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A 913-nm diode-pumped quasi-three-level $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ laser

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***Abstract*.** **Lasing parameters of a mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystal emitting at the 913-nm $^4F_{3/2}-{}^4I_{9/2}$ laser transition are studied. The output power of up to 600 mW was obtained upon longitudinal diode pumping for the absolute and slope laser efficiencies of ~13 % and ~17 %, respectively.**

Keywords: *mixed vanadate, diode pumping, quasi-three-level laser.*

1. Introduction

The efficient generation of mixed $Nd^{3+}:Gd_xY_{1-x}VO_4$ vanadate lasers emitting at the 1.06-μm $^4F_{3/2}-{}^4I_{11/2}$ transition of neodymium have been recently studied in a number of papers. The highly efficient cw lasing, *Q*-switching and generation of picosecond pulses have been obtained [1 – 3].

One of the main advantages of mixed vanadates as an active medium for solid-state lasers is the possibility to change their lasing properties in a broad range by varying the concentration of crystal components, for example, the Y and Gd ions. In this way, one can change the important properties of laser crystals such as the emission wavelength, the stimulated-transition cross section, the luminescence linewidth, etc.

The lasing properties of mixed $Nd:YVO_4$ and $Nd:GdVO_4$ vanadate lasers at the $^4F_{3/2}-{}^4I_{9/2}$ transition of neodymium were studied first in paper [4] and then in papers [5, 6]. It was shown that the high lasing efficiency for the high average output power can be achieved despite the quasi-three-level lasing at comparatively large intracavity losses due to a small splitting of the ground state of the laser transition. The aim of this paper is to achieve lasing upon diode pumping and to study the lasing properties of a mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystal at the 913-nm $^4F_{3/2}-{}^4I_{9/2}$ laser transition.

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2. Spectral and luminescent parameters

The mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystals (the atomic concentration of Nd being 0.5 %) were grown by the Czochralski method. The crystal boules had a high optical quality over the entire length and nearly all the boule volume was used to fabricate laser elements.

Figure 1 shows the π-polarised luminescence spectra of a mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystal and, for comparison, of neodymium-doped gadolinium and yttrium vanadates. One can see from Fig. 1 that the luminescent band of the mixed vanadate is located between the luminescent bands of yttrium and gadolinium vanadates, the position of the band being determined by the ratio of the Gd and Y concentrations in the mixed vanadate. In our case this ratio is 0.7 : 0.3, which agrees well with the experimental position of the luminescence band of the mixed vanadate. Therefore, because the dependence of the luminescence band position on the concentration ratio of the crystal components is close to linear, we can select the required wavelength of the luminescence band, and, hence, the lasing wavelength of mixed vanadates.

The σ-polarised luminescence spectra of vanadate crystals and mixed vanadates in the wavelength range from 900 to 930 nm (Fig. 2) almost coincide in shape with the π-polarised spectra of these crystals.

3. Lasing parameters

An active element studied in our paper was a 2-mm thick $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ crystal (with the atomic concentration of

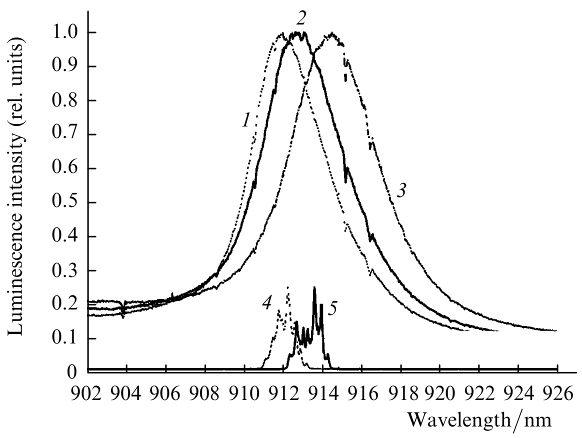

Figure 1. π-polarised luminescence spectra of $Nd^{3+}:GdVO_4$ (*1*), $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ (*2*) and $Nd^{3+}:YVO_4$ (*3*) crystals and emission spectra of $Nd^{3+}:GdVO_4$ (*4*) and $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ (*5*) lasers.

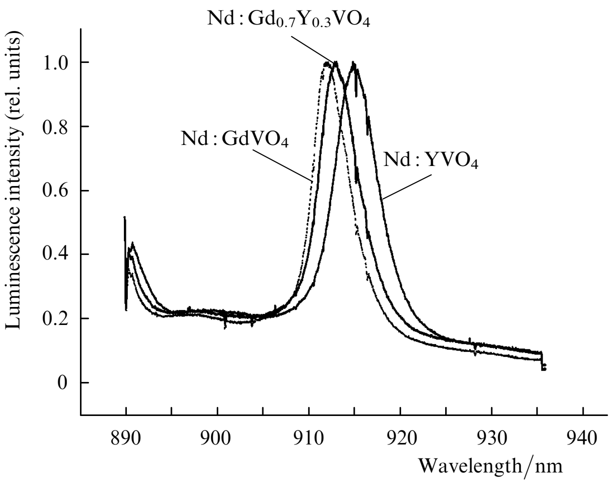

Figure 2. σ-polarised luminescence spectra of $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$, $Nd^{3+}:GdVO_4$, and $Nd^{3+}:YVO_4$ crystals.

