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Ti : sapphire laser pumped by the second harmonic of a pulsed diode-pumped Nd : YAG laser for two-photon spectroscopy

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Abstract. **The characteristics of a ring Ti : sapphire laser with gain modulation and frequency tuning using a prism beamsplitter are presented. The output pulse duration was about 50 ns at a pulse repetition rate of 7 – 18 kHz, and the frequency tuning range was 30 nm. The radiation bandwidth of the laser with a 0.7-mm-thick intracavity Fabry – Perot etalon was 12 GHz. The maximum average output power reached 160 mW at the pump power of 4.5 W and the pulse repetition rate of 7 kHz. As a pump laser, we used a diode-pumped frequency-doubled *Q*-switched Nd : YAG laser.**

Keywords: *ring Ti : sapphire laser, diode-pumped Nd : YAG laser, frequency doubling, Q-switching, prism beamsplitter.*

1. Introduction

Since publication [1] on lasing in the $Ti^{3+} : Al_2O_3$ crystal, Ti : sapphire lasers have been objects of numerous researches, and, at present, they are the most widely used solid-state lasers. These lasers have a wide tuning range (660 – 1100 nm), which makes them a convenient and multipurpose source of laser radiation. These lasers can be used in laser photochemistry, nonlinear excitation of atoms and molecules, laser photokinetics, remote probing of atmosphere, photobiology, spectroscopy, isotope separation, etc.

Because the nonlinear excitation of atoms is, at least, a two-photon process, it requires rather high laser output powers. High powers are easily achieved in the pulsed regimes of Ti : sapphire lasers. However, this laser operation regime is associated with problems in radiation frequency selection and tuning with a Lyot filter, which is usually used to control the radiation frequency in lasers with a wide wavelength tuning range. In the case of two-photon excitation of atoms, two optical schemes are used, namely, with co- and counterpropagating beams [2]. The second scheme is preferable because it allows one to avoid the Doppler background in the absorption and can be easily constructed without an optical diode in the ring cavity.

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In this paper, we describe a ring Ti : sapphire laser with counterpropagating beams and a wide tuning range (due to the use of a multiprism beamsplitter), which is intended for two-photon spectroscopy. The $Ti^{3+} : Al_2O_3$ crystal of this laser is pumped by the second harmonic of a diode-pumped *Q*-switched Nd : YAG laser.

2. Experimental setup

The optical scheme of the laser is shown in Fig. 1. The laser cavity was formed by four mirrors: concave mirrors M1 and M2 with radii of curvature of 122 and 150 mm, respectively (mirror M1 was meniscus with a transmittance of about 80 % at 532 nm), and plane mirrors M3 and M4. Mirror M4 with a transmittance of 3 % at 760 nm served as an output coupler; the other mirrors were highly reflecting with the reflection coefficient $r > 99\,\%$. The prism beamsplitter consisted of five 60° TF5 glass prisms. Further narrowing of the laser line was performed using a 0.7-mm-thick fused quartz Fabry – Perot etalon, whose plates had the reflection coefficient $r = 0.3$. The laser radiation parameters were measured with a power meter and a scanning Fabry – Perot interferometer with a variable base or an MDR-23 monochromator. The $Ti^{3+} : Al_2O_3$ crystal (length 10 mm, diameter 5 mm, absorption coefficient $\sim 1\ cm^{-1}$ at 532 nm) was pumped by the 532-nm radiation from a diode-pumped *Q*-switched frequency-doubled Nd : YAG laser [3]. The pump pulse duration was ~ 70 ns. The pump radiation was focused by a lens with the focal distance $f = 20$ cm. One of the $Ti^{3+} : Al_2O_3$ laser beams could be reflected back into the cavity by an

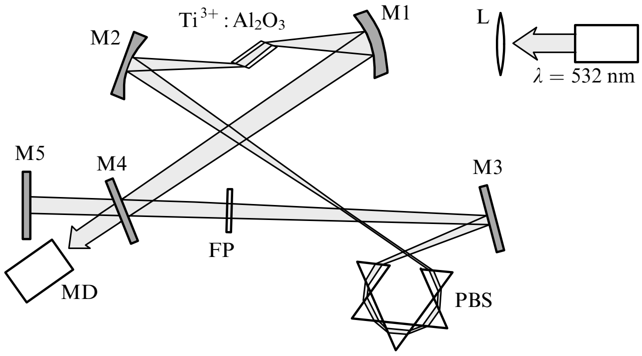

Figure 1. Optical scheme of the laser: (M1 – M5) mirrors; (L) lens; (PBS) prism beamsplitter; (FP) Fabry – Perot interferometer; (MD) measuring device.

