Thermal lens spectrometry in Nd:YAG without and with laser action at 1064 and 1340 nm

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Abstract

The pump-probe TL spectrometry was used, for the first time to our knowledge, to study heat generation, fluorescence quantum efficiency, and thermal properties of Nd:YAG under laser action at 1064 and 1340 nm, and without laser operation. The results showed that the thermal loading was strongly dependent on laser emission wavelength, being >2 times when operating at 1340nm compared to 1064 nm. Our results indicate that the fluorescence quantum efficiency in Nd:YAG, for low concentration up to 1 at. %, is really over 0.93, showing that no nonradiative ``dead-sites'' exist, as postulated in literature.

Introduction

Pump-induced thermal focusing is of primary importance, because of its consequences in beam quality, efficiency, resonator stability, oscillating mode sizes, etc. The availability of diode pumped solid-state lasers brought more attention to thermal lens due to the much localized heat deposition, mainly in high power end-pumped solid-state lasers. The quantitative determination of effective focal length due to thermal effects in end-pumped lasers is difficult compared to lamp-pumped due to the small size involved and higher sensitivity required. Several different approaches have been used to study Thermal Lens (TL) in end-pumped configuration based on interferometry, output beam parameters, transverse mode beat frequency, and degeneration resonator length [1-3]. However, most of them are not very convenient, being very indirect or complicated. The dual-beam mode-mismatched TL spectrometry was developed to improve the sensitivity of TL measurements aiming applications in analytical chemistry. It is a very sensitive, accurate and a simple method for the determination of TL induced phase-shifts and thermo-optical properties. Recently, it has been successfully applied to the characterization of optical materials such as determination of thermal diffusivity (D), temperature coefficient of optical path length (ds/dT), and fluorescence quantum efficiency (η) [4]. Particularly in Nd^{3+}:YAG, several methods have been used to study thermal loading, including luminescence integrating sphere, separate lifetime and absorption measurements, photoacoustic spectroscopy, laser calorimetry, interferometric calorimetry, as well as theoretical modeling of luminescence kinetics [3,5,6]. The advantage of the photothermal methods, compared to pure optical techniques, is the ability to measure the absolute nonradiative quantum efficiency without recourse of complicated and often inaccurate absolute detector calibration procedures [4]. In this work, the pump-probe TL spectrometry was used, for the first time to our knowledge, to study heat generation, fluorescence quantum efficiency, and thermal properties of Nd:YAG under laser action at 1064 and 1340 nm, and without laser.

Theory

In the TL experiment, an excitation beam with Gaussian intensity profile generates a temperature distribution with radial symmetry $\Delta T(r, t)$ in the sample. A probe laser beam crosses the heated sample region and its central intensity, monitored in the far field, is measured. Details of the experimental set-up can be found elsewhere [4]. The probe beam intensity change is proportional to the TL induced phase shift, which normalized by the absorbed pump power is given by:

$$\Theta = -\frac{\theta}{P_{abs}} = C\varphi \qquad (1)$$

in which $C = (\lambda_p K)^{-1} ds/dT$ is a constant, λ_p is the probe beam wavelength, K is the thermal conductivity, and φ is the fraction of absorbed energy converted into heat [4]. In fluorescent samples, part of the absorbed excitation photon energy (hc/λ_{ex}) is converted into heat and part is converted in fluorescence, generating a photon with average energy $hc/<\lambda_{em}>$. In this case, φ is given by (without laser action):

$$\varphi_{nl} = 1 - \eta \lambda_{ex} / < \lambda_{em} > \tag{2}$$

and when under laser action by:

$$\varphi_l = 1 - \lambda_{ex} / \lambda_l \tag{3}$$

in which λ_l is the laser emission wavelength.

Results and Discussions

Figure 1 presents the laser curves and results of the TL in the cavity, in the case, for laser oscillations at 1064 nm. From these data and with help of the equations (1), (2), and (3) η and ds/dT were obtained and compared very well with values previously achieved [7].

The results showed that the thermal loading was strongly dependent on laser emission wavelength, being >2 times when operating at 1340nm compared to 1064 nm. Our results indicate that the fluorescence quantum efficiency in Nd:YAG, for low concentration up to 1 at. %, is really over 0.93, showing that no nonradiative "dead-sites" exist, as postulated in literature [3].

It is interesting remark that our data of the Figure 1 can be used to calculate the effective focal length of the TL in an end-pump thin disk configuration with Gaussian pump. In fact, the theoretical model used assumes only radial heat flow to obtain an analytical solution for the temperature profile [4]. Innocenzi et. al. [1] used the same strategy to calculate thermal focal length. Therefore, the TL effective focal length can be expressed by $f^{-1} = \frac{P_{abs}}{\pi w_e^2 K} \varphi \frac{ds}{dT} = -\frac{\lambda_P \theta}{\pi W_E^2}$. This expression predicts a TL power (dpt/W) about twice of that considering only *dn/dT*, in agreement with experimental data of the Ref. [7].

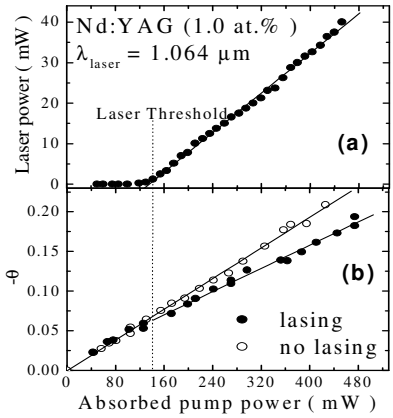

Figure 1: (b) Laser emission at 1.064 μm and (a) phase shift as a function of the absorbed pump power for Nd:YAG doped with 1.0 at.%.

Conclusions

In summary, TL spectrometry intra-cavity was applied to Nd^{3+}:YAG crystals in order to determine heat spectra (not shown here) and accurate values of η, ds/dT, and dioptric power. From our data, we concluded that the pumping efficiency of Nd^{3+} metastable state ($^4F_{3/2}$) is constant at the range of excitation wavelengths of 515-880nm (data not shown here). The thermal loading is strongly dependent on laser emission wavelength, being >2 times when operating at 1340nm compared to 1064 nm. Our results indicate that the fluorescence quantum efficiency in Nd:YAG, for low concentration up to 1 at.%, is really over 0.93, showing that no nonradiative "dead-sites" exist, as postulated in literature.

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