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Crystal growth, spectroscopy and high-power diode-pumped CW laser operation of a new laser medium: Nd:Lu:YLF

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Abstract: We report the development of a new laser material, Nd:Lu:YLiF₄ (Nd:LuYLF), that presents a higher Nd concentration than Nd:LuLF, and a spectral broadening of the emission linewidth, 24% greater than Nd:YLF. No other significant differences were found in the spectroscopic or CW laser parameters of these laser materials. In QCW diode pumped laser operation, an output power of 4.4 W was obtained for 14 W of pumping power.

OCIS codes: (140.3530) Lasers, neodymium; (140.3480) Lasers, diode-pumped

Introduction

Lutetium is a well-known size-compensating codopant for Nd:YAG (Nd:Y₃Al₅O₁₂) laser crystals, allowing the incorporation of greater amounts of Nd into YAG without significant degradation in the optical quality, and broadening the emission lines by around 10 to 35% [1]. Recently, a new fluoride laser material has been demonstrated: Nd:LuLF (Nd:LuLiF₄) [2]. This material presents almost the same spectral and physical properties as Nd:YLF laser crystals (Nd:YLiF₄), and one significant difference: the broader spectral width. It is easier to grow, but can incorporate smaller Nd ion concentration (around 0.6% at maximum, whereas in Nd:YLF it is typically 1.5%), due to the lower segregation coefficient compared with YLF. Another inconvenient is the higher costs of lutetium compounds. However, broadening the spectral gain width is a desirable enhancement for crystalline Nd laser media in order to obtain ultrashort pulses, especially when using passive mode locking techniques. In this case, the minimum pulse width, obtained by balancing the nonlinear phase effects with net group-velocity dispersion, is inversely proportional to the square of the gain spectral linewidth [3, 4].

We have studied the codoping of lutetium in Nd:YLF crystals in order to obtain significant line broadening and enhanced Nd concentration, also aiming to lower the production costs compared with those of Nd:LuLF. We verified that, by using 50% of lutetium and 50% of yttrium, the obtained laser crystal presented a higher Nd concentration than in Nd:LuLF, the same physical and spectroscopic parameters, and a significant spectral broadening of the emission linewidth, compared with Nd:YLF (at 1047 nm). We named this laser material as Nd:LuYLF.

Crystal growth and sample preparation

The binary rare earth and yttrium fluorides were prepared from pure oxide powders (99.99%) by fluorination in a stream of argon gas and HF gas at 850° C. The same synthesis procedure was used for YLF and LuLF starting materials. For YLiF₄, it was used a composition of 49.5 mol% of YF₃ and 50.5 mol% of LiF; for LuLF, 50 mol% of LuF₃ and 50 mol% of LiF. They were purified by a single pass

zone-refining process. The single crystals were grown by Czochralski technique, under argon gas atmosphere. The crystal pulling rate was 1 mm/h and rotation rate was 25 rpm. For the growth of the Nd:LuYLF crystal reported in this work, the melt composition was 48,85 mol% of YLF, 48,85 mol% of LuLF and 2,3 mol% of NdF₃ (the same nominal NdF₃ concentration was used for the growth of all crystals). The growing direction was parallel with the [100] crystallographic axis. The Nd concentrations were determined by different measurements, and are around 1,3 mol% for Nd:YLF, 0,9 mol% for Nd:LuYLF, and less than 0,6 mol% for LuLF. The final concentration of Lu was around 50 mol% in Nd:Lu:YLF.

All spectroscopic and laser samples were extracted along the growth direction. The optimum active medium length for longitudinally pumped at 792 nm Nd:YLF lasers is approximately 1 cm, for Nd concentrations around 1 mol%, and considering high quality pumping sources [5]. For high-power diode laser pumping, however, the high M² factor of the laser beam limits the pumping length to lower values. Despite this pumping problem, and considering a four-level laser model for the 1047 nm Nd laser transition, we prepared active elements 1-cm long, with transversal dimensions of approximately (0,2 x 0,5) cm. The optical facets were prepared at Brewster angle for the π polarization, and polished to a flatness of $\lambda/4$. The transmission of the laser samples around 1050 nm was better than 0,995(5) for both Nd:YLF and Nd:LuYLF laser crystals.

