Optica Applicata, Vol. XIX, No. 3, 1989

Method for testing the uniformity of Nd:YAG laser rods

Z. Puzewicz, J. Czeszko, S. Kaczmarek, Z. Mierczyk

Institute of Quantum Electronics, Military Technical Academy, 00-908 Warszawa, Poland.

The method for testing the degree of homogeneity of Nd:YAG laser rods there is described. This method, consisting of measurement of the duration of giant pulse produced by a laser system with passive Q-switching and spatial intensity distribution across the generated laser beam, provides a useful measure of the degree of optical homogeneity of the laser rod and of its suitability for laser use.

1. Introduction

Suitability of Nd:YAG single crystals for laser use is determined by the following features:

– homogeneity of structural and optical properties, which can be affected by fluctuations in Nd^{3+} and other dopants,

– energetic stability of doping centres and of ions forming the crystal lattice,

– presence of centres, such as metallic inclusions, gas bubbles and other defects in crystal structure (dendrites, different crystal phases etc.), leading to dispersion of radiation,

– quality of a rod active surfaces.

Control of optical properties of Nd:YAG single crystals and their qualification for laser use are generally carried out by means of interferometric methods [1]–[3]. These are often complemented by thermoluminescence topography studies [4] and other optical methods [5], [6].

Quantitative measure of the quality of a laser rod is given by the so called optical quality defined as the number of interference fringes across the rod cross section per unit of length, measured in a Twymann–Green or Mach–Zehnder interferometer with zeroth background.

Interferometric studies of laser rods can be completed by polariscope studies and measurements of lasing properties [7], [8] (measurement of the loss coefficient ϱ of the active medium and of the gain coefficient $\varkappa$).

Previous studies on Nd:YAG laser rods have shown that, apart from non-homogeneities detected with interferometric methods, there can also exist non-homogeneities undetectable by optical methods in routine use.

Nd:YAG laser rods for use in lasers with passive Q-switching should be characterized by a high optical homogeneity, since non-uniform illumination of the nonlinear absorber in the switch has a significant effect on the propagation of radiation emitted by the laser and on the lifetime of the absorber material.

The described method for testing the degree of homogeneity of Nd:YAG laser rods, consisting of the measurement of the duration of giant pulse produced by a laser system with passive Q-switching and spatial intensity distribution across the generated laser beam, provides a useful measure of the degree of optical homogeneity of the laser rod and of its suitability for the laser use.

2. Theory

Operation og giant pulsed Nd:YAG laser was approximated by a model with instantaneous loss switching [9] combined with an account for interference and multiple reflection effects in the resonator cavity [10].

It is assumed that an optically nonhomogeneous rod can be approximated by means of N channels along the laser axis, with varying ϱ and $\varkappa = \sigma n_0$, where ϱ is the loss coefficient of the active medium, $\varkappa$ is the gain ratio, σ is the active cross-section for generation and n_0 is the concentration of active ions (Fig. 1).

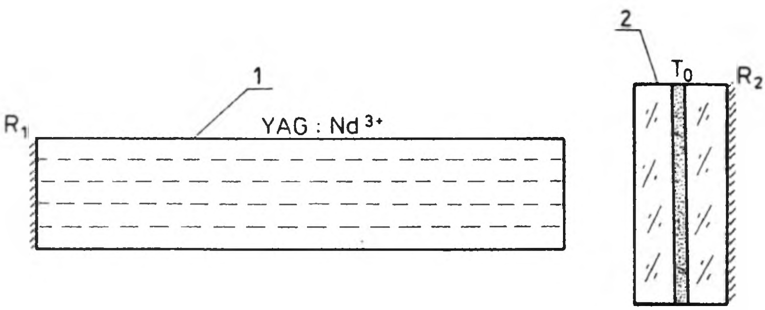


Fig. 1. Diagram of experimental apparatus: 1 – laser rod under test, 2 – passive Q-switch (R_1, R_2 – mirrors)

Generation of a giant pulse in channel i will be strated as soon as the pumping pulse produces a degree of population inversion given by [9]

$$y_{0(i)} = \frac{1}{\varkappa_{(i)}}(\varrho_{(i)} + k_r + k_a^0) \tag{1}$$

where: k_r – coefficient of transmission losses in the resonator per unit length of an active element,

k_a^0 – coefficient of initial absorption by the absorber per unit length of an active element.