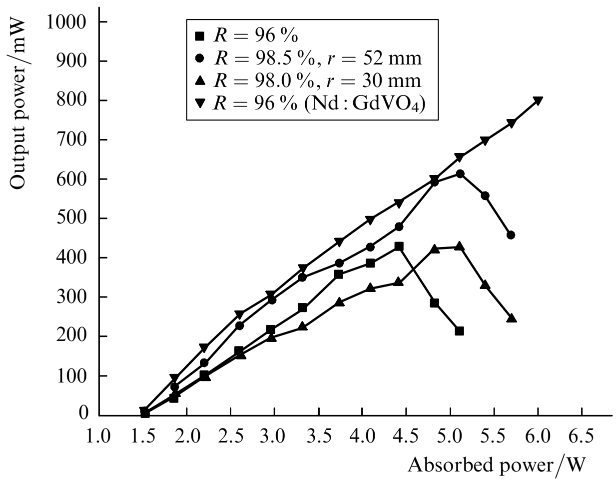

Figure 3. Dependence of the output power of the $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ laser on the absorbed pump power in the plane–parallel (■) and plane–spherical (●,▲) cavities with different output mirrors; the same dependence for the Nd : $GdVO_4$ laser with the plane–parallel cavity (▼).

Nd equal to 0.5 %) cut along the *a* axis, which was mounted on a Peltier thermocooler. The laser cavity of length ~10 mm was formed by a dielectric mirror with the reflectivity of $R = 99.9\,\%$ applied directly on one of the surfaces of the active element and an output mirror. The reflectivity of the output mirror was varied and was 96 % for the plane mirror and 98 % and 98.5 % for the concave spherical mirror with the radius of curvature of $r = 30$ and 52 mm, respectively. The mirror coating on the active element provided transmission of no less than 97 % of the pump radiation at 808 nm. The other side of the active element had an AR coating at wavelengths of 913, 1064 and 1340 nm. The output mirror had an AR coating at 1064 and 1340 nm to suppress lasing at these wavelengths. The pumping was performed with a LIMO laser array (Germany) with a fibre pigtail (the numerical aperture ~0.3). The pump radiation was focused into a spot of diameter ~150 μm.

Under these conditions lasing was obtained at the 913-nm $^4F_{3/2}-^4I_{9/2}$ laser transition of neodymium in the active element made of the mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystal. The dependence of the output power of this laser on the absorbed pump power is shown in Fig. 3. The output parameters of the Nd : $GdVO_4$ laser obtained under similar conditions are presented for comparison.

The highest output power of the mixed vanadate laser achieved 610 mW when a spherical output mirror with the radius of curvature of 52 mm and the reflectivity of 98.5 % was used (see Fig. 3). In this case, the highest values of the absolute and slope laser efficiency of ~13 % and ~17 %, respectively, were obtained. Note that these lasing efficiencies well agree with the corresponding efficiencies close to the limiting ones, which were obtained for the Nd : $GdVO_4$ vanadate crystal under similar conditions [5].

Other conditions being the same, the efficiency of the Nd : $GdVO_4$ laser was slightly higher than that of the mixed vanadate laser. This can be explained by the fact that the luminescence band of the gadolinium vanadate crystal is narrower than that of the mixed vanadate (see Fig. 1).

The radiation wavelengths of gadolinium vanadate and mixed vanadate lasers nearly coincide with the maxima of the corresponding luminescence bands. The emission lines exhibit local peaks, which indicates the multimode lasing. The lasing linewidths for the mixed and gadolinium vanadates were 1.4 and 1.0 nm, respectively. The emission wavelength for the mixed vanadate was 913 nm.

The experimental dependence of the output power of the mixed vanadate laser for the pump power exceeding ~610 W has a drastic drop until lasing vanishes (Fig. 3). Meanwhile, under similar conditions, the Nd : $GdVO_4$ crystal provides efficient lasing without a noticeable decrease in its efficiency. Our analysis showed that this effect is related to a lower thermal conductivity of mixed vanadate crystals and is caused by a higher optical strength of the induced thermal lens, which leads to the cavity instability. As the instability regime is approached, the diameter of the resonator mode drastically increases in the crystal region into which the pump radiation is focused. Intracavity lasing propagates mainly outside the pump region, where absorption losses from the upper sublevels of the ground state are high. This leads to an increase in the intracavity losses and, hence, to a decrease in the power and the lasing efficiency.

4. Conclusions

We have obtained a highly efficient lasing at the 913-nm $^4F_{3/2}-^4I_{9/2}$ laser transition in a mixed $Nd^{3+}:Gd_{0.7}Y_{0.3}VO_4$ vanadate crystal. It has been demonstrated experimentally that the active elements made of mixed vanadates are not inferior in efficiency to active elements made of Nd : $GdVO_4$ vanadate crystal [4].

It has been shown that the emission wavelength can be changed by varying the concentration of the Gd and Y components in mixed vanadates. This unique possibility of tuning the radiation wavelength in the vicinity of 913 nm can be used to extend the applications of these lasers.

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