Spectroscopic characterization

Lifetime measurements were performed at room temperature, by exciting the spectroscopic samples with a dye laser, pumped by a pulsed nitrogen laser (10 ns). The polarized Nd emission was analyzed using a 1-m Spex spectrometer, an S-1 photo-multiplier and a boxcar averager. The measured ⁴F_{3/2} lifetimes were 481 ms and 476 ms for Nd:LuYLF and Nd:YLF, respectively.

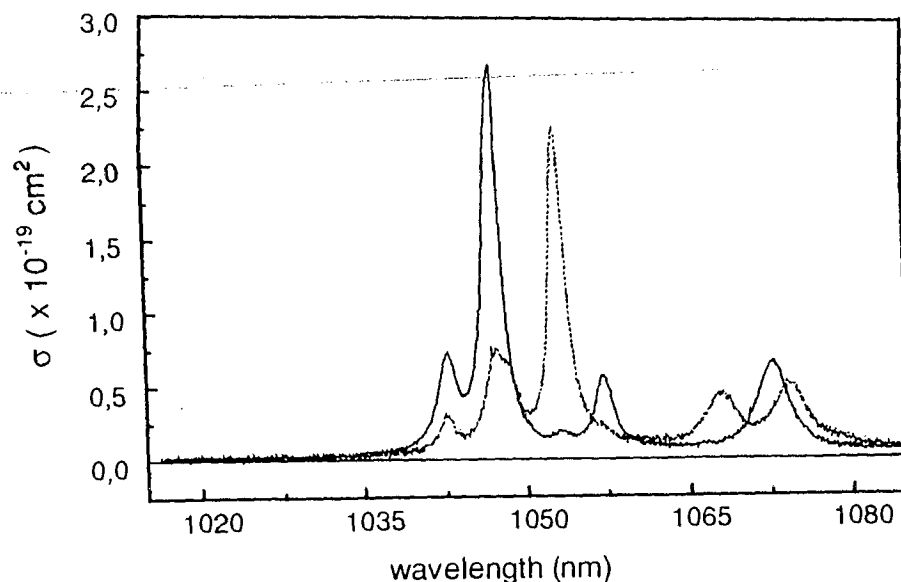


Fig. 1. Nd:Lu:YLF emission cross-sections for π -polarization (straight line) and σ -polarization (dotted line)

The emission and absorption spectra of both Nd:LuYLF and Nd:LuLF are similar to those of Nd:YLF. In this case, we have used a 4W GaAlAs diode laser (SDL2382P1) for the pumping excitation at 792 nm. The emission cross-sections for the ${}^4F_{3/2} \rightarrow {}^4I_{11/2}$ transitions (π and σ polarizations), were obtained by using the method of McCumber [6]. The peak emission cross-sections for Nd:LuYLF were $2.7 \times 10^{-19} \text{ cm}^2$ at 1046 nm (π polarization), and $2.2 \times 10^{-19} \text{ cm}^2$ at 1052 nm (σ polarization), as showed in Fig. 1. A detailed measurement of the fluorescent emission spectrum around 1047 nm for Nd:YLF, Nd:LuYLF and Nd:LuLF allowed the determination of the spectral linewidths presented in Fig. 2 (filled circles). The dotted line is an empirical fit, also considering preliminary results obtained for different Lu concentrations. We readily notice that Nd:LuYLF has almost the same emission linewidth as Nd:LuLF, broadened approximately by 25% compared with that of the Nd:YLF sample, under this high intensity diode laser pumping.

