Pulse-Energy-Enhanced, Strongly Modulated Er:YLF Laser for Medical Applications

Alessandro M. Deana*, Niklaus U. Wetter*, Sonia L. Baldochi*, Izilda M. Ranieri*

*IPEN – Instituto de Pesquisas Energéticas e Nucleares, Av. Prof. Lineu Prestes, 2242. São Paulo SP, Brasil

Abstract. In this paper we demonstrate a tenfold pulse power enhancement by operating the Er:YLF laser at the strongly modulated relaxation oscillation region, at 3µm wavelength. We obtained 1.2W of average power for 250µs pulse duration and up to 400Hz of repetition rate for a 6.8W, jitter free, single spike with nearly Gaussian temporal shape without any kind of intracavity Q-switching device.

INTRODUCTION

The laser emissions in the 3-µm wavelength range is of great interest because of it is strong absorption due to the OH vibration in water vapor, liquid water [1] and consequently, biological tissue [2], therefore, it is possible to use this wavelength in laser surgery and for LIDAR measurements of atmospheric humidity. For this kind of application a small laser system is desirable. A good compact pumping source for the Erbium laser is a laser diode emitting at 973nm [3].

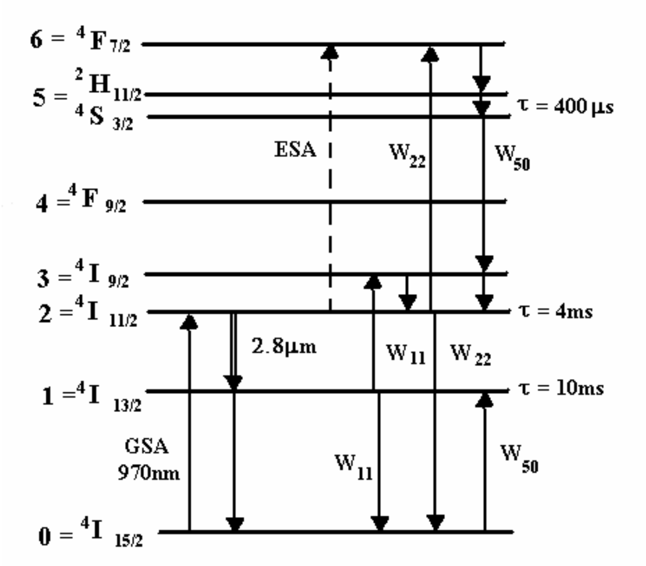

FIGURE 1 - Energy level scheme of the 2.8µm E^{3+}:LiYF$_4$ laser indicating that interionic processes dominate the excitation mechanisms of the laser levels of the 2.8-µm transition. ESA is significant only under a tight pump focus. The given lifetimes are mean values approximated from data published in the literature [3].

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The Erbium transition $^4I_{11/2} \rightarrow {}^4I_{13/2}$, depending on the host material, emits light of 2.7-2,94μm. Pulsed lasers are required for microsurgical applications and there exist occasions were the surgeon wishes just a small amount of coagulation to achieve homeostasis and other effects where no coagulation at all is desirable [4]. In this second condition the thermal load should be confined to the focus of the laser and the pulse should be long enough to minimize the stress in the tissue. For these cases, the favorable pulse duration at 3μm wavelength is of the order of 0.1-1μs and the repetition rate should vary from a few pulses per second up to 10kHz [5]. Flashlamp pumped systems provide pulses typically of hundreds of microseconds [1] and Q-switched and mode-locked systems emit in the nano and picosecond range [6,7 and 8]. Pulses of favorable duration have been reported but with lower avarage power, lower frequency and moving parts, like rotating mirrors or choppers, inside the resonator [4].

Our method has been reported for the first time for the Er:YLF laser at 2,8μm. It is possible to increase the repetition rate up to 2000Hz (5% duty cycle) with a small improvement of the cooling of the crystal, without the risk of damaging it.

In our paper, we report on a 6.8 W single spike and 1.2 W, 250μs Er:YLF laser. The low phonon energy laser host is YLF [9,10]. By modulating the temporal behavior of the pumping diode we investigate the Er:YLF laser emission. Our technique leads to a very compact device with the desired pulse length and 400Hz repetition rate.

EXPERIMENTAL SETUP

The main resonator was pumped by a fiber coupled diode array (opto power) with a collimating telescope that delivers a maximum of 21,5W peak power at 975nm. The collimating telescope provides a high intensity circular beam (232μm radius, beam quality $M^2 = 159$) that is focused at the pump surface of the crystal. A schematic sketch of the laser set-up is shown in fig. 2.