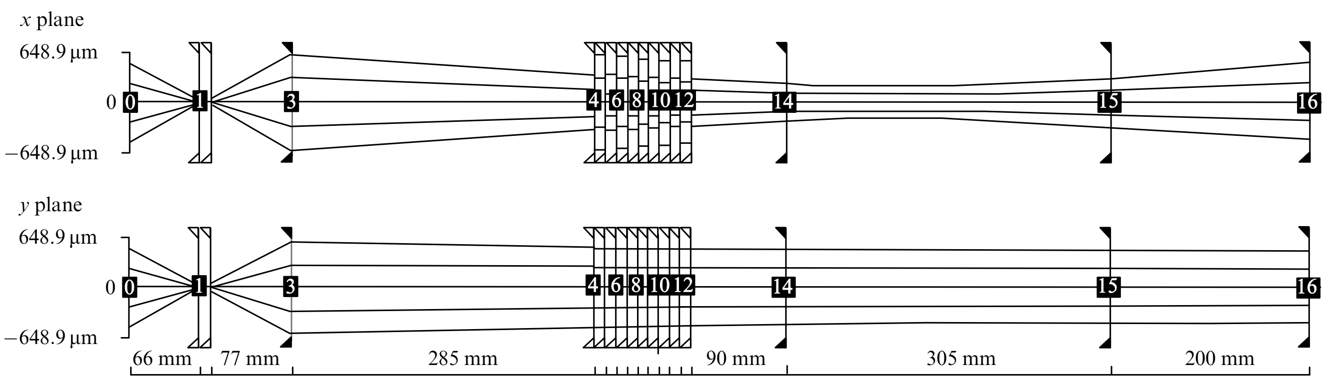

Figure 2. Propagation of beams in the cavity (explanations are given in the text).

additional plane mirror M5 ($r > 99.5$ %), which allowed us, if necessary, to obtain lasing with copropagating beams [4] (the regime with counterpropagating beams occurred without mirror M5). The dependence of the Ti : sapphire laser power on the pump power was measured with an LM-2 (Carl Zeiss) power meter. The linewidth of the laser radiation was measured with a scanning Fabry – Perot interferometer with a variable base. The frequency of the Ti : sapphire laser was selected using a prism beamsplitter placed at the Brewster angle and a Fabry – Perot etalon. To measure the tuning characteristics, we used an MDR-23 monochromator and an LM-2 power meter placed instead of mirror M5.

Figure 2 demonstrates the propagation of beams in the laser cavity. The calculations were fulfilled by the matrix method in the sagittal and azimuthal planes, i.e. in the x and y planes, respectively. The figures denote the optical surfaces of laser elements (some of surfaces in Fig. 2 are unnumbered): (0) and (16) surface of mirror M1; (1) and (2) Ti : sapphire crystal; (3) surface of mirror M2; (4) – (13) prism beamsplitter; (14) and (15) surfaces of mirrors M3 and M4, respectively. The calculation begins from mirror M1 (element 0) and ends at the same mirror (element 16). The figures near element (0) correspond to the coordinates of the intersection points of boundary beams with plane (0). The effect of the intracavity Fabry – Perot etalon on the intensity distribution is weak and neglected in the calculation.

3. Experimental results

We obtained the following experimental results. The linewidth of the Ti : sapphire laser with a prism beamsplitter similar to that used in [5] was 110 GHz and narrowed to 12 GHz after placing a thin 0.7-mm-thick Fabry – Perot etalon into the cavity. Further narrowing of the laser line can be easily achieved by introducing an additional thick Fabry – Perot etalon.