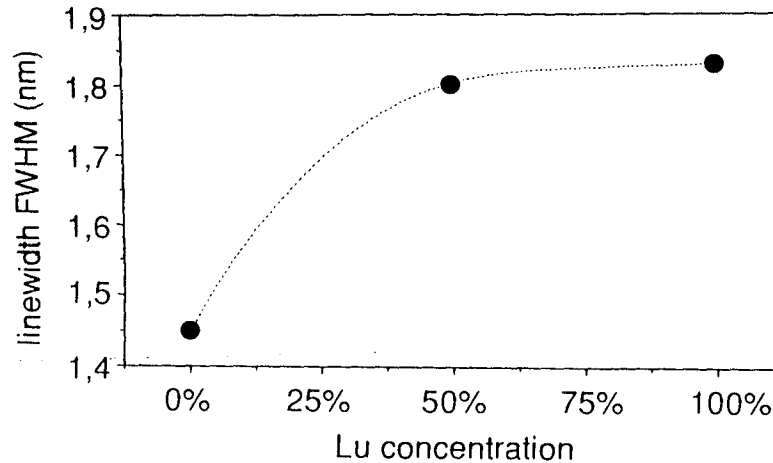


Fig. 2. Measured spectral linewidths at the 1047 nm emission (π), for Nd:Lu:YLF crystals with different Lu concentrations (YLF, LuYLF and LuLF).

Diode-pumped laser performance

The laser experiments were performed using a 20 W diode laser array, emitting at 792 nm, as the pump source. As the diode laser bar is composed by 24 emitters arranged in a line, the output beam has dimensions of $w_x = 1 \text{ cm}$ parallel to the bar and $w_y = 0.2 \text{ mm}$ perpendicular to the bar. The laser beam, collimated by a pre-assembled fiber lens, was reconfigured into two columns of twelve beams each, using the two mirror beam shaper technique [7]. This reconfigured beam was focused by an optical system, and had dimensions and quality factors of $w_x = 200 \text{ mm}$, $M_x^2 = 120$ and $w_y = 120 \text{ mm}$, $M_y^2 = 56$, respectively, at the laser crystal position. The laser resonator consisted of a 1-m radius concave mirror, high reflector for 1050 nm, with 94 % transmission for the pump beam, and flat output couplers with varied transmission at the laser wavelength. The total cavity length was 5 cm. The complete laser setup is shown in Fig. 3. For 20W of diode laser output power we had a total peak pump power incident on the crystal of 14W due to losses in the beam shaper, lenses and the back mirror of the resonator. The duty cycle was only 10% due to a non-optimized crystal heatsink.

Measurements of the output power as a function of the output reflectivity were performed, as shown in Fig. 4. By fitting the following expression from the laser oscillator model [8]: $P_{OUT} = K \cdot (1-R) \cdot [G / (L \cdot \ln(R)) - 1]$, we determined the equivalent non-saturated gain, G , the cavity losses,

L , and $K = A.I_s/2$, where A is the beam area at the active medium, and I_s the emission saturation intensity. The determined parameters are also plotted in Fig. 4 (insert). The observed lower laser output power for Nd:LuYLF is attributed to the lower Nd concentration in this sample.

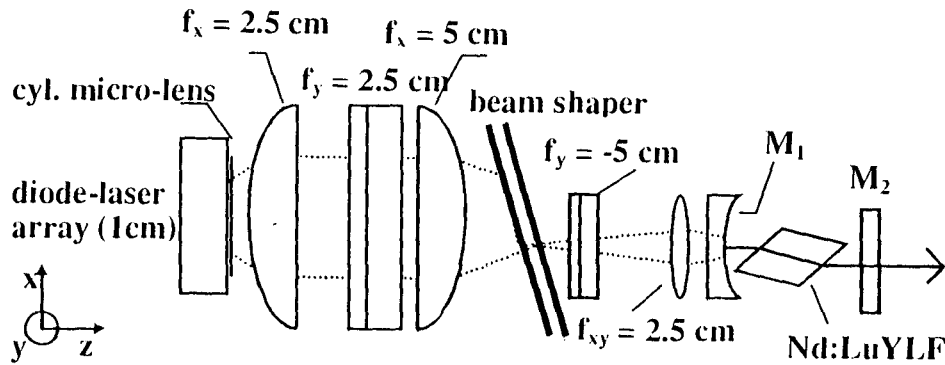


Fig. 3. Setup of the diode-pumped Nd:LuYLF laser using a two mirror beam shaper.

