HIGH ENERGY DIODE SIDE-PUMPED Cr:LiSAF LASER

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ABSTRACT

A diode **side-pumped** Cr:LiSAF laser has been demonstrated with a 33 mJ normal mode output energy, and an optical to optical efficiency of 17%. Improved optical quality laser material has been grown with several Cr concentrations. Optimum Cr concentration has been calculated and experimentally confirmed.

KEY WORDS

Rare earth and transition metal solid-state lasers, Lidar, Diode Laser Arrays, Laser material processing

INTRODUCTION

For both aircraft and space-based missions, novel diode-pumped, solid-state lasers are projected to be the lasers of choice. One solid-state laser material, Cr:LiSAF, lases at wavelengths suitable for the measurement of water vapor and can be frequency tripled to monitor both aerosols and ozone. Recently, high energy outputs and relatively high efficiencies have been demonstrated with flashlamp pumped Cr:LiSAF lasers [1]. Although material quality and flashlamp heating of the material has limited the pulse repetition frequency to less than 5.0 Hz in high power systems, the results achieved with flashlamps indicate that Cr:LiSAF-based laser systems can meet development goals.

Until recently, the low threshold, high power visible laser diodes needed to side-pump Cr:LiSAF have not been available. However, NASA Langley has been working in conjunction with SDL, Inc, via an SBIR contract, to develop high power (360W per array) GalnP/AlGalNP laser diodes at ~670 nm to be used as pumping sources for Cr:LiSAF. Flashlamps emit white light, which contains all of the wavelengths of the spectrum. Each wavelength that does not coincide with the useable region of the absorption band is converted to heat, thus introducing unwanted thermal deposits in the laser rod. Since the laser diodes emit a very narrow spectrum of light, which can coincide with the peak of the Cr:LiSAF absorption band, the majority of the emitted light can be converted to laser light, thus increasing the coupling efficiency.

Langley SBIR funding has also enabled Lightning Optical to develop the technology for the growth of higher quality (as low as 0.1%/cm scattering losses) LiSAF doped with various levels of Cr^{3+}.

THEORETICAL ANALYSIS

In order to reach a maximum level of output energy with a side diode-pumped system, scattering losses and coupling losses had to be minimized, and absorption in the mode volume had to be optimized. Therefore, a theoretical model which would predict the optimization of the dopant concentration for a fixed rod radius was established.

An optimum Cr concentration can be determined by considering the absorption characteristics of the laser material. Since the Cr absorption features are relatively strong and Cr can be incorporated into $LiSrAlF_6$ in any desired concentration, an optimum Cr concentration can be determined by considering the distribution of absorbed energy. A simple example can be used to approximate the optimization process. In a side pumped laser rod geometry, it is difficult to extract the stored energy near the periphery of the laser rod. If the absorption coefficient is too large, too much of the stored energy is near the periphery where it is difficult to extract, detracting from the efficiency. On the other hand, if the absorption coefficient is too small, too much of the pump radiation passes through the laser rod without being absorbed. Unabsorbed pump radiation also detracts from the efficiency because it cannot contribute to the stored energy. An optimum concentration is a compromise of these two effects.

An approximate but closed form expression can be obtained to estimate the optimum concentration. Continuing with the example, consider a laser rod with radius a_r supporting a circular profile laser beam with radius w_c. For a pump beam which travels along the diameter of the laser rod, the pump energy absorbed within radius w_c is given by

$$E_{paw} = E_{p0}[\exp(-ß_a(a_r-w_c))-\exp(-ß_a(a_r+w_c))].$$

where E_{p0} is the incident pump energy and $ß_a$ is the absorption coefficient. Maximizing this quantity produces

$$ß_a = \sigma_a N_S C_A = (1/2w_c)\ln((a_r+w_c)/(a_r-w_c))$$

where σ_a is the absorption cross section, N_S is the number density of active atom sites, and C_A is the concentration of the active atoms. Assuming that the beam radius should be approximately 2/3 the diameter of the rod, the optimum concentration becomes

$$C_{Aopt} = \frac{3\ln 5}{4\sigma_a N_s a_r}$$

Using a laser rod of radius 2.0 mm, the optimum concentration was calculated to be 1.6%.

More detailed calculations average over the various directions for the pump radiation as well as the pump wavelengths and hence the absorption coefficient [2]. However, for diode pumping of a transition metal such as Cr, the variation in the absorption coefficient over the range of diode wavelengths is relatively small.

