ELSEVIER Optics and Lasers in Engineering 39 (2003) 277–282

OPTICS and LASERS in ENGINEERING

Room temperature 2 μm Tm,Ho : YLF laser

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Received 8 January 2001; received in revised form 8 May 2001; accepted 9 May 2001

Abstract

We present the results obtained with a Tm,Ho : YLF crystal, grown in the new crystals growth facility realized in the Dipartimento di Fisica of the Università di Pisa. The 2 μm laser performance has been studied for three different pump sources, a Ti : Sapphire, a diode—tuned at 792.7 nm—and a Co : MgF_2 laser, tuned at 1.682 μm.

Keywords: Tm,Ho : YLF laser; Ti : Sapphire; Tuned diode; Co : MgF_2

1. Introduction

The 2 μm laser emissions are generating great interest in many fields and applications, like optical communications, coherent laser radar, and medical instrumentation [1–4]. Among the laser sources, those based on solid-state materials now represent the main area of development because of their reliability and compactness.

The transition $^5I_7 \rightarrow {}^5I_8$ of the Ho^{3+} is one of the 2 μm lines largely studied in the past. Several authors reported laser action of this ion in different host crystals, both in pulsed and cw regime, and at different operating temperatures [5]. In this work, we describe the growth of codoped 5.2% Tm, 0.5% Ho $LiYF_4$ (YLF) samples at Dipartimento di Fisica of the Università di Pisa, and their laser characteristics at room temperature.

We use three different pumps to measure the laser properties of our samples. In particular, we use a Ti : Sapphire and a diode laser to excite the $^3H_6 \rightarrow {}^3H_4$ Tm^{3+}

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PII: S0143-8166(01)00125-7

transition at 792 nm wavelength, and a Co : MgF_2 laser to pump the $^3H_6 \rightarrow ^3F_4$ transition at 1682 nm wavelength. For all pumping conditions we have observed the Ho^{3+} 2 μm laser emission from $^5I_7 \rightarrow ^5I_8$.

2. The growth system

In this section we describe the crystals growth facility realized in the Dipartimento di Fisica of the Università di Pisa. The apparatus is based mainly on a conventional-resistive heating Czochralski furnace, working in a controlled atmosphere.

The starting material was prepared by mixing LiF and YF_3 powders in a platinum crucible, together with opportune quantities of TmF_3 and HoF_3 powders to obtain the crystal doping. The material was heated to a temperature of 809°C in a high purity Argon atmosphere (99.999%).

The rotation speed during the growth of the sample was 5 r.p.m. and the pulling rate 1 mm/h. We obtained a YLF crystal doped with 5.2% Tm, 0.5% Ho of 20 mm in diameter and 35 mm in length, and its weight was about 24 g. After orientation in an X-ray Laue apparatus, an oriented sample was cut, so that an edge is parallel to "*c*"-axis. The dimensions of the laser sample are $6 \times 6 \times 2.4\,mm^3$. The wider faces are optically polished by a standard technique to laser quality.

By using a CARY 500 spectrophotometer, we recorded the polarized absorption spectra ($E \| c$ and $E \perp c$) from the UV up to the IR wavelength region. The UV spectrum at around 200 nm clearly showed the lack of typical absorption bands of OH-radicals in the crystal, so that its optoelectronic properties are not compromised.

The visible and infrared spectra of the $E \| c$ polarization show many absorption bands useful for optical pumping. Among them, we have chosen the peak at 792.7 nm for pumping with the Ti : Sapphire and the diode lasers, and the peak at 1.682 μm for pumping with the Co : MgF_2. These lines belong to the transition bands $^3H_6 \rightarrow ^3H_4$ and $^3H_6 \rightarrow ^3F_4$, respectively, and their absorption coefficients are about 4 and $9\,cm^{-1}$. Fig. 1 shows the absorption coefficient corresponding to the $^3H_6 \rightarrow ^3H_4$ Tm^{3+} band, in the red region, while Fig. 2 shows the absorption coefficient corresponding to the $^3H_6 \rightarrow ^3F_4$ Tm^{3+} band, in the infrared.

Another preliminary verification of the crystal optical quality has been performed by measuring the lifetime of Ho^{3+} upper laser level; the experimental setup consisted of a chopped Ti : Sapphire laser source, a focusing system and a suitable monochromator to collect and analyze the fluorescence, and a fast detector connected to a digital oscilloscope. We measured a lifetime of about 14.5 msec, a value that agrees very satisfactorily with those reported in the literature [6].

