Peculiarities of the GGG:Nd-Microlaser Performance under Various Pulse Pumping Conditions

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Abstract. *Domestic optical materials have been used to manufacture a* $Gd_3Ga_5O_{12}$*:Nd-microlaser having a generation wavelength of 1062.4 nm, and its generation properties have been investigated under various conditions of pulse-periodic pumping by a laser diode.*

Key words: $Gd_3Ga_5O_{12}$:Nd, microlaser, pulse-periodic generation mode.

I. INTRODUCTION

For the time being, Ukraine has no series production for solid-state lasers, and the enterprises which produce them for their own demands fully depend on the imported components. Therefore, the main purpose has been to create a microlaser based on a GGG:Nd gain medium, using domestic materials.

The gadolinium-gallium garnet single crystals doped with neodymium ions ($Gd_3Ga_5O_{12}$:Nd; GGG:Nd) are the most widely used gain media for solid-state lasers. They are inferior in thermo-optical properties to $Y_3Al_5O_{12}$:Nd, but offer advantages that are equally essential – the crystals grown have a high structural and optical perfection, and allow to introduce into the crystal a greater quantity of Nd^{3+} ions, up to 4 at.% [1, 2]. Thus, active elements of GGG:Nd single crystals can be successfully used in lasers which operate in pulsed modes using diode-pumping. The choice of GGG:Nd has been also supported by the SRC «Carat» experience in producing such a crystal.

In addition, there are no publications known dealing with the investigation into the GGG:Nd single crystal microlaser performance under various pulse-diode-pumping conditions. Therefore, another purpose has been to study how the GGG:Nd microlaser output power depends on the power of pumping by a laser diode under various pulse-periodic conditions.

II. EXPERIMENTAL RESULTS

The GGG:Nd crystals have been grown by the Czochralski method, using the Physitherm (France) installations, and following the technology described in [3]. Based on the data concerning the coefficient of Nd^{3+} distribution into the GGG structure [4], the content of the resulting raw material has been calculated to ensure that the Nd^{3+} content in the obtained crystal is equal to 2 at.% compared to content of Gd ions. The photometric analysis of the crystal has shown that the Nd^{3+} concentration is equal to 1.7 at.%.

With the help of the engineering and measuring equipment from Logitech (Great Britain), developed are the technological instructions for processing the crystals, and produced are the GGG:Nd active elements having the dimensions of up to 3×3×5 mm, the flatness of λ/10 and the facet non-parallelism of at least 20´´.

To assess the material quality, the Ekspla (Lithuania) nanosecond luminescence spectrometer has been used to measure the luminescence spectra within 1000…1100 nm and the luminescence decay time for λ = 1062.4 nm. The results are given in Fig.1 and Fig.2. The data obtained match the known literature data [2], and show that this material can be used as the active element of a laser.

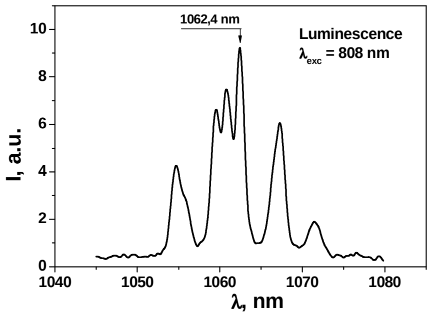

Fig. 1. Luminescence spectrum of $Gd_3Ga_5O_{12}$:Nd single crystal.

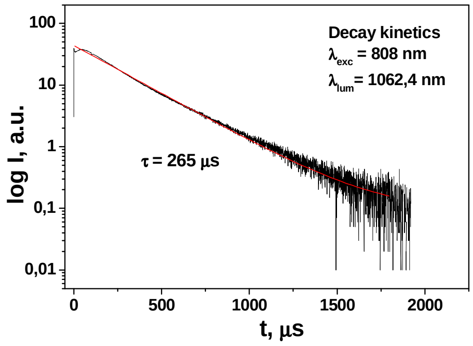

Fig. 2. Luminescence decay kinetics of GGG:Nd at λ = 1062,.4 nm.

To have the microlaser built as a basic design, there has been used a resonator with two flat mirrors. The design calculation and the manufacture of the resonator mirrors and of the translucent coatings of the active element’s working facets have been performed by SPE «Carat» using the electron-beam evaporation plant from Torr International

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(USA). The transmittance of the output mirror was equal to 93% at the generation wavelength (1062.4 nm). The input mirror transmits 95% of the pumping radiation, and fully reflects the laser radiation. SiO_2 has been selected as an AR coating for the GGG:Nd crystal. The transmittance of the active elements with AR coating at the wavelength of 1062.4 nm was equal to 99.8%. Fig. 3 shows the absorption spectrum of the active element with translucent working facets within the pumping region (808 nm).

