Energy extraction of diode pumped laser rods : a comparison Nd : LNA vs Nd : YAG

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Energy extraction of diode pumped laser rods: a comparison Nd: LNA vs Nd: YAG

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1. - Introduction. The Nd: LNA laser material, whose chemical formula is $Nd_{(x)}La_{(1-x)}MgAl_{11}O_{19}$ may be doped with a Neodymium proportion x=15 %. It has a smoothly varied bandwith of absorption [1], which is a highly desirable feature for diode pumping. In this paper, we present new results devoted to large size rods in the long pulse and Qswitched modes of operation, and a computation of the crystal's effective stimulated emission cross section and quantum efficiency. Twenty GaAlAs stacks from Spectra Diode Labs., each made of four 795 nm laser bars and referenced as SDL 3230 TZC parts, are closely coupled to 4 mm in diameter LNA rods. The overall peak pumping power is 4.8 Kwatts, within 400 μs wide pulses.

2. - Laser experiments and calculations. The laser head is placed inside a plano concave resonator which is defined by a 3 m concave high reflector and a flat 70% reflecting output coupler, the length of the oscillator being 50 cm. The very high order multimode beam completely fills the rod volume so as to extract as much of the available energy as possible. In a first step we analyse, with the help of a CCD camera, the spatial distribution of the induced fluorescence across the rod. The measurements are compared to the results of a Monte carlo computation [3]. The derivation of the diode deposited energy is made throughout the rod's whole cross section, on Fig. 1, and the optical losses are also computed over it's dark side. Our simulation takes into account a number of parameters, such as the linear absorption of the Nd:LNA at 795 nm (4.5 cm^{-1}), the rod diameter (4 mm) and diode-rod distance (0.5 mm), the intensity diagram (40 degrees divergence in the direction perpendicular to the diode junction plane) and mean near field emittance of the diodes, and the rod surface diffusion term. That way, best Monte carlo fits are obtained with 30% diffusion. The computed diodes-rod coupling efficiency equals 81%.

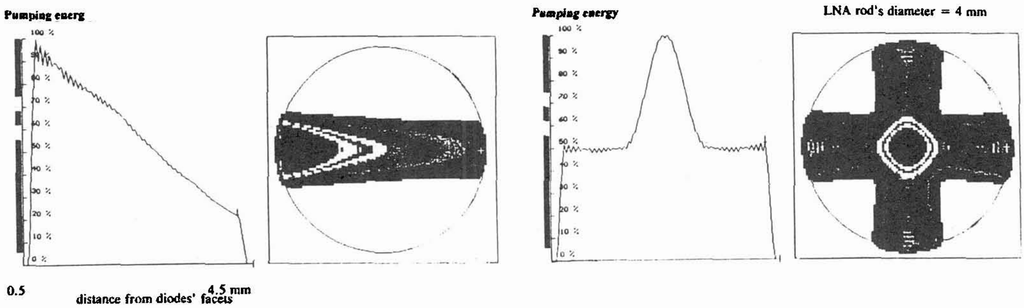

Fig.1. - Modelling the spatial distribution of the pumping energy inside the LNA rod, closely pumped by one diode plane: the best fit with fluorescence measurements is obtained with 30% Lambertian diffusion and 70% Fresnel refraction.

Then, we fire the complete laser head inside the above resonator. When free running at 25°C without any other intracavity optical component, the LNA rods generate 300 to 350 mJ within 400 μs in the long pulse mode. The corresponding optical efficiency is 16 to 18 %. Fig. 2 illustrates the decrease of the output energy when a deuterated KD*P cell is placed inside the resonator, before it is activated. The Pockels cell is made of a KD*P crystal with plane-parallel faces and AR coated windows, and a Glan polarizer. The additional intracavity losses lead to an available output energy equal to 180 - 200 mJ, i.e. the optical efficiency is reduced to about 10%. Fig.2 also illustrates the short pulse efficiency, the above Pockels cell being operated at the quarter wave voltage 3.4 Kvolts. Depending on the actual LNA rod and intracavity polarizer used, the energy within the output pulse is 100 to 145 mJ, at a 20 to 40 ns fwhm width. The corresponding optical efficiency still equals 5.2 to 7.6 %.