3. Experimental setup and laser results

The experimental apparatus for studying the laser performance of our crystal was composed of an astigmatically compensated *X*-folded four-mirror cavity, where the crystal sample was placed at Brewster angle. It was mounted on a copper block,

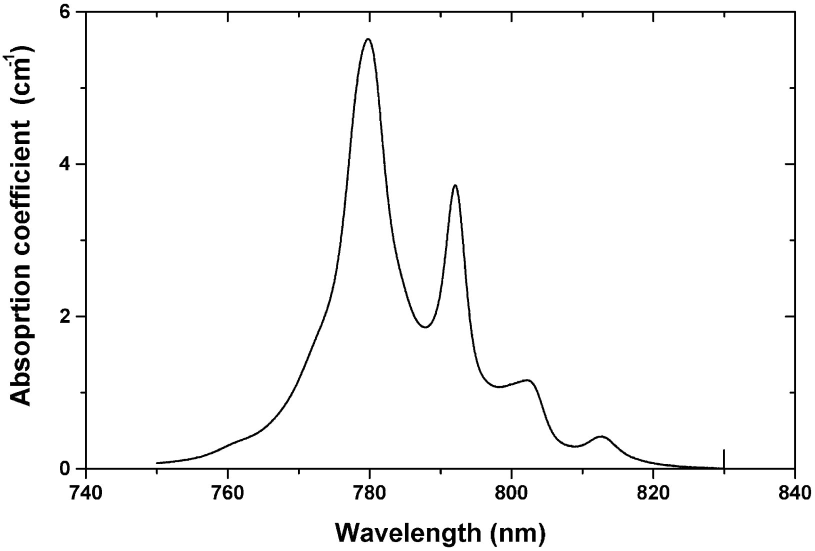

Fig. 1. Absorption coefficient in the red wavelength region for the $E \| c$ condition.

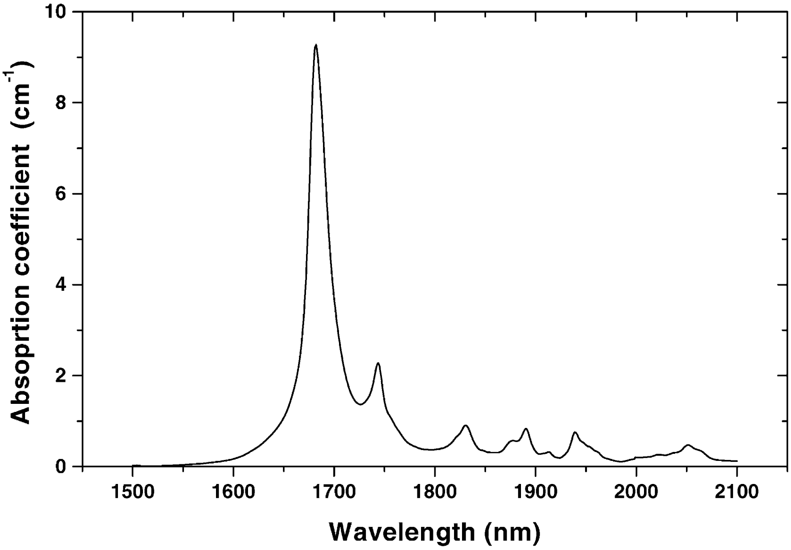

Fig. 2. Absorption coefficient in the infrared wavelength region for the $E \| c$ condition.

without any active cooling, and it was oriented with the crystallographic axis "c" parallel to both the pump and the emitted radiation. The cavity had two curved dichroic mirrors (radius of curvature 100 mm), placed at a distance of approximately 100 mm, a high reflectivity plane mirror, and an output coupler. The folding angles and the length of the two arms of the cavity were chosen to compensate for the astigmatism introduced by the crystal and to have a stable resonator.

The pump beam was focused with an uncoated lens to produce a spot size within the crystal comparable with the spot size of the four-mirror resonator. The focal length has been changed for each pump source, to match the optical quality of each of them.

The first source was a home made cw Ti : Sapphire laser; it could deliver up to 1 W in the spectral region of interest, when pumped by a multiline Ar laser. The optical quality of this radiation was quite good ($M^2 \approx 1$) with a nearly Gaussian output beam. Consequently, the focused pump beam waist was nearly symmetrical.