Figure 3 shows the $Ti^{3+} : Al_2O_3$-laser tuning curve, whose width is determined by the spectral range of mirrors and by intracavity losses. The output power of the Ti : sapphire laser monotonically decreased with increasing the pump pulse repetition rate (Fig. 4). This can be explained by the fact that an increase in the pulse repetition rate leads to a decrease (approximately inversely proportional to the rate) in the pump pulse energy with a simultaneous increase in their duration; therefore, the excess over the lasing threshold decreases. The entrance surface of the active

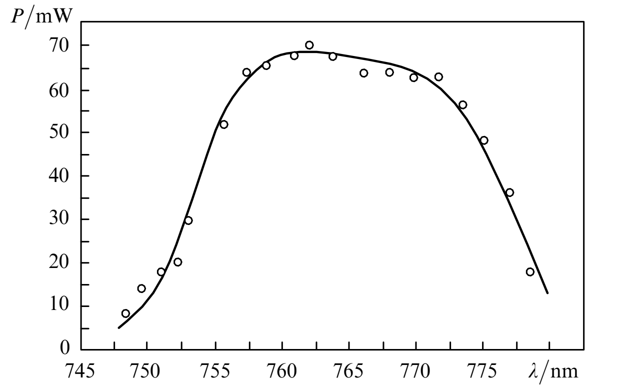

Figure 3. Dependence of the average output power P on the radiation wavelength λ.

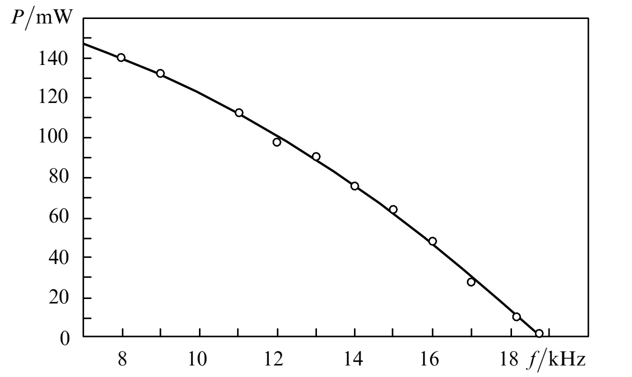

Figure 4. Dependence of the average output power P on the pulse repetition rate f.

crystal began damaging at a pulse repetition rate below 7 kHz. The damage threshold was $\sim 10^9$ W cm^{-2} (at 532 nm, pump pulse duration 70 ns, and 50-μm diameter of the pump beam on the crystal surface).

The dependence of the output power of the $Ti^{3+} : Al_2O_3$ laser on the pump power is shown in Fig. 5. This dependence was obtained at a pulse repetition rate of 10 kHz. The lasing threshold with respect to the pump power was 1.5 W. The rather high lasing threshold is caused by the low figure of merit of the active element (FOM = 30 – 50), high intracavity losses, and incomplete (~ 50 %) use of the pump radiation due to, in particular, reflection from mirror M1. The pulse duration of the $Ti^{3+} : Al_2O_3$ laser measured with

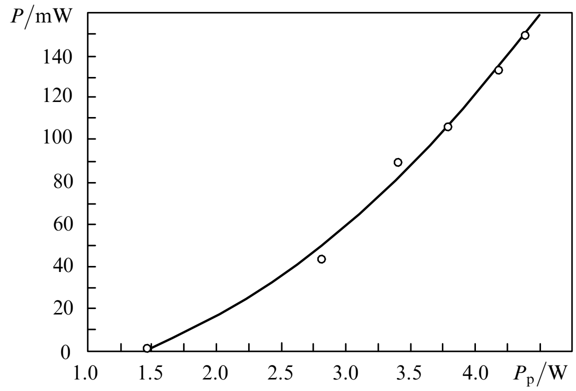

Figure 5. Dependence of the average output power P on the pump power P_p.

an LFD-2 photodiode and a Tektronix oscilloscope with the transmission bandwidth of 200 MHz was 50 ns. The measurements were performed at a pump power of 4W, a pulse repetition rate of 10 kHz, and a pulse duration of 70 ns.

4. Conclusions

We have designed a ring $Ti^{3+}:Al_2O_3$ laser with counter-propagating output beams, continuous frequency tuning, and a peak output power of $\sim$0.5 kW. The Ti:sapphire laser crystal was excited by the second harmonic of a diode-pumped Q-switched Nd:YAG laser. In the future, we plan to use this laser for two-photon spectroscopy of the 5S–7S transition in rubidium and for separation of its isotopes.

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