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# Investigation of lasing characteristics of 1% Nd:YAG laser ceramics

S.M. Vatnik, V.V. Osipov, I.A. Vedin, P.F. Kurbatov

***Abstract.*** **The lasing characteristics of 1% Nd:YAG laser ceramics synthesised at the Institute of Electrophysics, Ural Branch, Russian Academy of Sciences are studied. CW lasing is obtained in all the samples with the slope and total optical efficiencies of 25% and 18%, respectively. 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 creation of solid-state lasers achieved in recent years is associated with the development and investigation of new promising active media based on laser nanoceramics, including yttrium aluminium garnet ceramics. The lasing and spectroscopic properties of oxide laser ceramics have been studied since 1990s. Lasing in 1% Nd:YAG ceramics was obtained for the first time in 1995 [1], and already in 2001 the lasing efficiency of Nd:YAG ceramics was almost as high as of single crystals [2]. Laser ceramics has some important advantages compared to single crystals, among which are the relatively simple synthesis of large-size samples, the possibility of producing multilayer (composite) ceramic structures, and a comparatively low production cost [3]. All this makes the highly transparent ceramics very promising for wide application in multikilowatt solid-state laser systems. In this work, we present the results of investigation of the lasing characteristics of 1% Nd:YAG ceramics synthesised at the Institute of Electrophysics, Ural Branch, Russian Academy of Sciences. Detailed comparative analysis of the methods of producing highly transparent Nd:YAG ceramics from nanopowders is given in [4–11]. At the same time, despite a substantial progress in production methods and technology, the optimisation of synthesis parameters in order to improve the microstructural homogeneity and optical characteristics of ceramics still remains a topical scientific-practical problem in the field of creation of highly efficient laser media.

**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** Institute of Electrophysics, Ural Branch, Russian Academy of Sciences, ul. Amundsena 106, 620016 Ekaterinburg, Russia; e-mail: plasma@iep.uran.ru

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## 2. Experimental

The experiments were performed with disks of 1% Nd:YAG ceramics with polished plane-parallel surfaces. After measuring the transmission coefficients of the samples on a Shimadzu UV-3101PC spectrophotometer in the spectral range of 800–1100 nm, the surfaces of the disks were coated with dielectric films, namely, a broadband antireflection coating with the residual reflectance $R < 0.15\%$ for the pump (808 nm) and laser (1064 nm) wavelengths was deposited onto one surface, and the other surface was coated with a combined reflecting coating consisting of a highly reflecting mirror ($R > 99.8\%$ at $\lambda = 1064$ nm) and an additional metallisation layer, which ensured a high reflection coefficient for the pump radiation incident at angles of 0–30°. For efficient heat removal, the disks were mounted on copper heat sinks with an intermediate indium foil layer 100 μm thick using different methods of soldering and pressing.

All lasing experiments were performed in the geometry of a short linear cavity with the physical length $L = 12$ mm, which was formed by an external concave mirror and a highly reflecting mirror deposited on the active element from the side of the heat sink (Fig. 1). As output mirrors, we used spherical mirrors with the transmission coefficients $T_{out} = 3\%$ and 10% at the wavelength $\lambda = 1064$ nm and with the identical curvature radii $r = -40$ mm. The samples were pumped by a laser diode array with an optical power up to 30 W at a wavelength

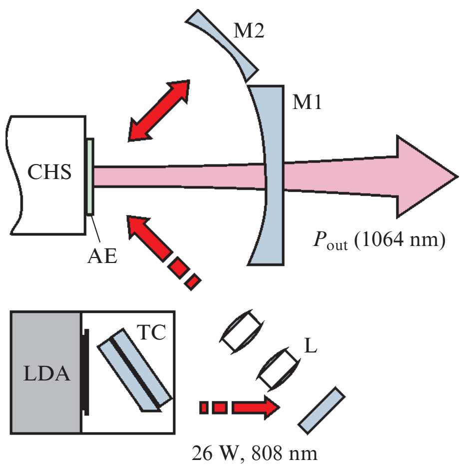


**Figure 1.** Scheme of the experimental setup for studying the lasing characteristics of 1% Nd:YAG ceramics: (AE) active element; (CHS) copper heat sink; (LDA) laser diode array (30 W, 808 nm); (M1) output spherical mirror ($T_{out} = 3\%$ or 10%, $r = -40$ mm); (M2) retroreflector; (L) focusing optics; (TC) two-mirror collimator.