As an active medium we used a Brewster-cut, 15% Er:YLF crystal of 20 mm length. In our experiments, we used a hemispherical, end pumped resonator based on one concave mirror with 10cm radius of curvature and highly reflective dielectric coating at 2.8μm with high transmission at 973nm. The flat mirror was made of CaF_2 with 1.4% transmission at 2.8μm [11].

The pump pulse was modulated to a square shape with a function generator (Wavetek, model 395). To avoid thermal fracture the duty cycle was kept below 5% and the pulse time was varied from 100μs to 1ms.

The laser emission was detected by a fast InAs detector (VIGO model VPDC - 20i/DR-1B) with preamplifier and a Tektronix TDS 360 oscilloscope. The beam energy was measured by a pyroelectric power meter (Ophir NOVA 2 with PE50V2 head for longer pulses and PE9V2 head for shorter pulses).

The function generator is programmed to provide a square pulse but the diodes' power supply emission has approximately a 40μs rise time and approximately the same decay time, as is seen in fig. 3a.

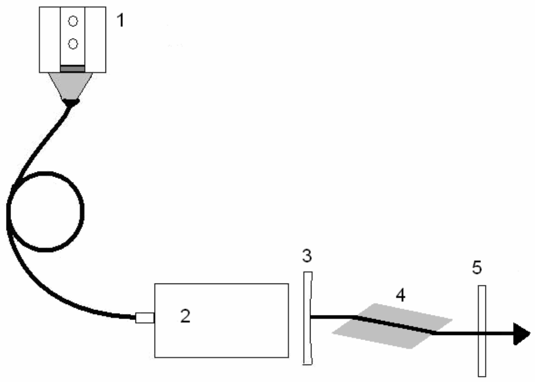
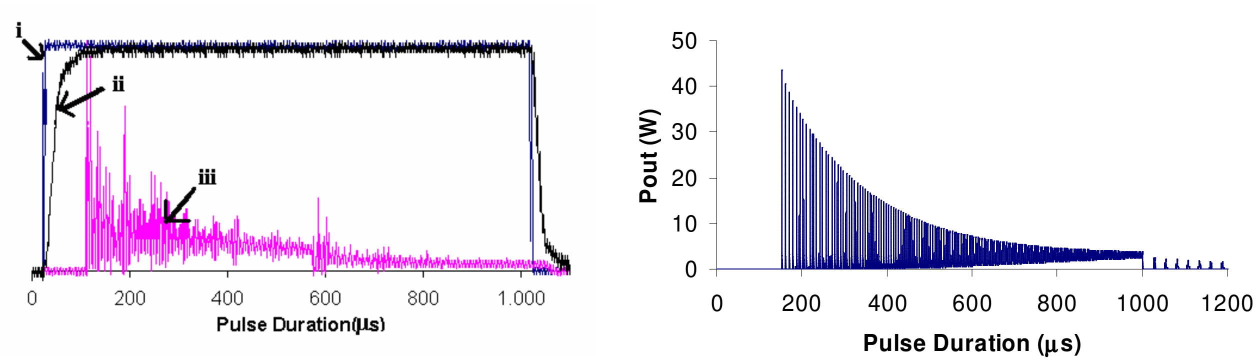


FIGURE. 2: Schematic layout of end-pumped Er:YLF main resonator: 1. Fiber coupled diode; 2. collimating telescope; 3. input mirror; 4. Brewster cut Er:YLF crystal; 5. output mirror with 1.4% transmission.

RESULTS AND DISCUSSIONS

In a previous paper [11] we have shown that, due to the strong relaxation oscillations (fig. 3 (a) and (b)) associated to the Er^{3+}YLF laser, it is possible to operate this laser with smaller pulses in order to achieve higher power.



(a)

(b)

FIGURE. 3 – a)Temporal behavior of the function generator signal (i), pump beam (ii) and Er^{3+}:YLF laser (iii); b) Simulation of the temporal laser output behavior using a set of 5 differential coupled rate equations.

Our simulations (fig. 3b) are performed with a simplified set of five coupled differential equations [12]. The results are in very good agreement with our experiments, as can be seen in fig 3. The build up time and the output power have approximately the same values in our simulations and experiments.

In fig. 4 we observe that the lasers output power as a function of pulse length rapidly increases up to a maximum and then slowly decrease to reach a value significantly lower than the maximum. This is probably due to the fast population of the $^4I_{13/2}$ level (fig 1) and its slow depopulation because of its long lifetime (10ms) [13].

