Vol. 93 (1998) *ACTA PHYSICA POLONICA A* No. 4

INFLUENCE OF THE γ-RADIATION ON THE GENERATION CHARACTERISTICS OF THE $YAlO_3$:Nd CRYSTALS

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(Received October 14, 1997; in final form December 18, 1997)

The results of investigation of the influence of γ-radiation by ^{60}Co-source on the $YAlO_3$:Nd laser generation characteristics are presented in this paper. The significant decrease in the output energy after γ-irradiation was obtained. The energetic characteristics are restored after illumination of the γ-irradiated laser rods by 1000–10000 pulses of the pumping lamp light. The additional absorption spectrum is induced by γ-irradiation in the crystals. The nature of the created in this way colour centres is discussed. The mechanism of influence of the colour centres on generation properties of the crystals is discussed.

PACS numbers: 42.70.Hj, 61.72.Ji

1. Introduction

The yttrium-aluminium perovskite single crystals $YAlO_3$ (YAP), doped with rare-earth ions, are the most widespread materials for creation of the solid-state laser active elements. The colour centres (CC) created during the growth procedure, post-growth thermal treatment, or under influence of ionizing radiation (IR), including the ultraviolet part of the pumping lamp radiation, influence the performance of the YAP crystals in laser systems. For example, the CC arising during growth process in the gas atmosphere can completely suppress laser generation in

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active elements. The reduction of the crystal laser generation characteristics can be achieved by post-growth annealing of the crystals in the reducing atmosphere or in vacuum [1–3].

The investigations of the influence of the ionizing radiation on the physical and chemical properties of yttrium-aluminium garnet (YAG) crystals, very similar to the properties of the YAP crystals, were carried out very widely in the past. More than 100 articles, many reviews and monographs [4–8] is devoted to the problem of the radiation stability of the YAG crystals. Influence of the ionizing radiation on the YAG-Nd laser generation properties is investigated in detail in Refs. [9–12]. On the other hand, studies of the influence of the ionizing radiation on the optical properties of the YAP-Nd crystals remain limited [4, 13–16].

In addition, the recent reports [9, 12] on the possibility of improvement of the YAG laser elements generation characteristics after irradiation, define the special interest in studying of the IR effect on laser crystal properties. The authors of Ref. [12] found out the so-called "effect of small doses" in the irradiation of the YAG:Nd by γ-quanta (absorbed dose 10 Gy) and electrons (fluence 10^{10} cm^{-2}), which cause an increase in the laser output energy by 5–12%. It is supposed that "healing" of loosely bounded structural distortions or defect complexes, generated during the crystal growth, occurs during the irradiation.

It has been established [9] that the output energy of the YAG:Er laser (wavelength of generation — 2.94 μm) increases almost twice after irradiation of active elements by a dose of 10^5 Gy. Therefore, we can expect the improvement of the lasing characteristics after irradiation also in other laser crystals.

The results of investigation of the γ radiation influence on the YAP-Nd crystals generation properties are presented in this paper.

2. Experiment

The YAP-Nd crystals were grown in b direction by the Czochralski method in iridium crucibles in the atmosphere of 98% Ar and 2% O. The Nd content in the crystal did not exceed 1 at.% (in relation of number of the Y^{3+} ions). After growth the crystals were annealed in the vacuum at the temperature 1400–1600°C during 15–20 hours.

Plane-parallel polished samples, cut perpendicular to the b direction, with the thickness of 0.5–2 mm were used for investigation of the optical properties. For studying of the laser generation characteristics, rods with diameter of 8 mm and length of 100 mm were made from the crystal parts which did not contain twins, strains and knots. The antireflection coating ($R = 0.3\%$) was put on the end faces of the rods.

Generation characteristics of laser elements were measured in a resonator with the length of 260 mm with one cavity end mirror and target mirror with the reflection coefficient of 45%. The active element was placed in the laser head KNIM 8/100, which was made of KLG quartz, for cutting off a short-wave part of the pumping radiation. The optical pumping was executed by the KNP 5/90 lamp. The lamp was powered by a BPL 66/33 block with a bank of 100 μF capacitors. The pulse duration was 90 μs. The laser output energy was measured with the IMO-2 calorimeter.

