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## All solid-state diode-pumped LiSAF laser

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### Abstract

We present here a tunable diode-pumped Cr:LiSAF laser which produces up to 78 mW at 850 nm with a 500 mW pump laser diode. The laser is tunable from 810 to 900 nm.

### 1. Introduction

During the past ten years, there has been considerable interest in the research and development on tunable diode-pumped solid-state laser materials because of their potential advantages over dyes in terms of reliability, ease of use, long term stability and longer energy storage lifetime. Today, the major commercial solid-state laser products are based on titanium sapphire because of its long fluorescence bandwidth in the near infrared. However, its blue-green absorption band makes the development of a diode-pumped titanium sapphire laser difficult due to the lack of blue-green diodes and the low average power of diode-pumped frequency doubled cw Nd:Yag lasers. Cr<sup>3+</sup> doped LiSrAlF<sub>6</sub> (Cr:LiSAF) has been demonstrated to be a very interesting laser material in this wavelength range for the realization of a tunable diode-pumped solid-state laser [1]. It exhibits a large fluorescence bandwidth similar to that of titanium sapphire (0.8-1 μm). Furthermore, its absorption band (600-700 nm) overlaps the emitting wavelength of GaAlInP laser diode, which is around 670 nm. The first demonstration of diode-pumping Cr:LiSAF used relatively low power diodes [2,3] and the best output power obtained was 20 mW for 100 mW pump power [2]. The advances in GaAlInP laser diodes and the recent commercialization of 500 mW red diodes allow new developments in more powerful diode-pumped Cr:LiSAF lasers.

In this paper, we describe the design, the optimization and the realization of a Cr:LiSAF laser pumped by a 500 mW laser diode.

### 2. Design and optimization

To pump the Cr:LiSAF crystal, we used a single stripe GaAlInP laser diode from Spectra Diode Laboratories (model SDL 7432) which produces 500 mW cw output power for 1.06 A driving current. The emitting area is 250 μm x 1 μm. The power available from the laser diode is not high enough to consider transverse pumping. We therefore developed so a longitudinal pumping configuration.

Compared with more mature diode-pumped solid-state lasers such as Nd:YAG or Nd:YLF pumped by AlGaAs diodes, a GaAlInP diode-pumped Cr:LiSAF laser has two handicaps. Firstly, the emission cross-section-lifetime product is more than ten times lower for Cr:LiSAF crystal than for Nd:YAG or Nd:YLF crystals. Secondly, GaAlInP laser diodes are less efficient than GaAlAs diodes. For example, the emitting area of our laser diode is five times larger than that of a GaAlAs laser diode emitting the same power (250 μm<sup>2</sup> versus 50 μm<sup>2</sup>). As a consequence, the beam is further from the diffraction limit. Thus, the design of a diode-pumped Neodyme doped laser could not be directly used in the case of a diode-pumped Cr:LiSAF laser. The focusing of the pump beam must be tighter and the pump

absorption in the crystal must be strong enough to obtain a low threshold and a good overlap between the pump beam and the cavity mode.

We used the most highly doped commercially available Cr:LiSAF crystals (3 % and 5.5 % doped in weight from Lightning Optical Corporation). We adapted the shape of the pump beam to the circular cavity mode by using an anamorphic optical system with two different magnifications in the direction parallel and in the direction perpendicular to the junction of the diode.

In order to optimize the output power, we have performed numerical calculations to find the dimensions of the diode image in the LiSAF crystal (5.5 % doped) and the waist of the cavity. It leads to a compromise between the spot size at the focus and the divergence of the pump beam in the crystal and we found that the diode image must be reduced from  $250\ \mu\text{m}$  to  $70\ \mu\text{m}$  and that the optimal waist diameter of the cavity must of the order of  $120\ \mu\text{m}$ .

### 3. Realization

The pump optics are described in figure 1 where a first objective (focal length : 15 mm, numerical aperture : 0.6) collimates the diode beam and a second objective (focal length : 50 mm, numerical aperture : 0.5) focuses the beam on the crystal. Between these two elements, a cylindrical afocal with a magnification of 8 reduces the beam size in the direction parallel to the junction. The 5.5 % doped Cr:LiSAF crystal is 2 mm thick plano-parallel and has a high reflection coating between 800 and 900 nm on the first face and an antireflection coating centered at 850 nm on the second plane face. The laser cavity consists of three mirrors : the crystal as the first plane mirror, a curved mirror with a radius of curvature of 200 mm and a plane output coupler with a transmission of 1 % between 800 and 900 nm (Fig.1). The distance between the crystal and the curved mirror was 105 mm. This configuration leads to a collimated beam between the curved mirror and the output coupler, making it possible to add intracavity elements such as a birefringent filter or an acousto or an electro-optic modulator.

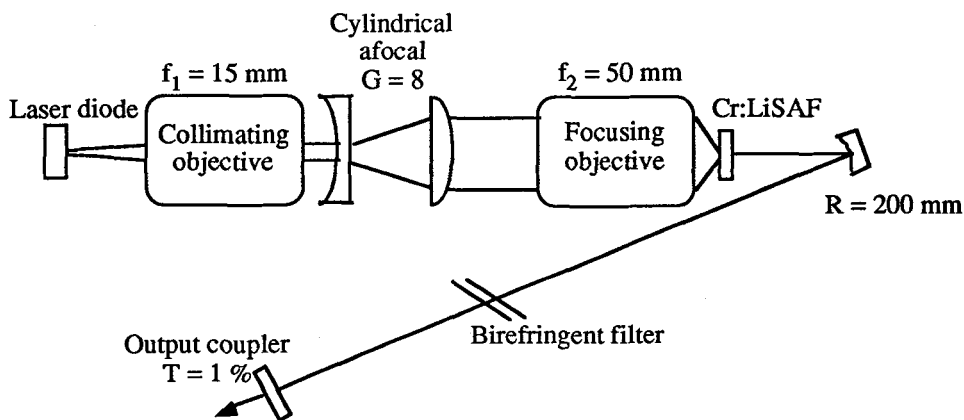


Figure 1 : experimental set-up.

