Simple set-up for measuring low transmission losses of optical materials used in laser cavities

Fabio Cavalcanti and Niklaus U Wetter
IPEN - Av. Prof. Lineu Prestes, 2242 São Paulo, SP - Brazil
nuwetter@ipen.br

Abstract: We use a very compact and simple set-up based on a double-beam, mode-controlled Nd:YLiF$_4$ laser and cavity ring-down spectroscopy in a high Q-cavity to measure losses of transparent laser cavity components with 0.001% resolution.
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1. Introduction

Cavity ring-down spectroscopy (CRDS) is a very sensitive and well-known method for the analysis losses in samples of gases, liquids and solids [1]. Because only the ring-down time *t* is measured with this technique, the result is independent of amplitude fluctuations. Additionally, this technique works by comparing *t* to the result for the empty cavity t_0 and is therefore auto-calibrated. This resolves a lot of the issues normally encountered with other technique when measuring very low transmission losses.

Today's solid state lasers need to comply with many requirements, reliability and efficiency being the primary ones. This poses large pressure on optical component and crystal manufacturers in terms of material purity. One such example are continuous intracavity solid-state Raman lasers that preferably use very low overall losses of less than 0.3% per roundtrip in order to function efficiently [2].

In order to measure the losses of these laser intracavity components we propose a set-up based on a very compact and low-cost Nd:YLiF$_4$ q-switched laser, which gives excellent TEM$_{00}$ beam quality, and a high Q-cavity and demonstrate the effectiveness of this set-up.

2. Q-Switched Resonator Setup

Although a significant amount of novel crystalline laser materials with important features for the usage as gain media in Q-switched lasers can be found in the literature, the neodymium lithium yttrium tetra fluorite (Nd:YLF) has proven some excellent thermo-optical characteristics along with its high energy storage capability due to its long upper laser level lifetime. Its natural birefringence and combination of negative refractive index variation and positive laser facet bulging with temperature leads to a very weak thermal lens and no thermal birefringence, allowing for a very high quality laser output beam. There are two main laser transitions in the Nd:YLF uniaxial crystal, 1047 nm and 1053 nm, corresponding to the polarization parallel (π) and perpendicular (σ) to the c-axis, respectively. The sigma (1053 nm) laser emission band presents lower laser gain, but the dioptric power of its thermal lens is a factor of 2.3 weaker than for the 1047 nm transition; besides, this wavelength is also of great interest in laser fusion experiments.

In this setup, the active medium is cut and polished in a square shape and the laser beam enters the side surface at Brewster angle, therefore no coating is required. The simple but robust design permits a double bounce configuration, with two total internal reflections at the pumped surface, increasing the overlap between the lowest order mode and the region with the highest population inversion. This approach effectively decreases the gain available for higher order modes by correctly adjusting the beam diameter and separation of both beams. It has been demonstrated that in a double pass cavity design, the TEM$_{00}$ mode is more efficient than higher order modes without the need for any other mode-selective techniques, depending only on the beam separation, pump power and beam waist [3-5]. For a given set of cavity mirrors and fixed distances among them, the waist of each transverse mode is fixed inside the crystal, such that only the distance D between both beams is variable, allowing for mode controlling of the beam quality in an easy manner. The absence of any additional mode-selective device in the resonator reduces losses for the TEM$_{00}$ and creates a very efficient laser cavity.

A diode laser, emitting at 792 nm when held at 25ºC, was used as pump source. The Nd:YLF crystal slab of approximately square dimension (14 x 13 x 3 mm^3) contained 0.8 mol% neodymium dopant at the yttrium site. The crystal was a-cut with its c-axis orientated parallel to the diode polarization in order to access the higher absorption cross-section of the π-polarization, which was perpendicular to the larger facets of the crystal (figure 1). The 40 W TM polarized diode laser emission was aligned with the c-axis and the crystal was placed at the Brewster angle within the laser cavity, resulting in a pump spot size of approximately 4 mm width and 0.1 mm height after focusing with a f = 25 mm spherical lens. The position of the crystal at the Brewster angle favors sigma polarized emission. A half wave plate was employed to rotate the diode's polarization by 90º in order to access the crystal's highly absorbing π-polarization. The diode laser was operated mostly in the quasi-continuous regime with a diode pulse width of 1 ms and repetition frequency of 70 Hz. The cavity was comprised of a flat output coupler with T = 40%, flat high reflector as end-mirror and a folding mirror of 3 m radius of curvature (ROC). A Cr^{4+}:YAG with 50% initial absorption was used as saturable absorber.

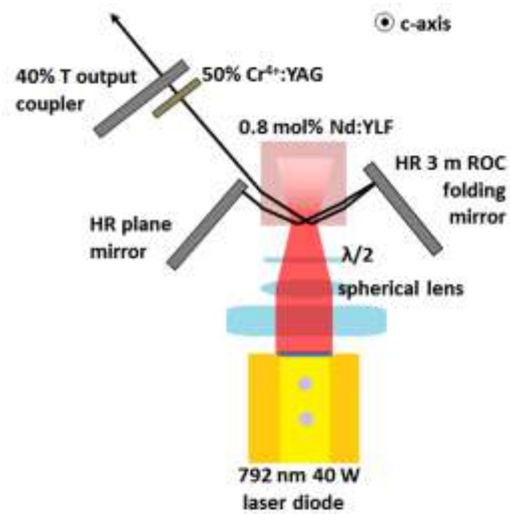

Figure 1 Schematic representation of the passively Q-switched resonator. Nd:YLF is the active medium, detail of the c-axis perpendicular to the plane of the drawing,

3. Resonant Cavity Ring-Down Setup

The highly reflective mirrors (R > 99.992%) of the ring-down cavity were separated by L = 110.854 ± 0.002 cm, as measured with great care, because this number is important for the precision of the results (figure 2). A signal proportional to the intracavity optical intensity is obtained by measuring at the rear mirror. The detector is a photomultiplier with 50 ns rise time. Mirror R1 has a ROC of 20 cm and R2 of 100 cm.

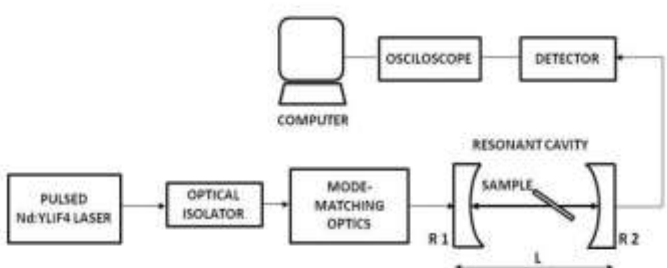

Figure 2: Experimental set-up.

4. Results

The Q-switched laser set-up generated an output power of 1.2 mJ with 5.5 ns FWHM pulse duration, approximately corresponding to 220 kW peak output power. The decay time of the empty cavity (τ_0) was 1.857 x 10^{-5} s ±3.7 x 10^{-8}.

Measurements were done close to the Brewster angle in order to subtract any reflection losses of the surface from the bulk material. The theoretical reflectivity curve was based on the equations for Fresnel reflectivity and generated by a MATLAB program. As an example, we measured a quartz window of 2 mm thickness and obtained a decay time of 3.57 x 10^{-6} s at 56º, corresponding to a single pass loss of 0.00042 ± 0.00002. This means that such a quartz plate, when used at Brewster angle, would already amounts for half of the acceptable losses (0.3%) when used inside a Raman laser cavity, as explained in the introduction.

4. Conclusion

We have demonstrated a simple set-up that can give reliable data on optical components used inside a low-loss laser cavity, such as continuous intracavity Raman lasers.

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