Irradiation of the crystals was conducted by γ-quanta with power of the exposition dose 170 R/s with the range of absorbed doses 10^2–10^5 Gy.

Transmission spectra of the crystals were measured in spectral range 52000–12000 cm^{-1} by means of the spectrophotometer SPECORD M40. The value of additional absorption (AA) ΔK induced by γ-quanta was determined as

$$\Delta K = (1/d)\ln(T_1/T_2),$$

where d — sample thickness, T_1, T_2 — samples' transmission before and after irradiation, respectively.

3. Results and discussion

The irradiation of YAP-Nd by γ-quanta results in additional absorption, the spectrum of which represents a wide complex band in the range of 48000–12000 cm^{-1}, with maxima at, approximately, 43500 cm^{-1}, 39500 cm^{-1}, 33000 cm^{-1}, 24000 cm^{-1}, and 19000 cm^{-1} (Fig. 1), which overlaps with the pumping lamp radiation spectrum (see, for example, [17]).

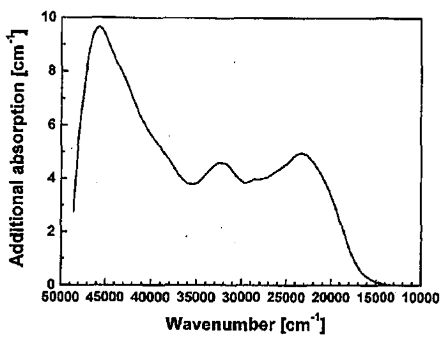

Fig. 1. Additional absorption spectra of the $YAlO_3$:Nd crystal irradiated by γ-quanta with absorption dose of 10^5 Gy.

The colour centres induced by γ-irradiation have probably ionization nature. They originate from changes of a charge state of the growth point defects present in the crystal. The charge carriers, generated by the radiation are trapped by the CC. The oxygen vacancies, the Y^{3+} ions in the crystallographic positions of the Al ions, as well as other uncontrollable impurities (first of all the Fe and Cr ions [2, 3, 15]) can constitute such growth defects.

Dependence of the laser efficiency η on pumping energy E_p for non-irradiated rod is shown in Fig. 2. Maximum η value (3.6%) is reached at pumping energy of 25–30 J.

The active element was placed in the same resonator after each dose of γ-quanta (10^2, 5×10^2, 10^3, 5×10^3, 10^4, 5×10^4 Gy) and the η value dependencies were measured as a function of number of pumping lamp flashes N. The measurements were conducted at the pumping energy of 11.8 J, which corresponds to the value of $\eta_i = 2.3\%$ (see Fig. 2). The efficiency decrease dependent on the absorbed dose of γ-radiation was observed after γ-irradiation. For the dose of 10^2 Gy

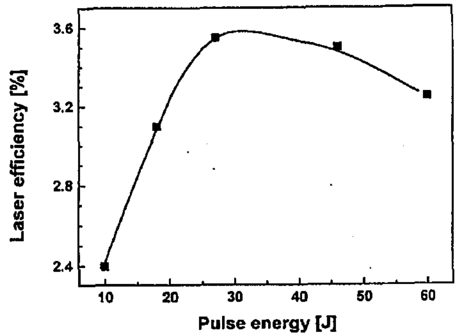

Fig. 2. Laser efficiency dependence on the pumping energy for laser on the base of the nonirradiated YAP:Nd laser rod.

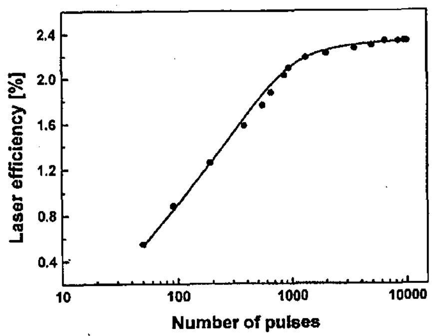

Fig. 3. Laser efficiency dependence on number of the optical pump pulses ($E_p = 11.8$ J) after γ-quanta irradiation of the YAP:Nd rod with absorption dose 10^5 Gy.

a minimum of the efficiency (first 10 pulses after γ-irradiation) reached value of $\approx 0.25\eta_i$, and after irradiation up to absorbed dose 10^5 Gy at the first 10 pulses of a pumping lamp, the laser generation ceased (after $N > 10$ it was again restored). In the range $100 < N < 1000$ the shape of curve $\eta_i(N)$ is identical for all doses of γ-irradiation. In that range mainly restoration of generation characteristics of active elements occurs. In the range of $1000 < N < 10000$ the initial efficiency is restored. The dependence $\eta_i(N)$ after irradiation of an active element with a dose of 10^5 Gy is shown in Fig. 3 as an example of this behaviour.

