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Multiwatt lasing of Nd:YAG laser ceramics containing 0.8 % and 1 % of Nd

S.M. Vatnik, V.V. Osipov, K.E. Luk'yashin, V.B. Kravchenko,
Yu.L. Kopylov, I.A. Vedin, P.F. Kurbatov

***Abstract.* The lasing characteristics of 1 % Nd:YAG and 0.8 % Nd:YAG laser ceramics synthesised, respectively, at the Institute of Electrophysics, Ural Branch, Russian Academy of Sciences and at the Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences are studied. Lasing was obtained in all the samples with a slope efficiency from 7 % to 25 % and a maximum output power exceeding 4 W. Intrinsic absorption and scattering losses in the ceramics are estimated.**

Keywords: *Nd:YAG laser ceramics, diode pumping, lasing efficiency, transmission spectra.*

1. Introduction

Significant progress in the synthesis of oxide laser ceramics achieved in recent years allowed one, in particular, to obtain large-size (up to 50 mm in diameter) samples of Nd:YAG ceramics with comparatively low intrinsic losses and residual porosity [3, 4] by domestic pressing and sintering technologies [1, 2]. At the same time, domestic ceramics are inferior to the best foreign samples in microstructural homogeneity, which is reflected on lasing parameters, including slope efficiency and threshold pump power. In this connection, it is very interesting to study the lasing characteristics of samples synthesised by different methods. In this work, we present the lasing characteristics of Nd:YAG ceramics synthesised at the Institute of Electrophysics, Ural Branch, Russian Academy of Sciences (IEP) and at the V.A. Kotel'nikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences (IREE); the methods of synthesis of initial nanocrystalline materials and the sintering technologies are described in detail in [1 – 6]. Our investigations are aimed at solving a part of the complex problem of overall optimisation of synthesis of ceramics in order to improve its optical characteristics and microstructural homogeneity, which is an important direction of scientific-practical research related to the creation of highly efficient laser media, including active elements for multikilowatt laser systems.

2. Experimental

The studied samples of Nd:YAG optical ceramics had the form of disks with dimensions of ∅16 × 3.1 mm (IREE, samples Nos 8 and 10), as well as ∅11 × 1.1 mm and ∅47 × 2.1 mm (IEP, samples Nos 408, 414, 418, and B2). After measuring the transmission coefficients of the samples on a Shimadzu UV-3101PC spectrophotometer in the spectral range 800 – 1100 nm, the faces of disks were coated by dielectric films: the first face was coated by a broadband antireflection film with the residual reflectance $R < 0.15\%$ at the pump (808 nm) and laser (1064 nm) wavelengths, and the second face was coated by a combined reflecting film consisting of a dense dielectric mirror ($R > 99.8\%$ at $\lambda = 1064$ nm) and an additional metallisation layer to achieve a high reflection coefficient for the pump beam incident at angles of 0 – 30°. For efficient heat removal, the ceramic disks were mounted on copper heat sinks with an intermediate indium foil layer 100 μm thick using different soldering and pressing methods.

The 1 % Nd:YAG ceramic samples Nos 408, 414, and 418 (IEP) were pumped by a laser diode bar with an optical power up to 30 W at a wavelength of 808 nm, whose radiation was focused on the active element using a two-mirror collimator and auxiliary optics [7], which formed an approximately round spot ~0.7 mm in diameter in the focus; the power loss in the entire optical channel did not exceed 10 %. For pumping of ceramic samples B2 (1 % Nd:YAG, IEP) and Nos 8, 10 (0.8 % Nd:YAG, IREE), we used two diode bars with the total power up to 50 W; the pump spot diameter in the waist was 0.95 mm.

All laser experiments were performed in a short linear cavity with the physical length $L = 20$ mm, which was formed by an external concave mirror and a rear mirror deposited on the active element from the side of the heat sink as is shown in Fig. 1 in [7]. As an output mirror, we used a spherical concave mirror with the curvature radii $r = -40$ mm and the transmittance $T = 3\%$ at the wavelength $\lambda = 1064$ nm. The pump and laser powers were measured using an Ophir L30A power meter. In general, the experimental scheme is rather close to the scheme described in [7] except for several technical improvements related to the conditions of thermal stabilisation of diode bars and active elements.

S.M. Vatnik, I.A. Vedin, P.F. Kurbatov Institute of Laser Physics, Siberian Branch, Russian Academy of Sciences, prosp. Akad. Lavrent'eva 13/3, 630090 Novosibirsk, Russia;
e-mail: vatnik@laser.nsc.ru, vedin@laser.nsc.ru;
V.V. Osipov, K.E. Luk'yashin Institute of Electrophysics, Ural Branch, Russian Academy of Sciences, ul. Amundsena 106, 620016 Ekaterinburg, Russia; e-mail: plasma@iep.uran.ru, vlad@iep.uran.ru;
V.B. Kravchenko, Yu.L. Kopylov V.A. Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Fryazino Branch, pl. Akad. Vvedenskogo 1, Moscow region, 141190 Fryazino, Russia; e-mail: vbk219@ire216.msk.su, ylk215@ire216.msk.su