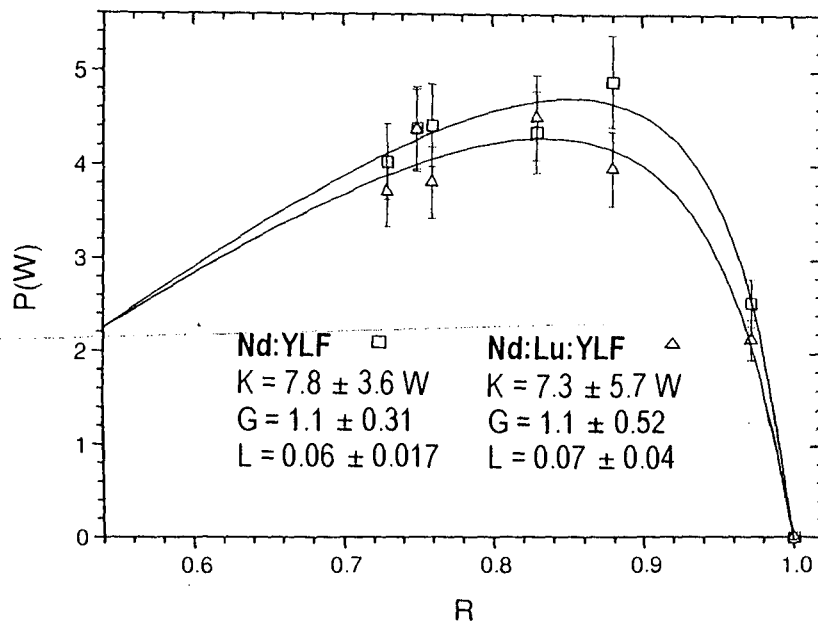


Fig. 4. Output power as a function of the output mirror reflectivity.

Except by the emission linewidth broadening, no significant differences were measured among spectroscopic or CW laser parameters of Nd:LuYLF and Nd:YLF. Thus, Nd:LuYLF can be used for mode locking purposes with advantages over Nd:YLF. A complete short-pulse operation of this system is currently under investigation.

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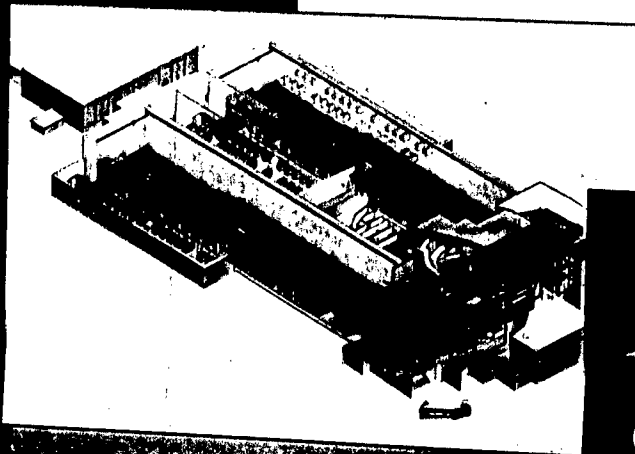
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References

- 1 L. A. Riseberg and W. C. Holton, "Nd ion site distribution and spectral line broadening in YAlG:Lu, Nd laser materials," *J. Appl. Phys.* **43** 1876-1878 (1972)
- 2 N. P. Barnes, B. M. Walsh, K. E. Murray, G. J. Quarles, V. K. Castillo, "Nd:LuLF a new Nd laser material," *TOPS* **10** 448-450 (1997)
- 3 E. P. Ippen, "Principles of passive mode locking," *Appl. Phys. B* **58** 159-170 (1994)
- 4 H. A. Haus, J. G. Fujimoto, E. P. Ippen, "Structures for additive pulse mode locking," *J. Opt. Soc. Am. B* **8** 2068-2076 (1991)
- 5 E. P. Maldonado and N. D. Vieira Jr., "Optimization of the active medium length in longitudinally pumped continuous-wave lasers," *J. Opt. Soc. Am. B* **12** 2482-2485 (1995)
- 6 D. E. McCumber, "Einstein relations connecting broadband emission and absorption spectra," *Phys. Rev.* **136** 954-957 (1964)
- 7 W. A. Clarkson, D. C. Hanna, "Efficient Nd:YAG laser end-pumped by a 20W diode-laser-bar," *Opt. Lett.* **21** 869-871 (1996)
- 8 E. P. Maldonado, G. E. C. Nogueira and N. D. Vieira Jr., "Determination of the fundamental laser parameters using an acoustooptical device," *IEEE J. Quantum Electron.* **29** 1218-1222 (1993)

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