of 808 nm, whose radiation was focused onto the active element by a two-mirror collimator [12] and an auxiliary focusing optics into an approximately round spot ~0.7 mm in diameter; the power loss in the entire focusing channel did not exceed 10%. The optical pump power and the laser power were measured with an Ophir L30A power meter. The pump unit and the laser cavity elements were mounted onto a common aluminium base. Since the laser diode array wavelength considerably depends on temperature, the temperature of its mount (CS type) was stabilised so that the absorption of the optical pump power was maximal at each measurement. In all cases, the change in the temperature of the diode array mount was about 6 °C, from ~27 °C at low powers to 21 °C at the maximum pump power (27.6 W). The temperature of the heat sink of the disk element (ceramics) was not specially controlled, but it did not exceed 30 °C in all regimes.

## 3. Results and discussion

The transmission spectra of 1% Nd:YAG ceramic samples Nos 408, 414, and 418 with dimensions ∅11 × 1.1 mm and a large-size (∅47 × 2.1 mm) sample B2 in the range of 800–1100 nm are shown in Fig. 2. The photographs of the samples and of one of the studied disk modules are given in the insets in Figs 2 and 3. As was expected, the absorption maxima in the near IR spectral region lie at a wavelength of 808 nm, which is typical for yttrium aluminium garnets doped with trivalent neodymium. Comparing the transmission coefficients $T_{exp}$ of the ceramic samples in the transparency range (1000–1100 nm) with the calculated transmission coefficient $T_c$ of the optical material with the refractive index $n = 1.80$ (for the ideal homogeneous ceramics taking into account only Fresnel reflection losses), it is possible to estimate the absolute absorption and scattering losses $T_{loss} = T_c - T_{exp}$ (Table 1).

Figure 3 presents the measured laser powers of samples Nos 408, 414, and 418 of 1% Nd:YAG ceramics in a short cavity ($L = 12$ mm, $T_{out} = 3\%$, $r = -40$ mm) for a four-pass scheme, in which a retroreflector M2 (see Fig. 1) provides two additional passes. In the absence of retroreflector M2, 50% of the pump power is absorbed in the samples per two passes, while the fraction of the absorbed power in the four-pass scheme increases to 75%. Thus, the slope and optical lasing efficiencies normalised to the absorbed pump power for the best of the studied samples (No. 418) of 1% Nd:YAG ceramics are 25.5% and 18.1%, respectively (Table 1).

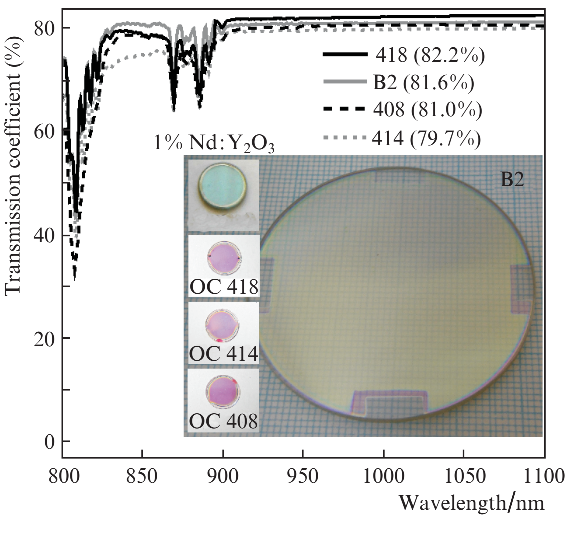


**Figure 2.** Transmission spectra of 1% Nd:YAG ceramics. The transmission coefficients of the samples $T_{exp}$ at a wavelength of 1064 nm are given in parentheses. The inset presents the photographs of the samples of 1% Nd:YAG and 1% Nd:$Y_2O_3$ ceramics [10].