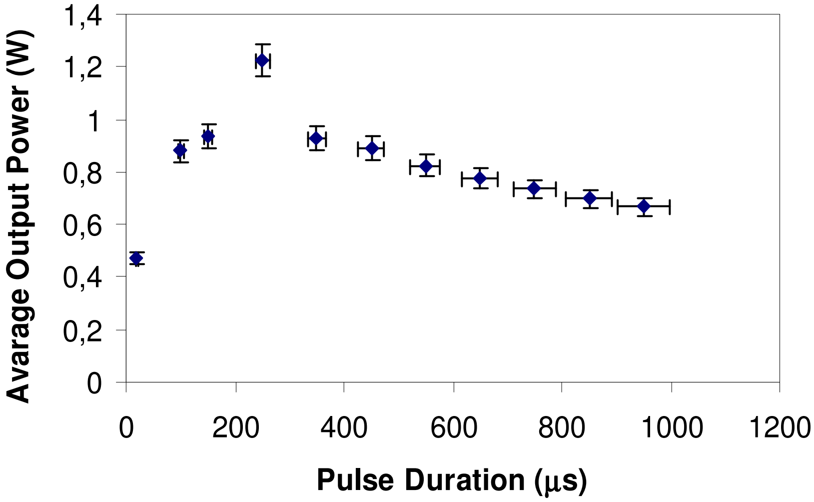


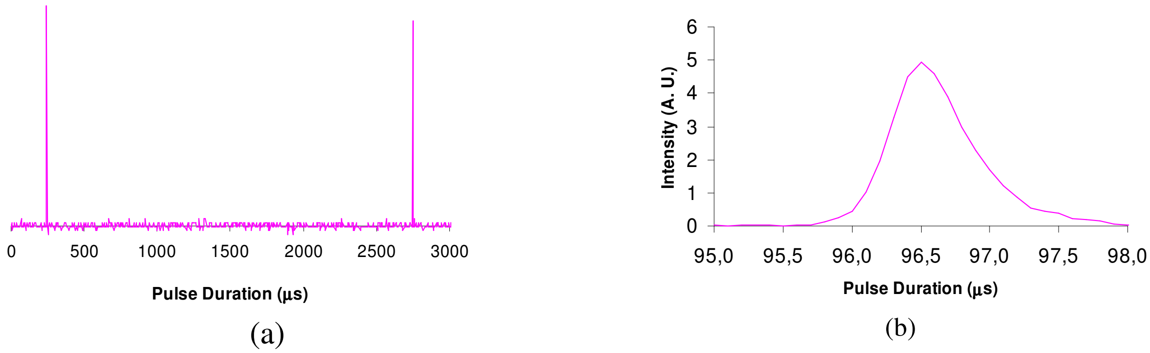
FIGURE 4. Output power as a function of the laser pulse duration.

A 1ms long laser pulse has 0,65W of average output power whereas a 250 µs long pulse has 1.2 Watt of qcw output power.

By shortening the pump pulse duration it is possible to achieve a single spike of the Erbium laser per pump pulse (fig. 5). At this regime, each pulse has 6,8W of peak power, which is in good agreement with our numerical simulation. The pulse duration is 0,65µs (FWMH), which in is the desirable time for our propose. In this kind of pumping regime the lower laser level of our system is nearly completely depopulated leading to a high population inversion, therefore, high peak power. Up to 400Hz repetition rate is achieved without any cooling of the crystal.

Compared to other passive switching regimes, where the pulse period is completely unstable, this single pulse regime is completely stable with no jitter at all, because the output pulse period is equal to the pump pulse period given by the power supply.

The diodes' power supply is not optimized for single spike operation; our simulations indicate that if the power supply had a shorter response time, a peak power of 45 W should be possible for single spike operation.



(a)

(b)

FIGURE 5. 400Hz single spike pulsed laser (a) and pulse temporal shape (b).

CONCLUSIONS

To the best of our knowledge, this is the highest output power reported for pulses with this pulse duration. So far 1.8 W have been reported in continuous operation for an Er:YLF laser pumped by two diodes[14] and 100 kW in a q-switched pulse of 22 ns[15]. We have achieved 1.2 W with a much simpler setup.

We also proved that is possible to operate an Er:YLF laser in the relaxation oscillation region in order to achieve higher power and µs range pulse, without any kind of Q-Switch, making a simpler, cheaper, more compact and reliable device.

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