The second source was a commercial diode array (SDL-2432-P1) which could deliver up to 1.2 W power with an emission bandwidth of approximately 2 nm. The astigmatism of its beam was compensated by an 8 mm focal length objective, placed in front of the laser diode output window, and by two anamorphic prisms with a × 4 magnification for the emission orthogonal to the junction plane. In this way the pump beam was focused on to an elliptical spot of approximately 100 × 25 μm in the laser crystal. When using these two sources, the best results were obtained by using a focusing lens of 70 mm focal length.

The last source was a home made cryogenic cw tunable Co : MgF_2 laser, pumped by a multiline Nd : YAG laser at 1.32 μm, delivering up to 1 W at 1.682 μm. The optical quality of this source was quite good, and the pumping spot in the crystal was symmetrical. With this laser, the performance of 2 μm laser was nearly insensitive to the focal length of the focusing lens: we changed it from 60 to 100 mm, and in the final measurement we used the 100 mm lens.

The input mirror could transmit about 95% of the pumping radiation around 800 nm, and about 84% at 1.7 μm.

Fig. 3 shows the results obtained with a 3% transmission output coupler at 2.06 μm. The three different sets correspond to the three pump laser: the Ti : Sapphire, the diode and the Co:MgF_2 lasers. The slope efficiency of the three curves are, respectively, 30% for the Ti : Sapphire, 23% for the diode, and 36% for the Co : MgF_2. These figures are computed with respect to the input power values, and do not take into account the real absorbed power. Therefore, the absorbed slope efficiencies are, respectively, 49%, 37% and 44%.

The thresholds we measured for the three pumping conditions are below 100 mW for the Ti : Sapphire and the Co : MgF_2 laser pumps, and around 160 mW for the diode. The discrepancies of behaviour between the Ti : Sapphire and the diode laser pump (both lasers emit the same wavelength) can be attributed mainly to the poorer optical quality of the diode beam [7].

The high efficiency obtained with the Co : MgF_2 laser pumping can be explained by supposing that in this case the direct excitation of the $^3F_4$ Tm level does not populate levels at high energy, and involves fewer mechanisms of losses.

We have also measured the intrinsic losses with two different methods based on the different output power obtained by changing the output mirror transmission: in the case of Co : MgF_2 pumping, both Findlay–Clay [8] and Caird [9] analysis give an intrinsic loss of about 4.5% cm^{-1} in single pass.

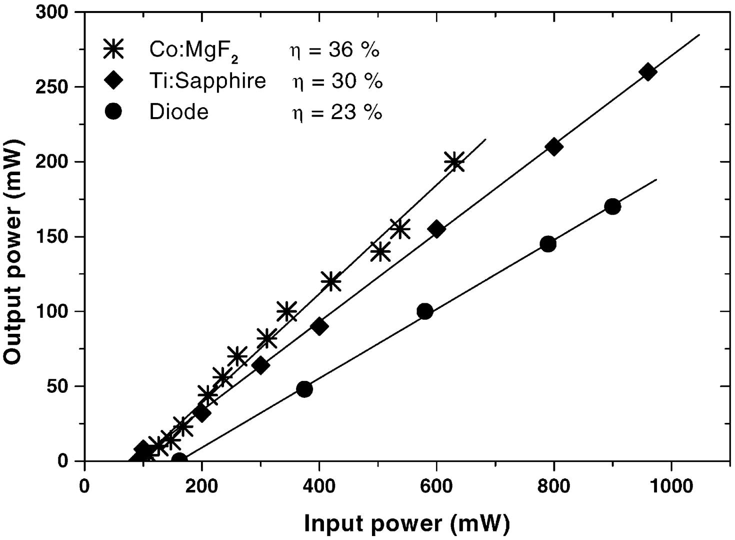

Fig. 3. Output power as a function of input power with a 3% output coupler; the three sets correspond to the three pump lasers, respectively, the Ti : Sapphire, the diode and the Co : MgF_2 laser.

4. Conclusions

The results we obtained show that the growth apparatus realized at the Physics Department of the Pisa University can produce samples of very high optical quality, suitable for room-temperature laser systems. The slope efficiency values which we measured both with the Ti : Sapphire and the diode laser pumping conditions, are comparable with the best values reported in the literature [10].

Moreover, for the first time we pumped a Tm,Ho : YLF crystal at 1.682 μm, obtaining an excellent slope efficiency. These results confirm the considerable versatility of the Tm,Ho : YLF crystal, and the possibility of producing a 2 μm room temperature laser system in configuration "all solid state" with many different pumping schemes.

Acknowledgements

The authors wish to thank Ilaria Grassini and Fabio Torri for their invaluable support in developing this work.

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