Quantum Electronics **42** (3) 208–210 (2012)

ACTIVE MEDIA

PACS numbers: 42.55.Rz; 42.55.Xi; 42.70.Hj; 61.05.Cp
DOI: 10.1070/QE2012v042n03ABEH014798

Effect of structural imperfections on lasing characteristics of diode-pumped YVO_4, $GdVO_4$ and mixed rare-earth vanadate crystals

G.Yu. Orlova, V.I. Vlasov, Yu.D. Zavartsev, A.I. Zagumennyi, I.I. Kalashnikova, S.A. Kutovoi, V.S. Naumov, A.A. Sirotkin

Abstract. **The efficiency of diode-pumped lasers with gain elements made from yttrium, gadolinium, yttrium–gadolinium and yttrium–scandium orthovanadate crystals has been shown for the first time to be influenced by structural imperfections (quality) of the crystals. This allows one to predict lasing parameters of such crystals in a preliminary step, without fabricating gain elements.**

Keywords: *yttrium vanadate, gadolinium vanadate, mixed rare-earth vanadates, structural imperfections, lasing parameters.*

The use of yttrium, gadolinium and mixed rare-earth vanadate crystals [1–9] as gain media of diode-pumped lasers imposes certain requirements on their quality. Very few X-ray diffraction (XRD) studies have been concerned with the quality of yttrium and mixed rare-earth vanadate crystals, and it is not yet clear how the structural perfection of such crystals influences their lasing performance. In connection with this, the study of the lasing parameters of diode-pumped rare-earth vanadate crystals in relation to their structural perfection is of scientific and technological interest.

In this paper, we report an XRD study [10] of the quality of yttrium, gadolinium, yttrium–gadolinium and yttrium–scandium vanadate crystals doped with neodymium ions ($CuK_{\alpha1}$ radiation, 1.54 Å). The neodymium content of the crystals was 0.5 at%.

The quality of the crystals was assessed from their XRD rocking curves: angular dependences of the diffracted X-ray intensity when the crystal is rotated through the Bragg angle [11–13]. We used the (100), (110), and (001) reflections. An important parameter of a rocking curve is its full width at half maximum (FWHM). In the one-crystal configuration used, the instrumental function (minimum rocking curve width) was 1.6′. Because the rocking curves of the rare-earth vanadate crystals studied ranged in FWHM from 2 to 19′, the one-crystal configuration used was suitable for sorting out the crystals according to their quality. From the rocking curve width, one can evaluate the mosaic spread of the single crystal, i.e., the crystal lattice disorder in the material.

We studied YVO_4:Nd^{3+}, $GdVO_4$:Nd^{3+}, $Gd_{0.7}Y_{0.3}VO_4$:Nd^{3+}, $Gd_{0.9}Y_{0.1}VO_4$:Nd^{3+} and $Y_{0.97}Sc_{0.03}VO_4$:Nd^{3+} crystals. Isomorphic substitutions are known to influence the theoretical rocking curve FWHM. In the case of rare-earth vanadate crystals, this influence can be neglected because crystal mosaicity has a much stronger effect on the rocking curve FWHM than does the structural disorder due to isomorphic substitutions. In view of this, the effect of crystal mosaicity on the lasing performance of the rare-earth vanadate crystals was analysed without taking into account their composition.

We examined a total of more than 50 rare-earth orthovanadate crystals. Here, we present results for typical crystals. XRD characterisation showed that the crystals differed in quality. They were divided into three groups according to their structural perfection and lasing efficiency: crystals of good quality, with a rocking curve FWHM, $\Delta\theta$, within 4′ and lasing efficiency, η, in the range 40%–60%; crystals of satisfactory quality, with $\Delta\theta = 4-6'$ and $\eta \sim 35\%$; and crystals of unsatisfactory quality, with $\Delta\theta > 6'$ and $\eta = 10\%-20\%$. Lasing efficiency is here taken to mean the ratio of the laser output power to the pump power absorbed in the active medium. As an example, Fig. 1 shows rocking curves of YVO_4:Nd^{3+} and $Gd_{0.7}Y_{0.3}VO_4$:Nd^{3+} crystals.