We experience a Findlay -Clay procedure [4] for the measurement of effective LNA's internal losses and small signal gain coefficient"g_o". Losses are determined by varying the output coupler reflectivity from 50 to 95%, and measuring the corresponding pump threshold. The main errors in the least square - straight line based - derivation come from the uncertainties on the measurement of the diode current, even though we used a wide range and large number of output reflectivities. These errors may be estimated as +/- 15% and +/- 10% peak to peak, respectively for the losses L and the gain. The rod's intrinsic losses and gain are L # 18% and Go # 2.76 for 1.9 Joule diode pumping. This means the gain coefficient g_o of the LNA equals 0.29 cm^{-1} at 1 Joule diode pumping, by comparison with 0.455 cm^{-1} for YAG [5]. The insertion of the Pockels cell inside the resonator lead to 10 - 14%additional losses.

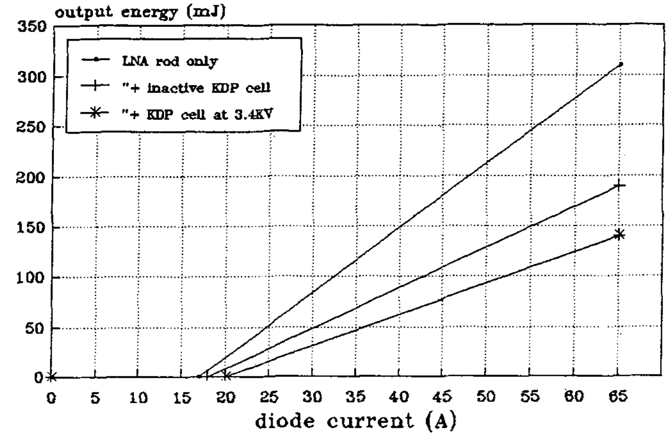

Fig.2. - LNA extracted energy vs optical configuration. long pulse and Qswitched moaes of operation with different intracavity optical components are investigated.

Table 1 below depicts the useful parts in the overall efficiency and energy-transfert mechanisms inside the oscillator. The Qswitch extraction efficiency η_E is derived at the optimum output reflectivity 70% with the help of Zayhowski's method [6]. The coefficient z, when defined as $z = 2^*g_o{}^*l_o/L$, is about 14, which leads to an extraction efficiency η_{eq} # 75%. In the former z expression, l_o and L represent the active rod length and Findlay-Clay losses. Accordingly, we find that the LNA's quantum efficiency η_q is half that of the YAG, which is about 95%[5]. For our actual LNA rods :

$$\eta_q = (E_{out}/E_{pump}) \,/\, (\eta_T.\eta_a.\eta_B.\eta_S.\eta_{st}.\eta_{ASE}.\eta_{EQ}) \ \# \ 45\% \qquad (1)$$

Notations	Energy transfert process	Estimated efficiency (%)	Criteria / assumptions
η_T	coupling geometry and diffusion	# 80	Fresnel losses only, due to the uncoated rod surface
η_a	Spectral absorption	80	LNA peak absorption
η_B	beam overlap with the pumped volume	100	fully multimode energy extraction
η_S	Stockes' shift	75.5	
η_{ASE}	reciprocal of the depopulation rate of the upper level, due to fluorescence	100	no amplified stimulated emission, with AR coated faces and moderated gain
η_{st}	storage efficiency in the upper level	52	pumping duration and fluorescence decay times # 400 μs and 280 μs
η_{eq}	Qswitch energy extraction from the upper level	75	cf. Zayhowski [6], with best output coupling # 80%

Table 1. Energy conversion processes, estimated numerical values and associated computation procedures.

In a second step, we develop a Runge-Kutta computation to determine the effective stimulated emission cross section σ. The modelization of the Qswitched laser operation is made with the help of a 4 level scheme, including the effects of a low but finite lower level lifetime τ_{10}: accounting for τ_{10} is of a prime importance with respect to the accuracy of the computed pulse shapes and energies [7]. But the value of τ_{10} in the case of LNA is not a well known value. As a result, we have to make the simulations within a broad range of values, namely from 1 to 100 ns.

dN_2/dt	=	$-\sigma/h\nu \,.\, I \,.\, \varphi_S \,.\, (N_2-N_1)$	(2)
dN_1/dt	=	$+\sigma/h\nu \,.\, I \,.\, \varphi_S \,.\, (N_2-N_1) - N1/\tau_{10}$	(3)
$d(I^*\varphi_S)/dt$	=	$+\sigma/h\nu \,.\, I \,.\, \varphi_S \,.\, (N_2-N_1) - I/\tau_c$ (4)	(4)
N_0	=	$1-N_1-N_2$	(5)

