Taguchi And H. Inaba, *Electron Lett.* **31**, 888–889 (1995).
7) S. Uemura and K. Torizuka, *Opt. Lett.* **24**, 780-782 (1999).
8) T. Shimada, J. W. Early, and N. J. Cockroft, *OSA Proc. Advanced Solid State Lasers*, 1994, pp. 188–191.
9) D. E. Klimek and A. Mandl, *IEEE J. Quantum Elec.* **38**, 1607-1613 (2002).
10) H. Takada, K. Miyazaki and K. Torizuka, *IEEE J. Quantum Elec.* **33**, 2282-2285 (1997)
11) S. A. Payne, L. K. Smith, R. J. Beach, B. H. T. Chai, J. H. Tassano, L. D. DeLoach, W. L. Kway, R. W. Solarz, and W. F. Krupke, *Appl. Opt.* **33**, 5526-5536 (1994).
12) F. Hanson, C. Bendall and P. Poirier, *Opt. Lett.* **18**, 1423-1425 (1993).
13) M. Stalder, M. Bass, and B. H. T. Chai, *J. Opt. Soc. Am. B* **9**, 2271-2273 (1992).
14) R. E. Samad, G. E. C. Nogueira, S. L. Baldochi and N. D. Vieira Jr., *Appl. Opt.* **45**, 3356-3360 (2006).
15) R. E. Samad, S. L. Baldochi, G. E. Calvo Nogueira, and N. D. Vieira, Jr., *Opt. Lett.* **32**, 50-52 (2007).