Q-switched mode in laser ceramics with Cr4+ for technological surface cleaning

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Abstract. A compact solid-state laser based on a Nd:YAG (1 at. %) ceramic active media in the Q-switched mode was studied. Ceramic YAG elements with different concentrations (0.1 to 1 at.%) of Cr⁴⁺ doping were used as a Q-switches, 50 to 500 ns pulses were registered with the high energy single pulse. Transparent ceramic obtained by thermosetting sintering. A laser scheme is proposed with a pulse duration and energy setting that contains a composite element for combining the properties of the studied samples of transparent ceramics in one volume. This scheme allows you to implement a compact laser to clean the surface of various materials (glass, concrete, plastic, steel, etc.) from contamination.

1. Introduction

Transparent ceramics (polycrystals) with a garnet structure doped with rare-earth elements (Re), and especially ceramics Y₃Al₅O₁₂ (YAG) and Lu₃Al₅O₁₂ (LuAG), are increasingly used in extreme-intensity laser technology for ultra-high power optical physics fields. Yttrium aluminum garnet is characterized by cubic syngony, which makes it possible to obtain transparent ceramics. Active laser media based on transparent ceramics have several advantages compared to single-crystal analogues, such as high mechanical strength, higher (compared to single crystals) permissible concentration with doping impurities Re, and an increased threshold for optical destruction. So, the efficiency of lasers based on this ceramics was about 70 % upon side-pumping [1]. Despite these advantages, there are additional methods and approaches to improving the properties of active laser media, in particular, obtaining a predetermined three-dimensional spatial distribution of the dopant in the ceramic volume. This will make it possible to implement coordination mechanisms for the spatial distribution of pump radiation and generated radiation, to reduce the losses of pump radiation, and to increase the uniformity of absorption of pump radiation in the volume of the active medium. When absorbing radiation, solid-state active laser media in the nodes of emitters and amplifiers are subjected to strong thermomechanical stresses due to inhomogeneous spatial temperature distribution, which leads to additional radiation energy losses caused by thermo-optical distortions, thermal population of the lower level of the laser transition, etc. Reduce the degree of influence inhomogeneous temperature distribution can be, in particular, the choice of material of the active medium. The novelty of our approach is the equalization of the volume density of the pump radiation power inside the active
medium due to the formation of an internal gradient structure that ensures the most efficient conversion of pump radiation.

Absorbers of spurious radiation (in the case of doping with Cr$^{3+}$ or Sm$^{3+}$) and as saturable absorbers for the implementation of the Q-switching mode (in the case of doping with Cr$^{4+}$) have also been developed on the basis of YAG ceramic elements. The YAG matrix allows you to realize the concentration of Cr$^{4+}$ in a wide range from 0.1 to 10 at.%, this allows you to control the duration of the laser pulses.

2. Methods

The technique for studying the generation characteristics was carried out in a transverse pumped laser diode circuit. The used transverse diode pumping circuit is shown in (Fig. 1). The laser cavity was formed by two mirrors 1 (HR) and 6 (AR). Flat mirror 1 was deaf (R = 99.96%) at a generation wavelength of 1064 nm. Flat mirror 6 had a reflection coefficient of 70% at the generation wavelength. The ends of the active element 3 were enlightened at a generation wavelength of 1064 nm and a pump wavelength of 806 nm. The pumping was carried out by arrays of diode lasers 4 (LD) with an output pulse energy of about 300 mJ and a radiation wavelength of 806 nm. A pulsed periodic pump mode was used. The spatial distribution of the intensity of the output radiation (including that scattered from the screen 7) and the generation threshold were recorded from the optical signal receiver (POS-1) of 5 recorded radiation wavelengths of 350 - 1100 nm.

![Fig. 1. Schematic diagram of the experiment with transverse diode pumping. 1 - mirror (HR), 2 - element Cr:YAG 3 - active element (Nd:YAG), 4 - matrix of laser diodes, 5 - optical signal receiver, 6 – mirror (AR, 70%), 7 - reference surface (screen).](image)

3. Results and Discussion

In the experiment, an active element (4x5x40 mm) is fabricated of Nd:YAG ceramics (1 at. % Nd) was used as a source of free-generation laser radiation with pulse duration of 425 ms, repetition rate of 1 Hz. Fabry-Perrot resonator with 70% feedback mirror was used to obtain maximum pulse energy about 480 mJ. Further, disk elements are fabricated of 0.1 and at. 1% chromium doped YAG ceramics were installed as a passive q-switcher. The thickness of the both elements was 2 mm.

In the case of 1% Cr:YAG, the free generation pulse was filled with a sequence of short pulses with a duration of about 50 ns FWHM with repetition rate about 40 kHz (Fig.2). In another case (at. 0.1%
chromium doping), the pulse duration was 500 ns FWHM at a frequency of 50 kHz. The optical transmission spectra are shown in (Fig.3).

Fig. 2. Temporal characteristic of q-switched laser radiation for 1% Cr:YAG.

Fig. 3. Optical transmission spectra for 0.1 and 1% Cr:YAG.

The results of the experiment are consistent with the results obtained in the paper [2] for end pumping of a composite ceramic active element.
One of the ways to increase the efficiency of a Q-switched emitter is to switch from one type of Nd³⁺ activator (rare-earth element) to another, the most effective is ytterbium Yb³⁺ (whose differential efficiency can reach 96%, in contrast to 72% for neodymium). However, in order to eliminate the negative effect of changes in the temperature of the active medium, it is necessary to correctly select the crystalline matrix based on its thermophysical properties, which was done in the second part of the work.

To evaluate thermal distortions in active media based on transparent ceramics, the thermal properties of ceramics based on solid solutions, lutetium-yttrium-aluminum garnets doped with ytterbium were studied. The use of matrices of these garnets as laser media was proposed by Kuwano et al [3]. A feature of LuYAG matrices as an active laser medium is the possibility of expanding the spectrum and/or spectral shift of the absorption band. In addition, as in the case of pure LuAG, high values of the thermal conductivity coefficient (k) are expected for LuYAG at high dopant concentrations.

The temperature dependence of the thermal conductivity of the Yb: LuYAG solid solution shown in (Fig. 4) demonstrates a lower value of thermal conductivity compared to Yb: YAG and Yb: LuAG samples. A decrease (about 30%) in the thermal conductivity of Yb: LuYAG compared to Yb: YAG is consistent with the results of studies carried out in [3] on undoped crystals.

![Graph showing thermal conductivity of YAG, LuYAG, and LuAG](image)

**Fig. 4.** The temperature dependence of thermal conductivity for various ceramic matrix.

From experimental data it follows that from the point of view of increasing thermal conductivity in active laser elements, the LuAG matrix is the most advantageous, in which a significant change in the concentration of Re changes the thermal conductivity coefficient only slightly. From the data obtained it also follows that the use of a LuYAG matrix for laser applications is advisable only with a Lu / Y ratio above 85/15.
4. Conclusions
The results of the experiment demonstrate that the chromium concentration increasing decreases pulse duration and radiation intensity. It is consistent with measurement and modeling of monocrystalline passive switcher [4]. However, ceramic elements ensure effective control of laser pulse duration by choosing dope concentration of saturable absorber with step 0.01 at. %.

The use of a composite element with a saturable absorber, the concentration of which varies from 0.05 at.% To 1 at.% By volume in the direction perpendicular to the axis of laser radiation, will allow the laser pulse to be tuned from 50 to 500 ns, the frequency and their energy. Such a laser emitter will allow you to choose the optimal surface cleaning modes, depending on the surface materials and contamination.

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