The shape of giant pulse generated in channel i, in the time dependence of radiation power density, is described by the Gauss profile (Fig. 2)

$$\varphi^{(i)}(t) = \varphi_{\max}^{(i)} \exp\left\{-\left[\frac{(t-t_{m(i)})}{\alpha_{(i)}}\right]^2\right\}. \tag{2}$$

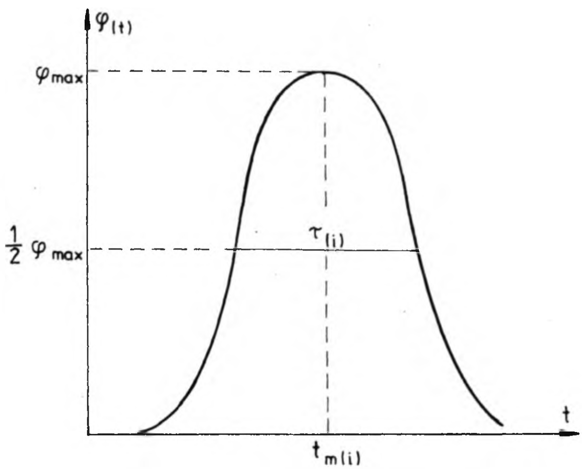


Fig. 2. Plot of $\varphi(t)$ dependence

$\varphi(t)$ reaches the maximum at time $t_{m(i)}$ determined by the parameters of the resonator [9]

$$t_{m(i)} = \frac{\ln\left(\frac{\varphi_{\max}^{(i)}}{\varphi_0^{(i)}}\right)}{v_{(i)}\mu_{(i)}(k_{0(i)}-k_{s(i)}^{k})} + \frac{(k_{0(i)}-k_{s(i)}^{k})\, n_{0(i)}\, h\nu}{4k_{s(i)}^{k}\,\varphi_{\max}^{(i)}\,\varkappa_{(i)}\, v_{(i)}} \tag{3}$$

where: $v_{(i)}$ – velocity of radiation propagation in the active medium,
$\mu_{(i)}$ – resonator filling coefficient, characterizing the structure of a resonator,

$$k_{0(i)} = \varkappa_{(i)}\, y_{0(i)} \tag{4}$$

$k_{s(i)}^{k}$ – saturated loss coefficient of the resonator, per unit lenght of an active element,
$\varphi_{0(i)}$ – power density of spontaneous emission in channel i at threshold of generation,
$h\nu$ – quantum energy of generated radiation.

Halftime of giant pulse generated in channel i $\tau_{(i)} = 2\sqrt{\ln 2}\,\alpha_{(i)}$ is given by [11]

$$\tau_{(i)} = \frac{\sqrt{\ln 2}}{\sqrt{\Pi}\, v_{(i)}\mu_{(i)}\, k_{s(i)}^{k}} \frac{k_{0(i)}-\mathrm{k}_{\min(i)}}{\left(k_{0(i)}-k_{s(i)}^{k}-k_{s(i)}^{k}\ln\frac{k_{0(i)}}{k_{s(i)}^{k}}\right)} \tag{5}$$

where: $k_{0(i)}-\mathrm{k}_{\min(i)} = k_{s(i)}^{k}\ln\frac{k_{0(i)}}{k_{\min(i)}}$, (6)

$k_{\min(i)}$ – minimum gain ratio.

