Quantum Electronics **41** (11) 1037 – 1039 (2011)

PACS numbers: 42.55.Rz; 42.55.Xi; 42.60.By; 42.60.Lh
DOI: 10.1070/QE2011v041n11ABEH014687

Power neodymium-glass amplifier of a repetitively pulsed laser

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Abstract. **A neodymium-glass diode-pumped amplifier with a zigzag laser beam propagation through the active medium was elaborated; the amplifier is intended for operation in a repetitively pulsed laser. An amplifier unit with an aperture of 20 × 25 mm and a ~40-cm long active medium was put to a test. The energy of pump radiation amounts to 140 J at a wavelength of 806 nm for a pump duration of 550 μs. The energy parameters of the amplifier were experimentally determined: the small-signal gain per pass ~3.2, the linear gain ~0.031 cm^{-1} with a nonuniformity of its distribution over the aperture within 15%, the stored energy of 0.16 – 0.21 J cm^{-3}. The wavefront distortions in the zigzag laser-beam propagation through the active element of the amplifier did not exceed 0.4λ (λ = 0.63 μm is the probing radiation wavelength).**

Keywords: *neodymium laser, phosphate glass, laser diode pumping, zigzag laser-beam propagation, linear gain coefficient, stored energy, optical quality of active elements.*

1. Introduction

The considerable progress achieved in solid-state laser physics in recent years is due to the development and investigation of a new generation of lasers – solid-state lasers optically pumped by laser diodes [1 – 8].

The advantages of diode pumping over flashlamp pumping – a narrow emission band in the energy-advantageous absorption band of the active medium and a high (up to 50%) electric-to-light energy conversion efficiency – enable a substantial improvement in laser efficiency and lighten the thermal load upon solid-state active media, which of special significance in the making of repetitively pulsed lasers.

The advancement in this area is moderated primarily by the high cost of diode pump as well as by its low energy parameters. However, the substantial recent progress in the production technology of diode lasers with integrated multi-element one- and two-dimensional array structures has brought the diode pump close in power characteristics to the conventional flashlamp pump. This technological advance permits considering the feasibility of making high-power repetitively pulsed solid-state lasers in the nanosecond duration range with an output energy of ~100 J, and with ~1 kJ in view, for a pulse repetition rate of the order of tens of Hertz [2, 4, 5].

In the present work we outline the results of investigation of the parameters of a laser-diode-pumped neodymium-glass amplifier intended for operation in a repetitively pulsed laser with a pulse repetition rate of several Hertz.

2. Amplifier design

For the active medium of the amplifier we selected neodymium-doped KGSS-0180 phosphate glass [9]. The neodymium ion density was equal to 1.4 × 10^{20} cm^{-3}. The virtue of this medium consists in that it possesses a suitable amplification cross section, which permits storing a large amount of energy in high-power amplifiers. Also quite acceptable is the lifetime of the upper state of the laser transition. Our measurements suggest that it is equal to ~370 μs for the glass selected. Manufacturing the active elements of sufficiently large size creates no difficulties, either.

The main disadvantage typical of glass-based active media is their low thermal conductivity. In a repetitively pulsed regime this gives rise to thermooptical distortions, which impair the directivity of the radiation being amplified. To eliminate this effect, the amplifier design developed in our work makes use of a zigzag propagation of laser radiation through the active medium involving reflections from side walls [2, 4].

The active element of the amplifier is a rectangle in its cross section measuring 25 × 32 mm; the element is 370 mm in length. The 32-mm wide side faces are polished. The element is pumped through these faces, which realise the zigzag propagation of the laser beam under the condition of total internal reflection. The working aperture of the amplifier measures 20 × 25 mm, the pumped part is 35 cm long. Figure 1 shows the lateral section of the amplifier. The medium is pumped by SLM-7-4 laser diode assemblies [Inzhekt Research and Production Association (NPO Inzhekt), Saratov] combined in four blocks. The pump radiation wavelength is equal to 806 nm, the total energy amounts to 140 J for a pulse length of up to 550 μs. The amplifier cooling is effected by two independent water circuits: the circuit for cooling the active element and the circuit for cooling the pump system. To compensate for the optical distortions in the direction perpendicular to the plane of the light beam zigzag, thermal compensators (the heater in Fig. 1) were introduced into the design, which fulfilled the function of weakening the thermooptical distortion gradients in this direction.