With a laser diode operating in quasi-cw (duty cycle 20 %, frequency 100 Hz) the laser produced 78 mW output power at 850 nm for 376 mW absorbed pump power (taking into account the transmission of the pumping optics and the coating on the crystal). The

threshold was 100 mW and the corresponding slope efficiency was 27.2 % [4] (Fig. 2). With a birefringent filter in the cavity, the laser was tunable between 810 and 900 nm (Fig. 3). The maximum output power in the figure 3 is less than 78 mW due to the additional losses brought by the birefringent filter. Although this laser produced high output power, several problems occurred. First of all, it was impossible to operate in pure cw because of thermal problems : when we increased the duty cycle, the output power decreased to zero for a 70 % duty cycle. Secondly the output beam was slightly elliptical as a result of uncompensated astigmatism introduced by the off axis curved mirror. The ratio between the two dimensions of the ellipse was 1.3.

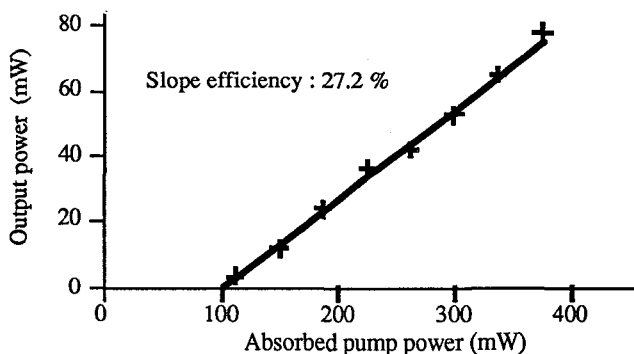


Figure 2 : slope efficiency in quasi-cw with the 5.5% doped crystal.

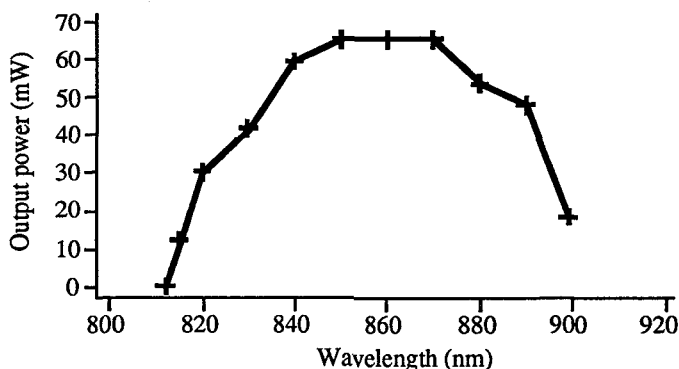


Figure 3 : tunability in quasi-cw operation.

To solve these problems, we removed the crystal and used a less doped Cr:LiSAF crystal (3 %) with a high reflection coating on the first face and with the second face Brewster angle cut. The astigmatism introduced by the Brewster angle face is compensated by the off axis curved mirror leading to a spherical TEM<sub>00</sub> output beam. We first tested the laser by operating the pump laser diode in quasi cw as with the previous crystal and we obtained nearly the same output power (75 mW). Moreover, it was possible to work in a pure cw operation with only a slight decrease in power. We obtained 60 mW of pure cw output power for 375 mW of absorbed pump power with a slope efficiency of 24 %; the pump power threshold was 125 mW (Fig.4). With the addition of a birefringent filter the laser could be tuned from 825 to 900 nm.

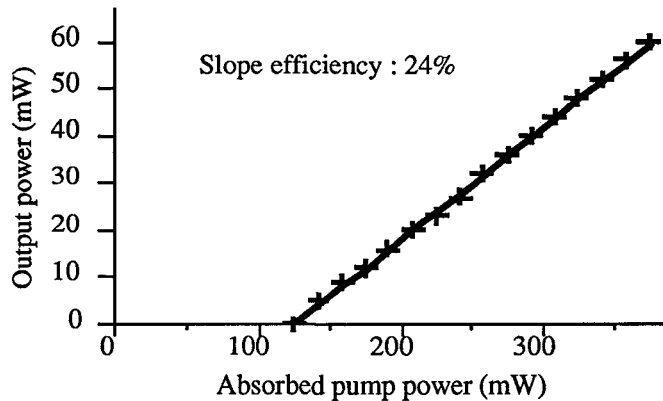


Figure 4 : slope efficiency in pure cw with the 3 % doped crystal

#### 4. Conclusion

In conclusion, we demonstrated the operation of a longitudinally cw diode-pumped LiSAF laser producing an output power of more than 60 mW and tunable from 810 to 900 nm. We tested two different crystals with different doping concentrations and geometries. We found that the 3 % doped Brewster angled cut crystal provides the best performances in terms of thermal properties and beam profile. The high pump power will make it possible to add intracavity elements such as an electro-optic or an acousto-optic modulator in order to produce pulses. Furthermore, it is possible to envisage the development of an ultrashort oscillator based on this laser and by using the Kerr lens mode-locking technique.

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