Duration of the pulse, resulting from generation in all channels (Fig. 3) is

$$\tau = (t_{m(i)}^{(\max)} - t_{m(j)}^{(\min)}) + \tfrac{1}{2}\tau_{(i)}(t_{m(i)}^{(\max)}) + \tfrac{1}{2}\tau_{(j)}(t_{m(j)}^{(\min)}). \tag{7}$$

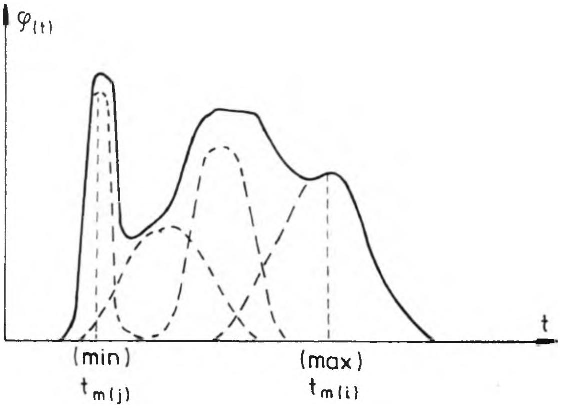


Fig. 3. Plot of time dependence of radiation power density $\varphi(t)$ of output of giant pulse laser with nonhomogeneous rod

where: $t_{m(i)}^{(\max)}$ – time at which the last maximum occurred in the radiation intensity,

$t_{m(j)}^{(\min)}$ – time at which the first maximum occurred in the radiation intensity.

The level of optical nonhomogeneity in a laser rod can be described by the nonhomogeneity factor $\eta = \tau/\tau_t$, defined as ratio of τ (the experimental duration of the giant pulse as determined in a laser configuration with passive Q-switching) to τ_t (the calculated duration of the giant pulse for this configuration), obtained from Eq. (5), is

$$\tau_t = \frac{1}{v\mu}\,\frac{(k_0 - k_{\min})}{k_s^k\left(k_0 - k_s^k - k_s^k \ln\frac{k_0}{k_s^k}\right)}. \tag{8}$$

3. Experimental results

Measurements of pulse duration and shape of giant pulses were carried out in a laser arrangement with passive Q-switching. Diagram of experimental apparatus is given in Fig. 4. A linear xenon lamp of LBL 5/50 type is placed together with the investigated laser rod, within an elliptical Au reflector. The following key laser generation parameters were measured: pulse duration, pulse output energy E_{out} and threshold energy for pulse generation E_t.

Over 300 Nd:YAG rods were subjected to tests. Tables 1–3 shows the results of measurements of optical and laser properties of six Nd:YAG rods of the cross-section of 4×55 mm. Optical parameters were determined at a wavelength of 632.8 nm (He-Ne laser line) in a Mach–Zehnder interferometer and in a polarimeter with crossed calcite polarizers. The measurement of giant pulse duration and relative measurements of the remaining generation parameters (output energy E_{out} of the pulse and threshold energy E_t for pulse generation) were carried out in a laser arrangement with passive Q-switching of a laser operating on the Nd:YAG rod

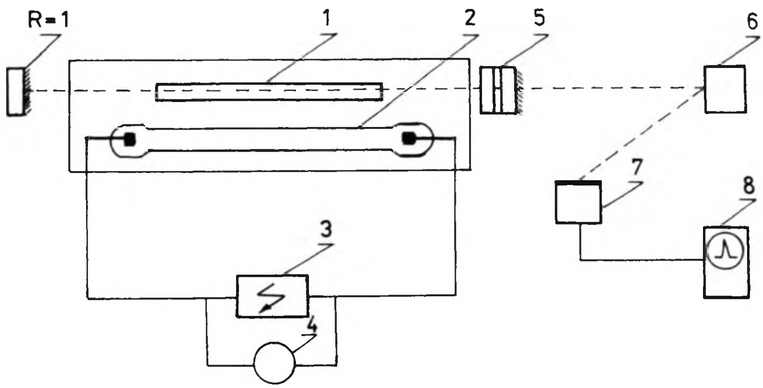


Fig. 4. Schematic diagram of experimental arrangement for measurement of key generation parameters of Nd:YAG rods: 1 – laser rod under test, 2 – LBL 5/42 xenon lamp, 3 – laser power supply, 4 – digital voltmeter, 5 – passive dye foil Q-switch type with output mirror R_2, 6 – ED–500 pyroelectric detector with energy meter, 7 – photodiode, 8 – TEKTRONIX 7633 oscilloscope

under test (resonator parameters: initial transmission of the absorber $T_0 = 0.52$, reflection coefficient of the output mirror $R_2 = 0.57$, filling coefficient $\mu = 0.45$).