Table2. - Simplified rate equations of the LNA. N_1, N_2, N_0 are the lower level, metastable and fundamental populations. I, $h\nu$ and τ_c are the associated photon density, photon energy and cavity lifetime. $\sigma/h\nu \,.\, I \,.\, (N_2-N_1)$ is the stimulated emission part, $-N1/\tau_{10}$ and $-I/\tau c$ are the relaxation parts. φ_S is a reference power level, expressed in Gwatts/cm².

Fig.3-a illustrates the dependancy of the pulse shape P(t) with σ, for a number of values ranging from 3 to 15 10^{-20} cm². We calculate that σ must equal 6 10^{-20} cm², in order to extract an output energy E_{out} = 1.3 J/cm² within 40 ns. The peak power is P_{peak} = 0.2 Gwatts/cm2. We examine on Fig.3-b the effects of τ_{10}: increasing τ_{10} from 1 to 10 ns only leads to tiny P_{peak} and E_{out} variations, while increasing τ_{10} within the 15-100 ns range of values leads to a dramatic increase of P_{peak}, at nearly the same pulse width.

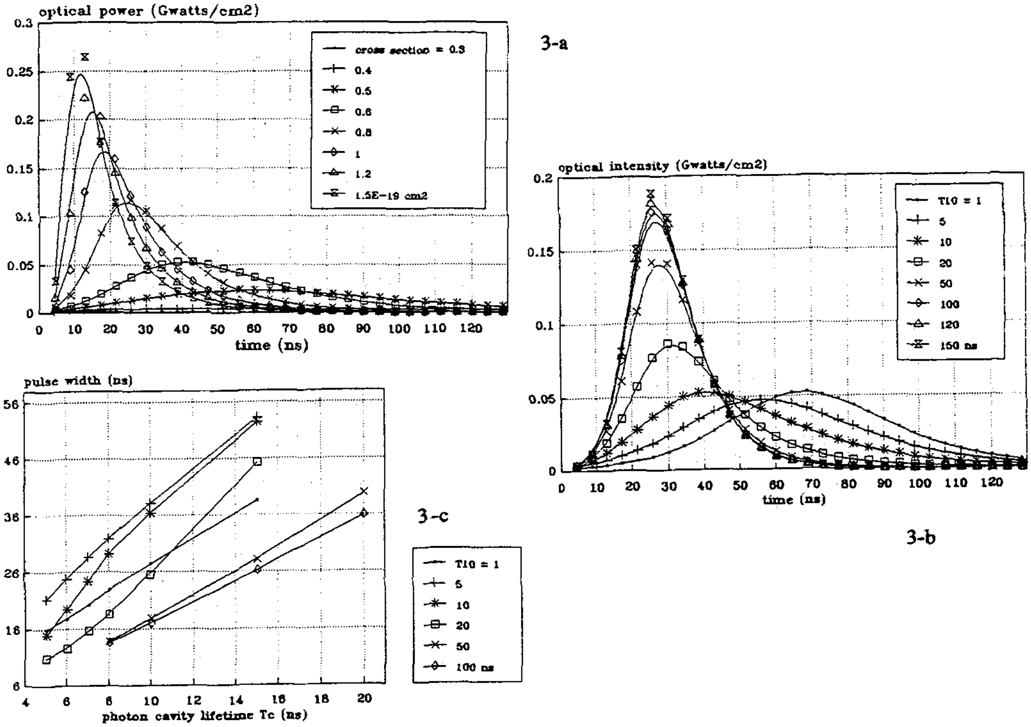

Fig.3.- Computation of the Qswitched pulse versus LNA laser parameters. The cavity length is 45 cm and the photon lifetime in the upper plots -a and -b.is τ_c = 7ns.

When we go on increasing τ_{10}, for example from 100 ns to 1μs, a weaker dependancy of E_{out} and P_{peak} is observed, and pulses tend to superimpose. We believe this occurs because $N1/\tau_{10}$ becomes negligible with respect to the other terms, in (2)-(5). Referring to otherwise published YAG's data [5], the value of τ_{10} for LNA is supposed to stand below 15 ns. So, the uncertainties on latter fits can be estimated at +/-10%. Fig.6-c illustrates the variation of the pulsewidth within the range E_{out} = 100 to 150 mJ, for τ_{10} = 1 to 15 ns and cavity lifetimes τ_c = 5 to 20 ns. Best fits of the simulations with experiments provide σ # 0.6 10^{-19} cm², at τ_{10} = 5 to 15 ns.