The η values in the maximum of the $\eta = f(E_p)$ curve for the active element, after cycle "irradiation by γ-quantum and 10000 pulses of light" at different absorbed doses of γ-radiation are shown in Fig. 4. As it can be seen from this figure, within the limits of accuracy measurements (relative error was 15%) the value of η is completely restored after 10000 pumping pulses.

It is possible to explain the increase in the generation efficiency in the YAG:Er observed in Ref. [9] and its reduction in YAP:Nd (Fig. 3) and YAG:Nd (Ref. [7, 8]) at high (10^4–10^5 Gy) irradiation doses as follows. In the case of the YAG:Er the colour centres formed at irradiation can act as sensibilizator centres,

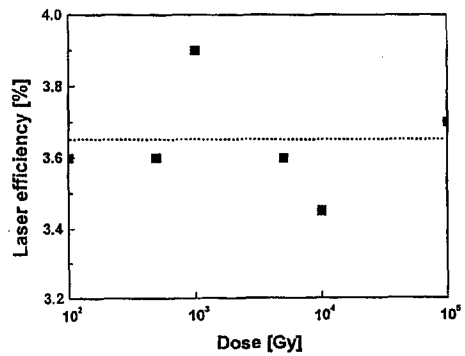

Fig. 4. The maximal value of the laser efficiency dependence on γ-radiation absorption dose after influence of 10000 pump lamp pulses on the γ-irradiated YAP:Nd rod (the laser efficiency level for nonirradiated rod is marked by dots).

which increases absorption of pumping energy. The additional absorption bands of YAG:Er (24000–26000 and 16000–20000 cm^{-1}) are well overlapped with main bands of the absorption of the Er ions ($^4I_{15/2} \rightarrow {}^2H_{9/2}, {}^4H_{11/2}, {}^4S_{3/2}, {}^4F_{9/2}$ transitions). Therefore the pumping energy absorbed by colour centres can be nonradiatively transferred to active ions. It should be noticed that the long-wave wing of the CC absorption reaches only near infrared area (up to 1.5 μm) and consequently passive losses, related to absorption on the wavelength of the YAG:Er laser generation (2.94 μm), are away.

At the same time the CC absorption bands in the YAG:Nd and YAP:Nd are also well overlapped with Nd ions absorption bands ($^4I_{9/2} \rightarrow {}^2G_{9/2}, {}^4G_{7/2}, {}^2G_{7/2}$, $^2G_{5/2}$ transitions) and sensibilization of Nd ions emission by the colour centres is not excluded. However, significant losses due to absorption of the colour centres on the generation wavelength (1.06 μm) results in a reduction of the generation efficiency.

Moreover, the CC arising in YAP:Nd as well as in the YAG crystals [1] can initiate a formation of short-lived colour centres, which in turn reduce generation efficiency of active elements.

4. Conclusions

Absorbing the pumping radiation, the colour centres lose carriers captured during γ-irradiation, and the defects restore the charge state which they had before γ-irradiation. Therefore the generation efficiency of the active elements is restored.

We have not found that the efficiency of laser generation is increased at absorbed doses of 10^2 Gy in YAP:Nd. This means that the "effect of small doses" [12] does not occur in our crystals.

It was thus established that the reduction of the efficiency of the YAP-Nd laser active elements induced by γ-radiation can be completely eliminated by the illumination of the laser host by the pumping lamp radiation in the spectrum of which the ultraviolet part is cut off.

For the YAP crystals activated by Tm, Ho or Er ions the laser generation occurs in the range of 2–3 μm (where passive losses induced by CC absorption are absent). Therefore, it is possible to expect the improvement of the generation efficiency owing to the sensibilization of these rare-earth ions by the colour centres.

Acknowledgment

This work was partially supported by the grant 8T11B05213 of the Committee for Scientific Research (Poland).

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