Optical nonhomogeneities in the studied rods are manifested not only in the duration of the giant pulse but also in spatial intensity distribution across the generated laser beam. The tables present the results of measurements of intensity distribution across the beam carried out with a linear pyroelectric detector array type AK–2900 produced by Laser Precision Corp.

These results confirm the qualitative model presented above which assumed the existence of channels of varying ϱ and $\varkappa$ in optically nonuniform laser rod. In rods, in which pulse duration is lengthened, one observed also nonuniform distribution of beam intensity which visualizes the distribution of generation channels.

Giant pulse duration calculated from Eq. (8) and with the parameters of the resonator used in the tests ($T_0 = 0.52$, $R_2 = 0.57$, $\mu = 0.45$) is 7 ± 1 ns for $\varrho \in (0, 0.1)$ cm^{-1} and, for an optically uniform laser rod, depends mainly on the structure of the resonator.

Based on the operational tests of Nd:YAG rods, it has been determined that rods, characterized by giant duration longer than the pulse duration not more than by a factor of two, calculated for the experimental arrangement (nonhomogeneity factor $\eta < 2$), fulfill the criteria required for the operation in a giant pulse laser (duration and shape of the pulse, output energy, intensity distribution in the beam).

The method for testing the optical homogeneity of Nd:YAG laser rods developed here gives useful information, concerning various properties of the rods, being of relevance for the use in giant pulse lasers. Experimental results in tables show that the method is highly sensitive and that nonhomogeneous rods are characterized by nonhomogeneity factor $\eta \gg 2$.

Table 1. Results of measurements of optical and laser properties of Nd:YAG rods of $\varnothing$ 1 × 55 mm size

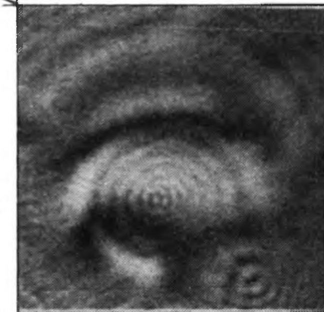
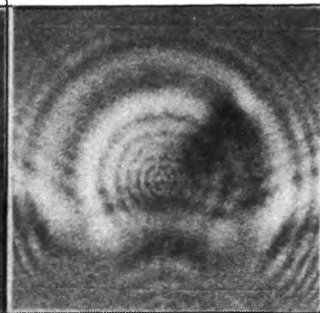
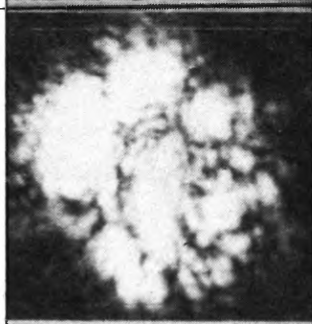
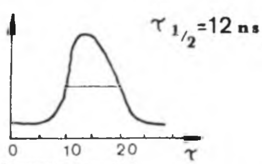
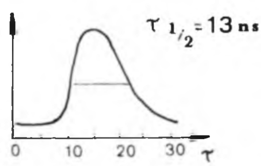
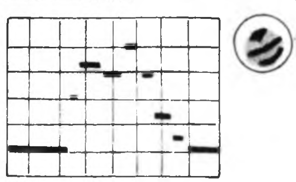
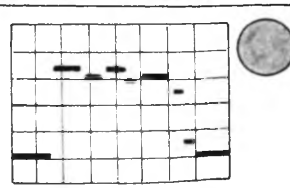
RODS NUMBER / PARAMETERS	861290455	861291455
INTERFERENCE FIGURE (MACH-ZEHNDER INTERFEROMETER)		
POLARISCOPE FIGURE		
OUTPUT ENERGY E_{out} [mJ]	5.0	10.6
THRESHOLD ENERGY E_t [J]	29.3	14.0
OSCILLOGRAM OF THE GENERATION PULSE		
SPATIAL INTENSITY DISTRIBUTION ACROSS THE GENERATED LASER BEAM		

Table 2. Results of measurements of optical and laser properties of Nd:YAG rods of $\varnothing 4 \times 55$ mm size