Some of the crystals studied (or some regions of the crystals) had a mosaic structure, which was evidenced by separate peaks in their rocking curves. The misorientation between the mosaic blocks in some of the crystals ranged from 3 to 40′. Such crystals were included in the third group (unsatisfactory quality) because the gain elements fabricated from them had very low lasing efficiency. Therefore, mosaic crystals should be rejected in a preliminary step and should not be used to fabricate gain elements.

The lasing performance of the crystals was studied in continuous mode under diode end-pumping. The laser diode (λ = 808 nm) provided cw radiation in a single transverse mode (TEM_{00}), with up to 16 W of power at the output fibre pigtail (100 μm diameter, NA = 0.22). The pump beam was focused into a gain element to a spot diameter of 200 μm. The cavity was formed by a high-reflectivity plane mirror and a 13% reflective output mirror. The relative uncertainty in our measurements was within ±15%.

Figure 2a shows the laser output power as a function of pump power for gain elements made from the $GdVO_4$:Nd^{3+}, $Gd_{0.9}Y_{0.1}VO_4$:Nd^{3+}, $Gd_{0.7}Y_{0.3}VO_4$:Nd^{3+} and YVO_4:Nd^{3+} crystals.

Analysis of the lasing performance of the gain elements from the yttrium vanadate, gadolinium vanadate, $Gd_{0.7}Y_{0.3}VO_4$:Nd^{3+}, $Gd_{0.9}Y_{0.1}VO_4$:Nd^{3+} and $Y_{0.97}Sc_{0.03}VO_4$:Nd^{3+} crystals in relation to their structural perfection (as assessed from the FWHM of their XRD rocking curves) showed that these parameters

G.Yu. Orlova, I.I. Kalashnikova, V.S. Naumov M.F. Stel'makh Polyus Research and Development Institute, ul. Vvedenskogo 3, 117342 Moscow, Russia;
V.I. Vlasov, Yu.D. Zavartsev, A.I. Zagumennyi, S.A. Kutovoi, A.A. Sirotkin A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia;
e-mail: vlasov@lsk.gpi.ru

Received 22 November 2011; revision received 13 February 2012
Kvantovaya Elektronika **42** (3) 208–210 (2012)
Translated by O.M. Tsarev