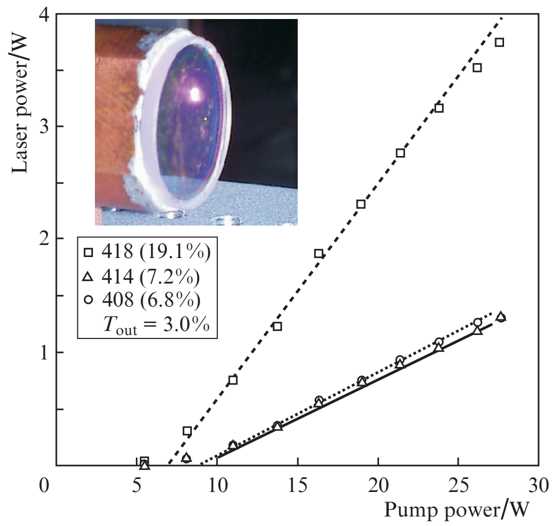


**Figure 3.** Dependences of the output power on the pump power for samples Nos 408, 414, and 418. Slope efficiencies are given in parentheses. The inset shows the photograph of one of the disk modules (sample No. 408).

**Table 1.** Lasing parameters of the samples of 1% Nd:YAG optical ceramics at the output mirror transmission coefficient $T_{out} = 3\%$.

| Sample No | Lasing threshold/W | $k$ (%) | $\eta$ (%) | $T_{loss}$ (%) |
|---|---|---|---|---|
| 408 | 8.7 | 4.9 | 6.8 | 2.1 |
| 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 | 1.5 |

Note: $k$ is the optical efficiency and $\eta$ is the slope efficiency.

The results of investigation of the lasing characteristics of sample B2 (∅47 × 2.1 mm) of 1% Nd:YAG ceramics are presented in Fig. 4 and in Table 1. In these experiments, the optical power of the pump unit was increased to 53 W (cw regime) due to the use of an additional diode array; in this case, the spot diameter in the focal plane was 0.95 mm. Comparing the slope efficiencies of lasing in the B2 ceramic sample at different transmittances of the output mirror (6.7% and 8.8% for $T_{out} = 3\%$ and 10%), we estimated the total losses in the laser cavity [13] to be 1.9%. Taking into account the losses at the mirrors and antireflection coatings (~0.5%), the intrinsic scattering and absorption losses for the sample B2 are ~ 1.4%, which almost coincides with $T_{loss} = 1.5\%$ determined from the transmission spectra. The losses in the B2 sample per unit length are $3.5 \times 10^{-2}$ cm$^{-1}$. The data in Table 1 show a reasonable qualitative relation between the lasing efficiency and estimated losses $T_{loss}$ in ceramic samples. For example, the best lasing efficiency corresponds to the highest optical transmission (sample No. 418). At the same time, for further increase in the lasing efficiency, the losses in ceramic samples must be considerably decreased, at least to a level of $10^{-3}$ cm$^{-1}$.

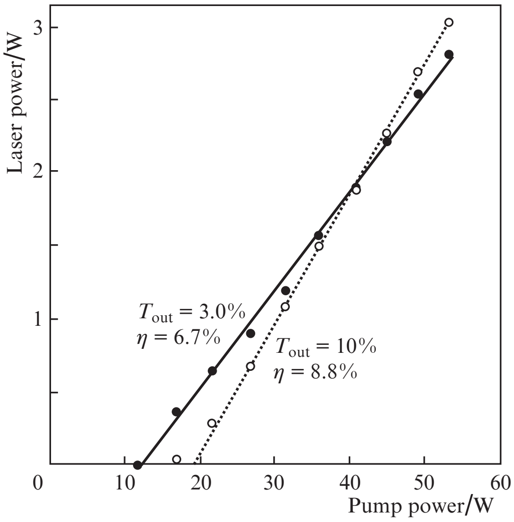


**Figure 4.** Dependences of the output power on the pump power for the large ceramic sample B2 (∅ 47 × 2.1 mm).

It should also be noted that the mechanical (strength) properties of all the studied samples of 1 % Nd : YAG ceramics, including the large sample B2, are quite satisfactory, because no one of the samples was broken at a pump power density of 6 kW cm$^{-2}$, and only in a few cases partial degradation of the metalised layer was observed.

## 4. Conclusions

The obtained results testify to a significant progress achieved to date in the improvement of the functional characteristics of laser ceramics developed in Russia. For example, the slope efficiency of 1 % Nd : YAG ceramics was demonstrated to be at a level of 25 %. The synthesis of a large-size (∅ 47 × 2.1 mm) Nd : YAG ceramic disk is also an important technological achievement. Nevertheless, further improvement of the optical homogeneity of laser ceramics in order to decrease the total losses remains a topical scientific-technical problem, which is of priority importance for development of new multikilowatt solid-state laser systems.

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