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Received 29 June 2011
Kvantovaya Elektronika **41** (11) 1037 – 1039 (2011)
Translated by E.N. Ragozin

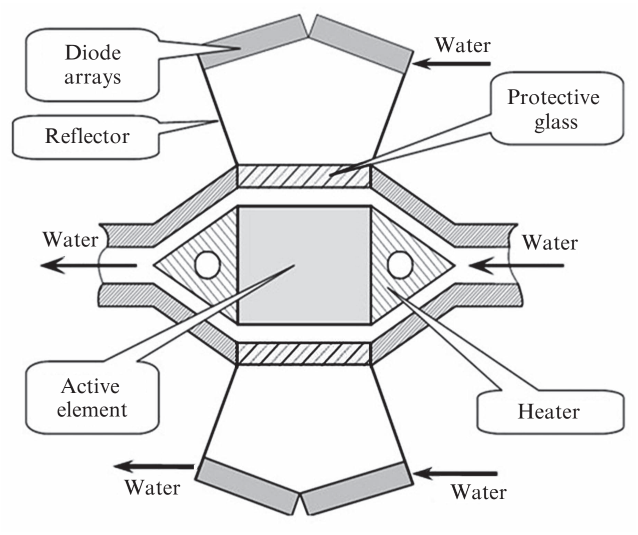

Figure 1. Transverse section of the amplifier

3. Optical quality of the active element

The key point in the design of an amplifier with a zigzag laser beam propagation through the volume of the active medium is the finish accuracy of the side surfaces of the element, which realise the zigzag regime – multiple (4–8 times) reflections of the laser beam propagating through the active medium of the amplifier.

The active element has 'disadvantageous' overall dimensions, i.e. the ratio between the length and the transverse section. The technology of processing such elements was developed at the Lytkarino Optical Glass Factory, JSC (LZOS, JSC). To date, a quality level has been reached whereby the wavefront of the laser beam travelling through a 'cold' active element is distorted by no more than 0.4λ ($\lambda = 0.63$ μm is the wavelength of the probe radiation). The results of finish quality testing performed with an interferometric technique are outlined in Fig. 2.

4. Energy characteristics of the laser amplifier

The energy characteristics of the amplifier were determined by measuring the small-signal gain. In the first series of experiments we recorded the gain in the central part of the working aperture as a function of the pump duration; in the second series we measured the gain distribution over the working aperture. In both cases use was made of the classical method of probing the active medium (the optical arrangement is given in Fig. 3).

The amplifier was probed by the radiation of an YLF crystal oscillator, which produced single 30-ns long laser pulses at a wavelength of 1.053 μm with an energy density of $\sim$0.05 J cm^{-2}. A two-pass scheme was used for the probing. In preliminary experiments we recorded the path transmittance without pumping the amplifier, which was subsequently taken into account. The active medium of the amplifier was pumped by a light pulse of constant power. The overall pump energy was varied by varying its duration; for a pump duration of 550 μs it amounted to 140 J.

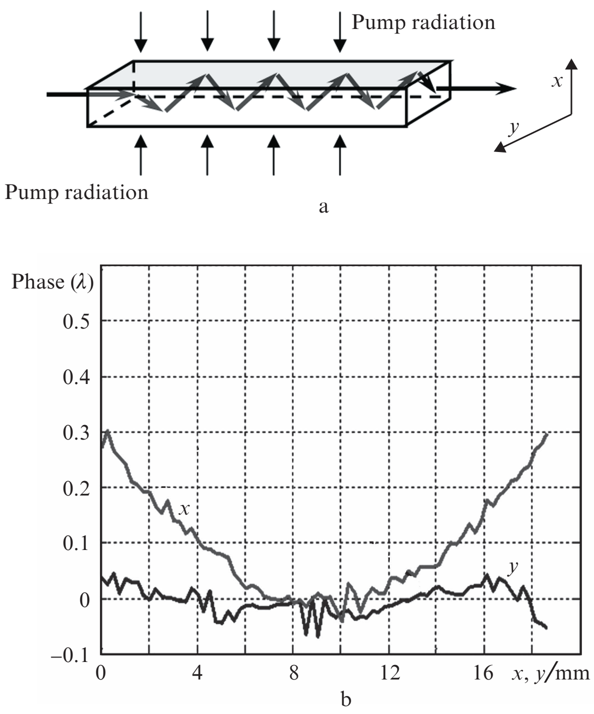

Figure 2. Diagram of laser beam propagation through the active element (a) and phase distortions of the probing laser beam at a wavelength $\lambda = 0.63$ μm (b) (the measurement accuracy is 0.02λ).

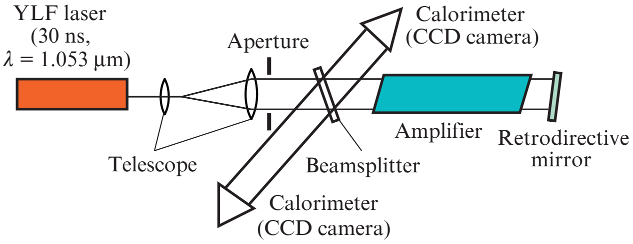

Figure 3. Optical arrangement for measuring the gain. Use was made of a circular aperture 5 mm in diameter or a square 20 × 20 mm aperture.

Figure 4 shows the measured single-pass gain K as a function of pump duration. Also shown here is the corresponding analytical curve for the gain of the active medium for an invariable pump power and a finite relaxation time of the upper laser level:

$$K \sim W\tau(1 - \exp[-t/\tau]),$$

where t is the pump duration; τ is the relaxation time (370 μs); and W is the pump power.