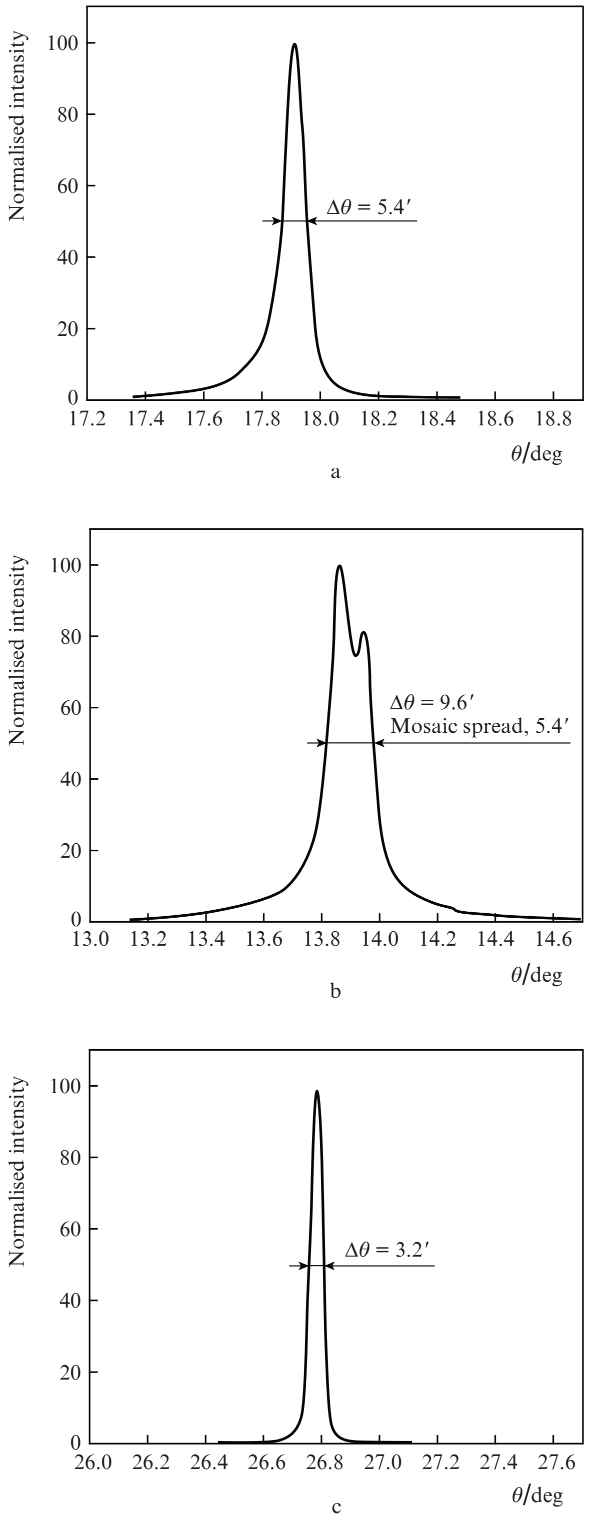

Figure 1. Typical rocking curves of gain elements: (a) $YVO_4:Nd^{3+}$ crystal of satisfactory quality ($\Delta\theta = 5.4'$), (b) $YVO_4:Nd^{3+}$ crystal of unsatisfactory quality ($\Delta\theta = 9.6'$), (c) $Gd_{0.7}Y_{0.3}VO_4:Nd^{3+}$ crystal of good quality ($\Delta\theta = 3.2'$).

were correlated in some manner. Figure 2b shows the lasing efficiency as a function of rocking curve FWHM at a pump power of 4.5 W. The lasing efficiency of the gain elements made from the rare-earth vanadate crystals is seen to be strongly influenced by structural imperfections, quantified by the XRD rocking curve FWHM.