Cr:LiSAF has been shown to exhibit a low thermal damage threshold, therefore laser-induced damage to the laser rod is very likely to occur when Q-switching with very short pulselengths. The peak internal fluence can be determined by the equation

$$F_p = \frac{2E_{LO}}{\pi w_o^2}\left(\frac{1+R_m}{1-R_m}\right),$$

where E_{LO} is the laser output energy, w_o is the mode radius, and R_m is the reflectivity of the output coupler. The damage threshold for Cr:LiSAF has been measured to be as low as 3 J/cm^2 [3]. Since the output coupler had a reflectivity of 98%, the maximum output energy allowed before damage could occur to the rod would be 2.5 mJ. Because of possible damage to the laser rod, we did not supply the maximum current to the diodes to investigate the maximum output power for the Q-switched operation.

EXPERIMENTAL RESULTS

1.0 Material Processing

The scatter loss reduction in the bulk Cr:LiSAF can be attributed to several key changes implemented during the crystal growth phase of this research. First, all gasses used to purge the growth furnace were passed through systems to dry out and filter any residual water or particulates carried from the initial gas canisters. Next, discussions were held with all vendors to review the impact of starting impurities on the final crystal quality. Material acceptance standards were raised and more stringent reject levels were implemented so as to minimize the potential for impurities or contaminants to be delivered in the raw fluorides. All fluorides currently purchased for this program are required to have a certificate of analysis which guarantees a minimum purity of 99.99%, and in some cases, a purity of 99.999% has been delivered. Since these fluorides are used to produce a single crystalline boule, it was imperative to eliminate any oxides or OH^- impurities that are directly responsible for oxide-type contaminants. These particular contaminants can give rise to defects ranging from very fine, uniform, particulate scatter throughout the bulk of the boule to large dark inclusions. If these opaque inclusions, which are typically associated with contaminants in the CrF_3, are incorporated into the solidified bulk crystal, catastrophic stress fracturing of the cooled boule typically occurs.

A final step of materials processing and purification takes place at Lightning Optical. The as-purchased raw chromium fluoride is reprocessed in a reactive atmosphere to eliminate any other contaminants, such as water or OH^- radicals, which might have been trapped or absorbed by the starting fluorides prior to their insertion into the Czochralski furnace. These steps have all been included as standard procedures for all Cr:LiSAF crystals grown at Lightning Optical. Combined, these materials processing and purification procedure changes have led to scatter loss reductions in high Cr-doped LiSAF from greater than 3%/cm in 1993-94, to documented losses averaging less than 0.15%/cm throughout the boules.

The reduced-scatter Cr:LiSAF boules produced for this research were grown via the Czochralski technique. The crystal growth parameters used during this materials refinement program included rotation rates which varied between 15 rpm and 18 rpm, pull rates ranging from 0.6 mm/hour to 1.0 mm/hour, and growth rates that added mass at the rate of 2 to 4.5 gm/hr. The combination of these rates yielded boules that were nominally 20 mm in diameter, 100 mm in length, and all with a near-flat growth interface.

2.0 Laser Experiments

Laser performance was characterized utilizing a side diode-pumped scheme, in which three 680 nm laser diodes where placed at 120° increments around the laser rod (see Figure 1). The laser rod was held in place by the three heat sinks, which were water-cooled, and indium was used to provide a thermal contact between the laser rod and the heat sinks. The laser diode mounts were also water-cooled to maintain wavelength selection and to promote heat dissipation.

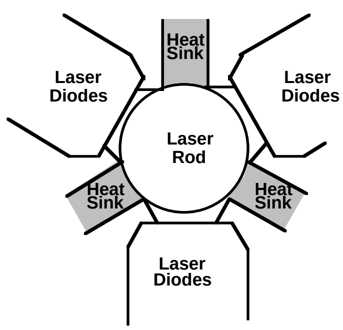

Figure 1. Side-pump configuration

The preliminary normal mode experiments featured a straight resonator, as illustrated in Figure 2. Without any tuning elements inside the resonator, the output power obtained was 33 mJ (see Figure 3). Since the resonator components were not optimized, the output beam was multimode.

