# ENHANCED EFFICIENCY OF A C.W. MODE LOCKED ND:YAG LASER BY COMPENSATION OF THE THERMALLY INDUCED, POLARIZATION DEPENDENT BIFOCAL LENS.

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***ABSTRACT*** *: New measurements of the bifocal, thermally induced lenses of a c.w. Nd:YAG laser were obtained. We observed the existence of four different focal lengths, polarization and direction dependent, that are thermally induced in the gain medium. The focal distance values were used to calculate very stable resonators with large fundamental mode filling in the laser gain medium, good beam profile and very well defined polarization. We developed a general approach for the optimization of single lamp, cw pumped Nd:YAG lasers. Up to 22 Watts of cw output power in the vertically polarized* $TEM_{00}$ *mode and 15 W in the horizontal polarization are obtained, for moderate lamp currents. In particular we demonstrate mode-locking with 56 ps pulse duration at 33 A of lamp current and up to 15 W of average output power.*

## INTRODUCTION

Continuous wave mode-locked Nd:YAG lasers are widely used in pulse compression experiments in optical fibers as well as pumping sources for color center lasers [1-3]. All these applications need high stability and output power in the $TEM_{00}$ mode. In spite of being a very well known and important laser system, only recently it was possible to increase the output power and stability of the fundamental mode $TEM_{00}$, at no expense of pump power. Due to the thermal load in the laser rod, produced by the lamp pumping, there is a thermally induced lens (f) in the gain medium. High stability and output power were achieved by increasing the fundamental mode volume within the laser rod, considering the thermally induced lens in the resonator design. Nevertheless, commercial configurations mostly use small diameter beams in the active region to diminish the effects of thermally induced birefringence [4] and spatial variation of the beam mode. Resonators with large mode volume, can be specially designed to compensate for some of these effects [5-7]. Magni et al. [8-11] demonstrated that for any resonator with an internal dynamical lens, there are two distinct stability zones ($0 < g_1g_2 < 1$) corresponding to two different sets of values of f. The minimum of the beam radius in the laser rod, in each of these stability zones, corresponds to a large range of focal distances. In the case of thermally induced focal length it means a large range of pump powers. In these zones, the resonator remains stable and shows very little output power fluctuations. In their work, optimization was achieved for one single polarization.

However, Koechner [4] has shown that there are two thermally induced, polarization dependent, focal lengths in the rod. Assuming a cylindrical symmetry, there is a focal length for the radial polarization of light ($f_R$) and a different focal length for tangential polarization ($f_\Phi$). Defining the parameter $\alpha$ as:

$$\alpha = f_\Phi / f_R \qquad \text{(exp 1)}$$

$\alpha$ can be calculated by considering the appropriate photoelastic coefficients of Nd:YAG; its theoretical value is $\alpha$ = 1.2. The experimental values are in the range between 1.35 and 1.5 [4].

## EXPERIMENTAL

The laser under investigation is a commercial model, polarized by an intracavity Brewster plate [12]. In order to measure the polarization and direction dependent focal length, an aperture was introduced, with two small rectangular slits, just before the laser rod. The use of two slits is twofold: avoids the central part of the rod where all the focus coincides and; provides the crossover of the two beams for precise determination of the focus. An expanded, collimated and polarized He-Ne beam illuminates uniformly the whole slit area. If the polarization of the HeNe beam is along the direction of the slits, the thermal lens for radial polarization is measured (figure 1); if the polarization is perpendicular to the direction of the slits, the thermal lens for tangential polarization is measured. The results of the focal length measurements for different lamp currents are shown in figure 2. Also, it is shown the best fit considering that f depends on the inverse of the lamp pump power. It is clearly seen that there are four different curves instead of the two expected ones, showing a spatial asymmetry of the geometrical index profile.

For the case of horizontal polarization of the light we measured a constant ratio of $f_\Phi^H$ to $f_R^H$ of 1.35 (Fig. 2). In the case of vertical polarization, $f_\Phi^V$ and $f_R^V$ show approximately the same value, which was not accounted for before, due to the assumption of an angular independence on these parameters.

A higher thermal gradient in the horizontal direction is expected due to the closer proximity of the rod to the pump lamp. Due to the non uniformity of the thermal gradient, the focal lengths of the polarization components are related by a function of the lamp current, $\beta$(I). Therefore we have