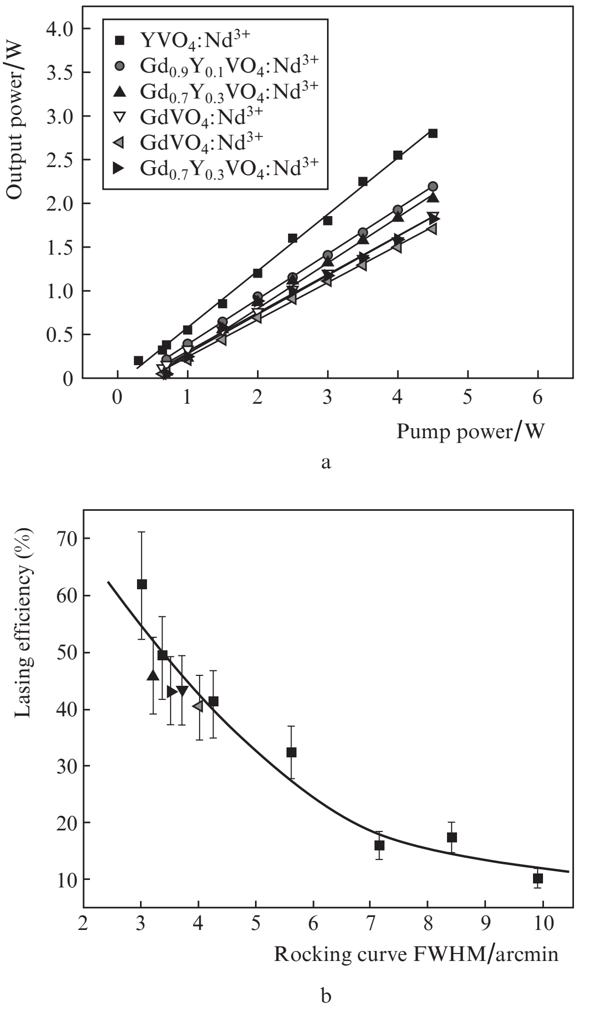

Figure 2. (a) Laser output power as a function of absorbed pump power for gain elements made from $GdVO_4:Nd^{3+}$, $Gd_{0.9}Y_{0.1}VO_4:Nd^{3+}$, $Gd_{0.7}Y_{0.3}VO_4:Nd^{3+}$ and $YVO_4:Nd^{3+}$ crystals. (b) Lasing efficiency as a function of rocking curve FWHM for $GdVO_4:Nd^{3+}$, $Gd_{0.9}Y_{0.1}VO_4:Nd^{3+}$, $Gd_{0.7}Y_{0.3}VO_4:Nd^{3+}$, $YVO_4:Nd^{3+}$ and $Y_{0.97}Sc_{0.03}VO_4:Nd^{3+}$ gain elements at a pump power of 4.5 W.

The correlation found here allows one to predict the lasing performance of crystals from XRD characterisation results, without fabricating gain elements for lasing experiments. This considerably facilitates and reduces the price of the fabrication of high-quality gain elements from rare-earth vanadate crystals.

References

1. O'Connor J.R. *Appl. Phys. Lett.*, **9** (11), 407 (1966).
2. Kalisky Y. *Opt. Mater.*, **13**, 135 (1999).
3. Chizhikov V.I. *Soros. Obraz. Zh.*, **7** (8), 103 (2001).
4. Kravtsov N.V. *Kvantovaya Elektron.*, **31** (8), 661 (2001) [*Quantum Electron.*, **31** (8), 661 (2001)].
5. Wu S. et al. *J. Cryst. Growth*, **266**, 496 (2004).
6. Zagumennyi A.I., Ostroumov V.G., Shcherbakov I.A., Jensen T., Meyen J.P., Huber G. *Kvantovaya Elektron.*, **19** (12), 1149 (1992) [*Sov. J. Quantum Electron.*, **22** (12), 1071 (1992)].
7. Sirotkin A.A., Vlasov V.I., Zagumennyi A.I., Zavartsev Yu.D., Kutovoi S.A. *Kvantovaya Elektron.*, **41** (7), 584 (2011) [*Quantum Electron.*, **41** (7), 584 (2011)].
8. Liu J., Wang Zh., Meng X., Shao Z., Ozygus B., Ding A., Weber H. *Opt. Lett.*, **28** (23), 2330 (2003).
9. Vlasov V.I., Garnov S.V., Zavartsev Yu.D., Zagumennyi A.I., Kutovoi S.A., Sirotkin A.A., Shcherbakov I.A. *Kvantovaya*

Elektron., **37** (10), 938 (2007) [*Quantum Electron.*, **37** (10), 938 (2007)].

10. Mirkin L.I. *Rentgenostrukturnyi analiz. Spravochnoe rukovodstvo* (X-Ray Structure Analysis: A Handbook) (Moscow: Nauka, 1976) p. 9.
11. Iveronova V.I., Revkevich G.P. *Teoriya rasseyaniya rentgenovskikh luchei* (Theory of X-Ray Scattering) (Moscow: Mosk. Gos. Univ., 1976) p. 187.
12. Bublik V.T., Dubrovina A.N. *Metody issledovaniya struktury poluprovodnikov i metallov* (Methods for Structural Analysis of Semiconductors and Metals) (Moscow: Metallurgiya, 1978) p. 167.
13. Klassen A.V., Kochurikhin V.V., Ivanov M.A., Matsucura M., Nakamura O., Miyamoto A., Furukawa Y., Orlova G.Yu. *J. Cryst. Growth*, **310** (11), 2895 (2008).