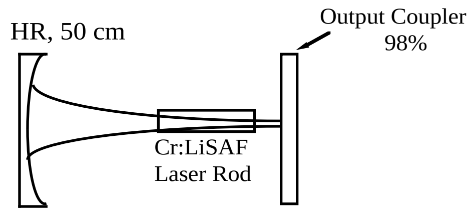

Figure 2. Normal mode resonator configuration

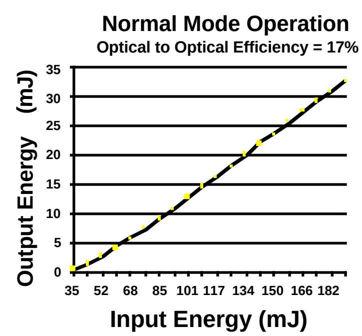

Figure 3. Laser performance of normal mode Cr:LiSAF laser

In order to verify the theoretical analysis for optimization of the Cr dopant concentration in $LiSrAlF_6$, laser rods were fabricated in three different dopant concentrations. Figure 4 illustrates the laser performance versus dopant concentration for the 4 mm diameter laser rods utilized in the system. As is evident in the data, the rod with a dopant concentration of 1.5%, which closest to the theoretical optimum of 1.6%, demonstrated the best laser performance.

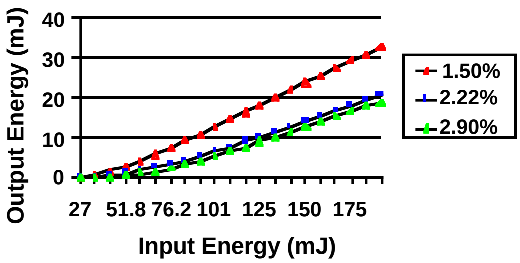

Figure 4. Laser performance with varied Cr concentrations

The 1.5% laser rod was then incorporated into the resonator illustrated in Figure 5. The resonator was acousto-optically Q-switched, and attained pulsewidths of approximately 200 ns. The laser performance of the Q-switched operation is illustrated in Figure 6.

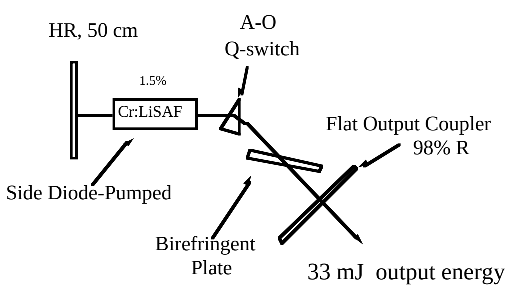

Figure 5. Cr:LiSAF resonator schematic. Laser rod length = 1.0 cm, Resonator length = 9 cm

The resonator was tuned via the use of a birefringent plate while the A-O Q-switch prism and the output coupler remained fixed. Consequently, the tuning range observed was from 780 to 900 nm (see Figure 7).

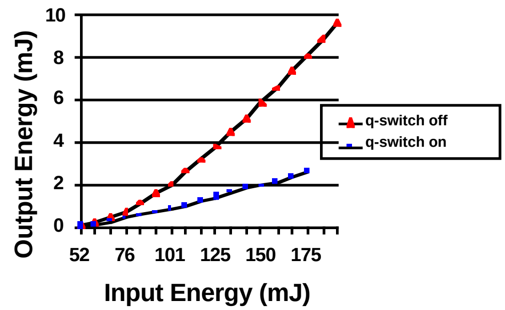

Figure 6. Unoptimized preliminary Q-switched performance

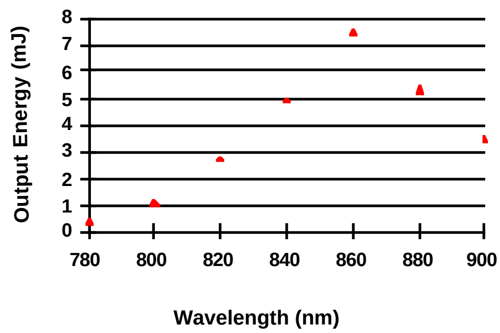

Figure 7. Wavelength Tunability

CONCLUSIONS

The visible laser diode technology is improving rapidly. The 360 W visible arrays appeared to show no degradation in performance up to 1 millions shots. With continued support of visible laser diode technology, and the markedly improved Cr:LiSAF laser crystals, all solid-state Cr:LiSAF high power laser systems become a real possiblity for space-based LIDAR applications.

With further optimization of the resonator configuration and other components of the system, energies at near the 50 mJ level should be attainable.

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