3. - *Room temperature effects*. At the opposite of the usual Nd:YAG crystal, and because of strong inhomogeneous broadening effects, the LNA exhibits a fairly flat absorption band between 792 and 806 nm. The YAG requires the diode temperature to be precisely adjusted so that the pumping wavelength is kept nearby 808 nm as closely as possible, and consequently, so that the output energy remains unchanged. The absorption spectrum of 5 mm thick LNA sample is plotted in Fig.4, together with the temperature behaviour of the above oscillator.

The temperature dependant output energy of our diode pumped oscillator is not only limited by the spectral coupling efficiency. It also depends on the variation of the crystal's intrinsic laser parameters, the induced optical effects, and on the shift of the diode current threshold with temperature. When pumped with 250 μs wide pulses, the YAG output roughly varies from 60 to 200 mJ with temperatures ranging between 5 and 65°C, while the LNA output varies from 130 to 150 mJ for 400 μs wide pumping pulses. The YAG's 220 mJ output is related to the highest pumping wavelength we could obtain for diode stacks' reasonable operating conditions, and is only 2 nm below the 808 nm peak absorption of the crystal. After the thermal shift of the diodes has been subtracted, the comparison of these 220 mJ with the LNA's 150 mJ output provides a good estimate of the discrepancy between peak efficiencies: about 8% with LNA, to be compared with nearly 13% with YAG.

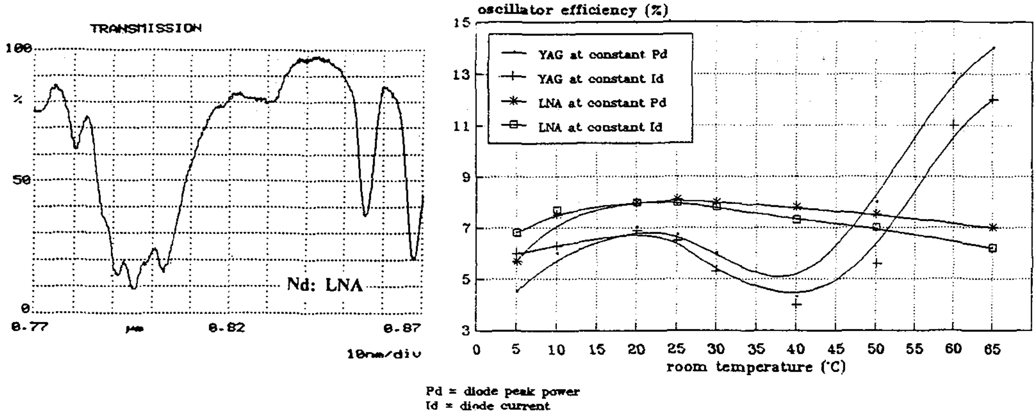

Fig.4. - Nd: LNA absorption spectrum and compared thermal behaviour of the Qswitched LNA and YAG oscillators.

4. - Conclusion. The implications of the differing features of Nd:YAG versus LNA may be discussed in terms of wall-plug efficiency and volume. The Nd:LNA material is a good candidate for high energy at high efficiency, compact lasers. Despite its somewhat reduced stimulated emission cross section, whose effective value 0.6 10^{-19} cm^2 is by a factor 4 lower than that of the YAG, the LNA material can produce Qswitched pulses in the 100 to 200 mJ range. We performed an 7.6 % optical Qswitch efficiency in the actual multimode configuration. This efficiency is limited by the intrinsic losses of additional intracavity components. There is no need of any temperature control within a 5 to 65 °C range of temperatures, and the material has a fairly good energy storage capability. This allows the number of stacks to be minimized, which provides a compact and temperature insensitive laser source.

5. - Acknowledgements. We would like to thank the CEA's team P. Cottin, A. Dechatre, A. Burkhart and W. D'Hespel for the promotion of the project and the numerous useful discussions we had, and our colleagues from the LETI/ Grenoble, C. Wyon and J.J. Aubert, and G. Girard from LASERDOT for their contribution.

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