The stored energy distribution over the amplifier aperture was measured using the same optical arrangement as in Fig. 3, with the following changes introduced into the arrangement: the calorimeters were replaced with CCD cameras and the measurements were performed within a larger aperture of 20 × 20 mm. The experiments were carried out for a pump duration of 300 μs. The limiting pump duration was equal to 550 μs and was limited by the parameters of the laser diodes in use. For this pump duration, the stored energy was calculated by extrapolating the experimental data with the aid of the dependence depicted in Fig. 4. The data are given in Figs 5 and 6; they show the distributions of the linear gain coefficient, which is proportional to the stored energy. Figure 5

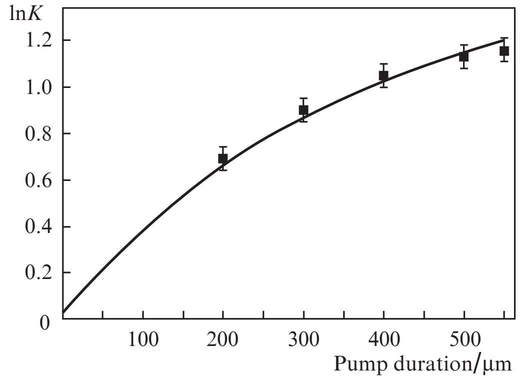

Figure 4. Single-pass gain K of the amplifier for different pump durations; the points represent experimental data and the curve shows the analytical dependence.

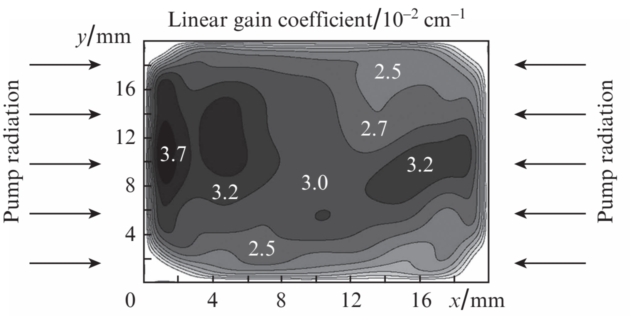

Figure 5. Distribution of the linear gain over the aperture of the amplifier.

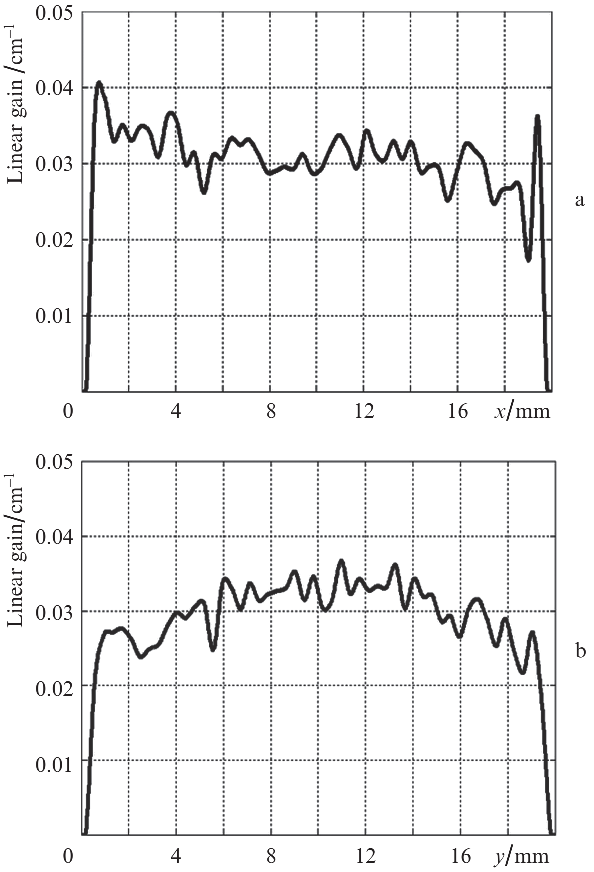

Figure 6. Distributions of the linear gain in the central mutually perpendicular sections of the amplifier aperture: over the x coordinate (a) and over the y coordinate (b).

depicts the two-dimensional distribution of the linear gain coefficient in the form of lines of equal gain coefficient using five-value gradations; Fig. 6 serves to illustrate linear gain coefficient distributions in the central horizontal and vertical sections of the aperture.

Therefore, we presented the results of investigation of a diode-pumped neodymium-glass laser amplifier carried out in a single-pulse regime. The highest measured small-signal gain was equal to ~3.2 and the linear gain was about 0.031 cm^{-1}. The nonuniformity of the linear gain coefficient distribution over the aperture was within 15%.

According to our estimates, for an amplification cross section of $(3.2 \pm 0.4) \times 10^{-20}$ cm^2 [7] the stored energy density is equal to 0.16–0.21 J cm^{-3}.

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