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3. Results and discussion

The photographs of the studied samples of laser ceramics and their transmission spectra in the range 800–1100 nm are presented in Fig. 1. As was expected, the absorption maxima in the near IR spectral region are centred at a wavelength of 808 nm, which is typical for aluminium–yttrium garnets doped with trivalent neodymium. Comparing the transmission of ceramics in the transparency range (1000–1100 nm) T_{exp} with the calculated transmission T_{c} of the optical material with the refractive index $n = 1.815$ (calculated for ideal homogeneous ceramics taking into account only Fresnel reflection losses), we can find absolute absorption and scattering losses $T_{\text{loss}} = T_{\text{c}} - T_{\text{exp}}$ (corresponding data are listed in Table 1).

Table 1. Lasing characteristics of Nd:YAG optical ceramics.

Sample number	Lasing threshold/W	η_{opt} (%)	η_{dif} (%)	T_{loss} (%)
408	8.7	4.9	6,8	1.5
414	8.7	5.1	7.2	3.4
418	7.0	13.6	19.1	0.9
B2	12.1	5.3	6.7	2.1
8	4.3	7.6	9.5	3.2
10	1.4	18.9	20.8	1.9

Note: The parameters are given with respect to the pump power incident on the active element (see Fig. 2) at the output mirror transmittance $T = 3\%$; η_{opt} is the optical-to-optical efficiency; η_{dif} is the slope efficiency.

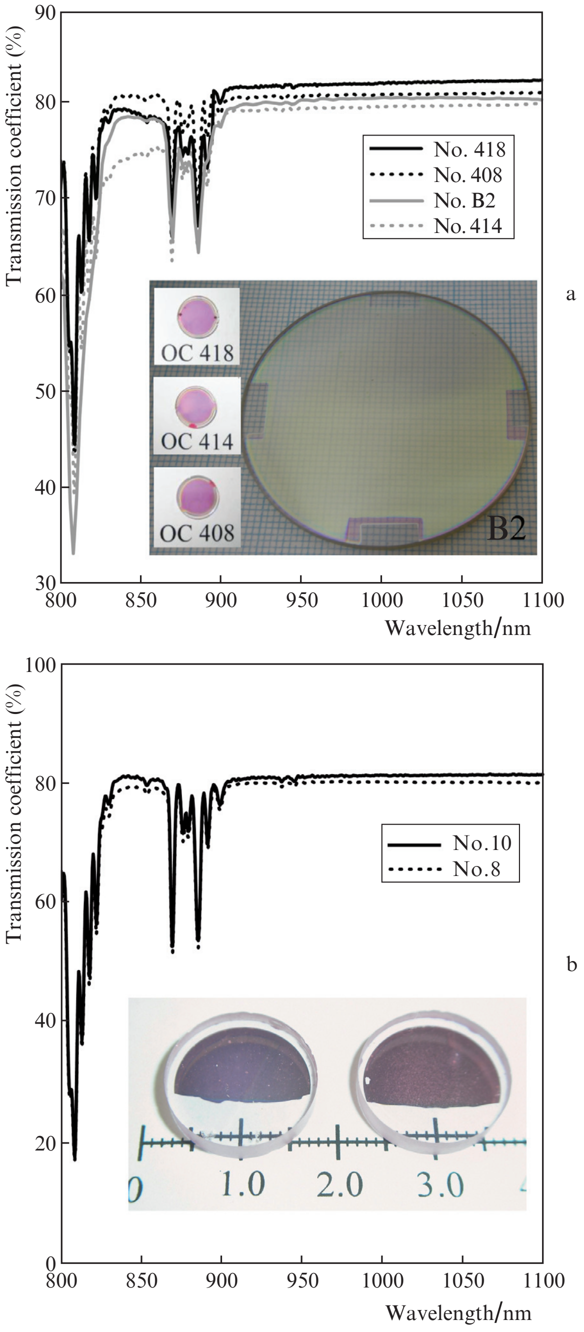

Figure 1. Transmission spectrum of 1% Nd:YAG (IEP) (a) and 0.8% Nd:YAG (IREE) (b) laser ceramics. The inset presents the photographs of the studied samples.

In the course of preliminary study of the lasing characteristics of the samples, it was found that a change in the physical cavity length by 20–40 mm only slightly (within 5%) affects the output laser power, while an increase in the cavity length by more than 40 mm causes a sharp decrease in the power because the cavity leaves the stability region. Therefore, all laser experiments were performed with the cavity length L = 20 mm, at which the output laser power was maximal (20 mm is the minimal length at which the pump beam is not blocked by the output mirror). At these cavity parameters, the Gaussian beam diameter is 0.16 mm. Since the pump beam spot diameter was considerably larger (~1 mm), the comparison of laser ceramics was performed with respect to the maximum output power and lasing efficiency, the mode composition being ignored. Figure 2a shows the measured lasing characteristics of 1% Nd:YAG ceramic samples Nos 408, 414, 418, and B2 for a four-pass pumping scheme, in which a retroreflector provides two additional passes (see Fig. 1 in [7]). In the absence of the retroreflector, the samples absorb 50% of pump power per two passes; in the case of four passes, the fraction of absorbed pump power increases to 75%. Thus, the slope and optical-to-optical laser efficiencies of the best sample of 1% Nd:YAG ceramics (No. 418, IEP) with respect to the absorbed pump power are 25.5% and 18.1%, respectively.