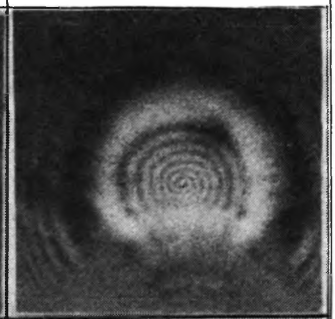
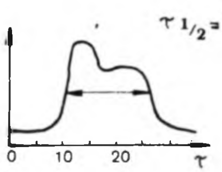
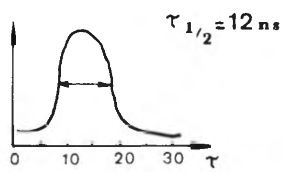
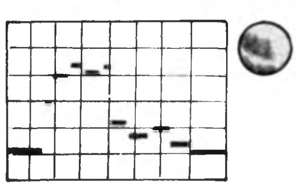
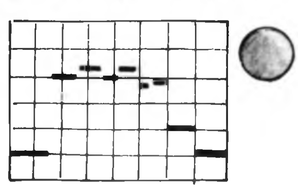
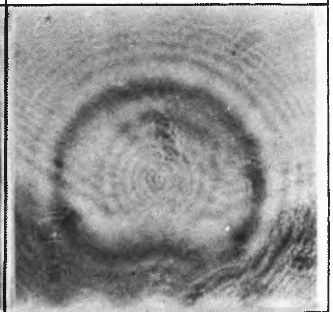
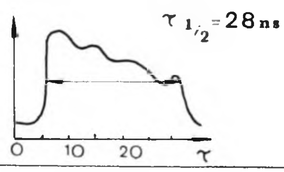
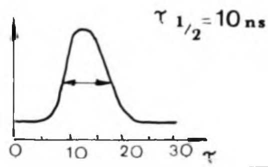
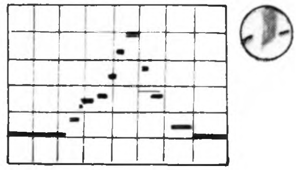
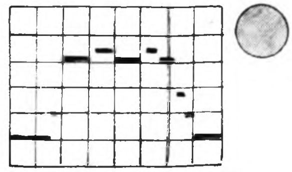
RODS NUMBER / PARAMETERS	86431455	58/2
INTERFERENCE FIGURE (MACH–ZEHNDER INTERFEROMETER)		
POLARISCOPE FIGURE		
OUTPUT ENERGY E_{out} [mJ]	9.6	9.0
THRESHOLD ENERGY E_t [J]	16.5	18.0
OSCILLOGRAM OF THE GENERATION PULSE		
SPATIAL INTENSITY DISTRIBUTION ACROSS THE GENERATED LASER BEAM		

Table 3. Results of measurements of optical and laser properties of Nd:YAG rods of $\varnothing 4 \times 55$ mm size

RODS NUMBER / PARAMETERS	11/87	60/2
INTERFERENCE FIGURE (MACH-ZEHNDER INTERFEROMETER)		
POLARISCOPE FIGURE		
OUTPUT ENERGY E_{out} [mJ]	11.0	10.5
THRESHOLD ENERGY E_t [J]	18.0	15.1
OSCILLOGRAM OF THE GENERATION PULSE		
SPATIAL INTENSITY DISTRIBUTION ACROSS THE GENERATED LASER BEAM		

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Received November 30, 1988,
in revised form April 4, 1989

Методика оценки неоднородности лазерных стержней Nd:YAG

В настоящей работе представлена методика оценки неоднородности лазерных стержней ND:YAG, заключающаяся в измерении времени продолжения и формы моноимпульса в системе лазера с модуляцией добротьї резонатора с исследуемым лазерным стержнем. Выведены теоретические зависимости на базе модели моноимпульсного лазера Nd:YAG с мгновенным переключением потерь резонатора, с учетом интерференционных эффектов и многократных отражений излучения в резонаторе. Экспериментальные результаты измерения неоднородности лазерных стрежней Nd:YAG, полученные по предложенному методу, сравнены с результатами применяемых до сих пор методов оценки качества.