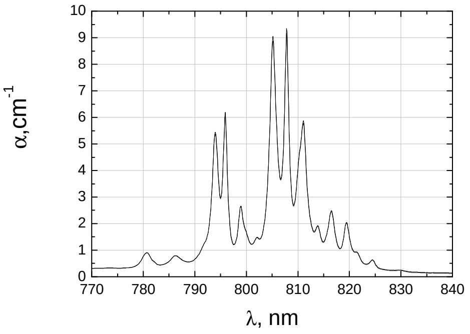

Fig. 3. $Gd_3Ga_5O_{12}$:Nd absorption spectrum within the pumping region.

The active element and the resonator mirrors have been secured in specially designed holders allowing for each element to be adjusted and fixed in an optimal position. The holders have been placed on a metal platform the temperature of which has been changed and maintained at a given level by means of Peltier elements being driven by a specialized control unit.

The microlaser pumping has been performed using the laser diode of ATC-C4000-200-AMF-808-3 type with the 808 nm wavelength and the 4 W output radiation power, produced by the company "Semiconductor Devices" (Russia). The laser diode control unit allowed the duration of pumping radiation pulses to be changed within $8 \cdot 10^{-5} \ldots 10$ s and the pulse repetition period to be changed within $10^{-4} \ldots 10$ s. The pumping radiation has been directed onto the optical system allowing to obtain a pumping light beam waist of approx. 100-μm diameter inside the active element volume. The pumping has been performed through one of the active element's working surfaces.

The pumping radiation power (P_{pump}), and the microlaser output power (P_{out}) have been measured using the device IMO-2N (Russia).

To measure the optimum pumping mode in terms of the relation between the laser diode pulse duration (τ) and the pulse repetition period (T), there have been measured the dependence between P_{out} and P_{pump} for different duty cycle ratio (T/τ). There has been determined that the microlaser operation is most effective when T/τ equals 1. The higher the T/τ value, the lower the generation effectiveness. At the same time, at a fixed value $T/\tau = 1$, and with the pulse repetition period being changed, the output power value remains practically unchanged. The examples of these measurements are given in Figure 4.

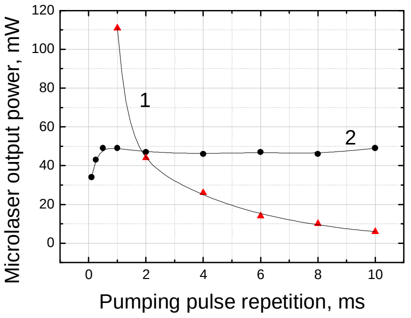

Fig. 4. Dependence of the microlaser P_{out} on the pumping pulse repetition frequency: 1 – for different duty cycles at P_{pump} = 1.9 W and τ = 1 ms; 2 – for fixed duty cycle T/τ = 1 at P_{pump} = 1.4 W.

Figure 5 illustrates the dependence of the microlaser output power on the pumping radiation power for the $T/\tau = 1$ and the pumping pulse duration $\tau = 1$ ms.

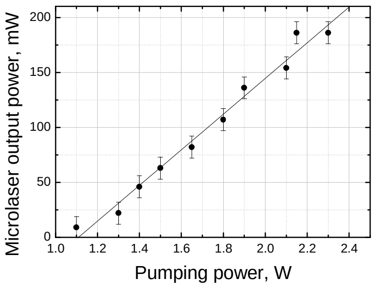

Fig. 5. Dependence of the microlaser P_{out} on P_{pump} for the duty cycle T/τ = 1 and τ = 1 ms.

As it can be seen from this figure, the laser differential efficiency is equal to approximately 16 %.

III. CONCLUSIONS

Based on the domestic Ukrainian materials, there has been designed and manufactured a microlaser with a $Gd_3Ga_5O_{12}$:Nd gain medium (activator content 1.7 at. %). The microlaser generation properties have been investigated under various pulse-periodic conditions. There has been shown that the proposed design allows for the highest efficiency to be reached when the pulse pumping is performed with the duty cycle equaling 1.

REFERENCES

[1] C.-H. Zuo, B.-T. Zhang, J.-L. He, H.-T. Huang, X.-L. Dong, J.-L. Xu, Z.-T. Jia, C.-M. Dong, and X.-T. Tao, "13.2 W cw output generated by a diode-end-pumped Nd:GGG laser", *Laser Phys. Lett.*, vol. 5, no. 8, pp. 582–584, 2008.

[2] A. Matkovskii, *Materials for Quantum Electronics*, Liga-Press: Lviv, 2000, pp. 292 (in Ukrainian).

[3] D. Sugak, A. Matkovskii, A. Durygin, A. Suchocki, I. Solskii, S. Ubizskii, K. Kopczynski, Z. Mierczyk and P. Potera, "Influence of color centers on optical and lasing properties of gadolinium gallium garnet single crystals doped with Nd^{3+} ions", *J. Luminescence*, vol. 82, no. 1, pp. 9–15, 1999.

[4] D. Sun, Q. Zhang, Z. Wang, J. Su, C. Gu, A. Wang and S. Yin, "Concentration distribution of Nd^{3+} in Nd:$Gd_3Ga_5O_{12}$ crystals", *Cryst. Res. Technol.*, vol. 40, no. 7, pp. 698–702, 2005.