The results of similar laser experiments for 0.8% Nd:YAG optical ceramics (IREE) are presented in Fig. 2b. Since the metallisation adhesion on the rear mirror of these samples was very low, the lasing characteristics were measured in the quasi-cw pumping regime with an off-duty ratio of 14% (7 ms/50 ms) at the maximum pump power 25 W. The best laser parameters were achieved for sample No. 10, for which the slope and optical-to-optical efficiencies with respect to the absorbed pump power (~90% of incident power) were 23.1% and 21.0%, respectively. The main experimental results are listed in Table 1.

As was noted previously in [7], there exists some qualitative correspondence between the lasing efficiency and losses T_{loss} in ceramics. For example, the highest lasing efficiencies correspond to the highest optical transmission (samples Nos 418 and 10). According to the data in Table 1, the specific losses T_{loss}/H (H is the sample thickness) for these samples are rather close and equal to about 7%/cm, and the differential and total lasing efficiency are also almost identical. Thus, taking into account the total set of presented experimental data, as well as the considerable variations in the lasing efficiency from one sample to another, it seems still

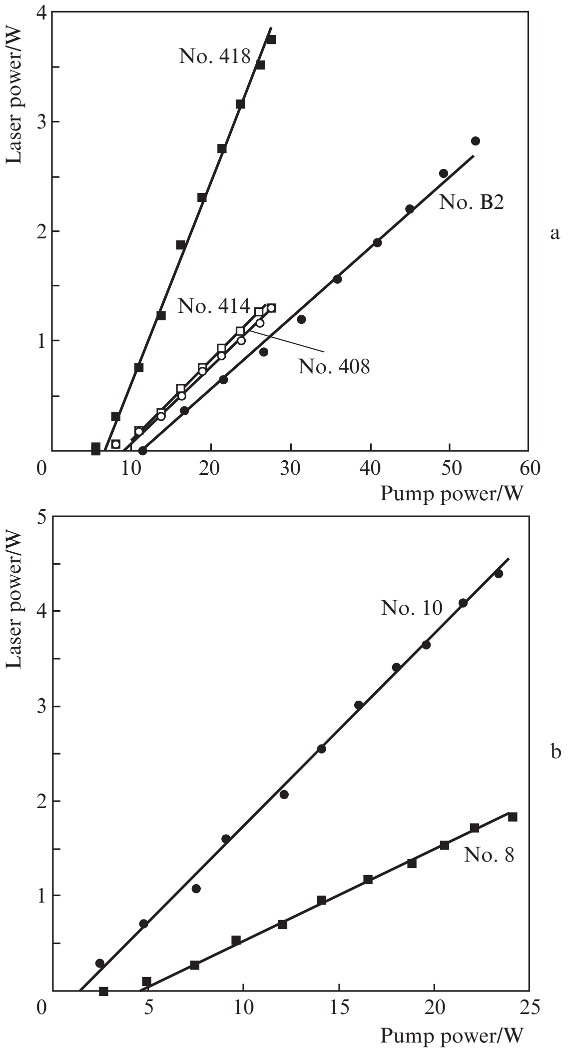

Figure 2. Dependences of the output laser power on the pump power for samples Nos 408, 414, 418, B2 (IEP) (a) and 8, 10 (IREE) (b).

impossible to make a conclusion on the advantages of some of the ceramics synthesis methods described in [1, 2, 4–6].

Note that samples Nos 408 and 414, whose losses T_{loss} differ by more than two times, showed almost identical lasing parameters, namely, very close thresholds and efficiencies (see Figs 1a, 2a and Table 1). Apparently, the lasing characteristics of ceramics depend not only on the optical losses but also on the degree of microstructural optical homogeneity, which must be sufficiently high to meet the phase coherence conditions. Thus, to increase the lasing efficiency, it is necessary to perform overall optimisation of the entire technological chain of ceramics synthesis in order to decrease the absorption and scattering losses to a level of 10^{-3}–10^{-5} cm^{-1} [8, 9].

4. Conclusions

Despite a considerable progress in the improvement of the functional characteristics of Russian laser ceramics (including large-size ceramic disks), high specific absorption and scattering losses do not allow one to realise all advantages of ceramic materials when applying them as active elements of high-power laser systems. In particular, according to the presented data, the slope efficiency of Russian Nd:YAG ceramics is about 25%, which is approximately twice as low as that of the best foreign analogues. Therefore, further improvement of the optical homogeneity of laser ceramics by decreasing the total losses remain a topical scientific and technical problem, which is of top priority for development of modern solid-state multikilowatt laser systems.

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