SYNTHESIS AND OPTICAL PROPERTIES OF $\mathrm{YAlO_3}$ CRYSTALS ACTIVATED BY $\mathrm{Nd^{3+}}$ IONS

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Abstract

Full Text

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SYNTHESIS AND OPTICAL PROPERTIES OF $YAlO_3$ CRYSTALS ACTIVATED BY Nd^{3+} IONS

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It is known ([1]) that in the Y_2O_3—Al_2O_3 system, besides the stable phase $3Y_2O_3 \cdot 5Al_2O_3$ ($Y_3Al_5O_{12}$), there are two more stable compounds: $Y_2O_3 \cdot Al_2O_3$ and $2Y_2O_3 \cdot Al_2O_3$, whose physical properties have practically not been studied. Of special interest among them is yttrium aluminate $Y_2O_3 \cdot Al_2O_3$ ($YAlO_3$), with a perovskite structure, stable in a very narrow temperature interval of 1875–1835° C. As our studies have shown, the synthesis of sufficiently large yttrium aluminate crystals is quite possible, since, unlike the phase $2Y_2O_3 \cdot Al_2O_3$, this compound has no polymorphic transitions down to room temperature.

Fig. 1. Absorption spectra at 300° K, corresponding to the transition ${}^4I_{9/2} \rightarrow {}^2P_{1/2}$, of $Y_3Al_5O_{12}$ crystals *(a)* and $YAlO_3$ crystals *(b)* activated by Nd^{3+} ions.

Fig. 2. Luminescence spectra, corresponding to the transition ${}^4F_{3/2} \rightarrow {}^4I_{11/2}$, of $YAlO_3$ crystals at 300° K *(a)*, $YAlO_3$ at 77° K *(b)*, and $Y_3Al_5O_{12}$ at 300° K *(c)*, activated by Nd^{3+} ions.

In contrast to garnet crystals $Y_3Al_5O_{12}$ with rare-earth ions (TR^{3+}), which are one of the principal materials for quantum electronics, $YAlO_3$ crystals must possess certain distinctive features. Since the symmetry of yttrium aluminate is lower than the symmetry of $Y_3Al_5O_{12}$ crystals, it should be expected that, under isomorphous substitution of Y^{3+} ions by TR^{3+} ions, the latter will enter mainly one type of optical centers, the optical properties of which will differ by large values of the probabilities of electronic transitions.

The incorporation coefficient of impurity TR^{3+} ions and of the iron group is considerably higher than in garnet and is close to unity. This circumstance makes it possible to grow crystals with a high activator concentration. At the same time, the lower melting point of this substance (1865°), compared with garnet

Figure 3. Schemes of the crystal-field splitting of the terms $^2P_{1/2}$, $^4F_{3/2}$, $^4I_{11/2}$, and $^4I_{9/2}$ of Nd^{3+} ions in $YAlO_3$ and $Y_3Al_5O_{12}$ crystals at 77 and 300°K. The positions of the levels are indicated in cm^{-1}, and the transitions between them in Å.

Figure 2: Figure 3. Schemes of the crystal-field splitting of the terms $^2P_{1/2}$, $^4F_{3/2}$, $^4I_{11/2}$, and $^4I_{9/2}$ of Nd^{3+} ions in $YAlO_3$ and $Y_3Al_5O_{12}$ crystals at 77 and 300°K. The positions of the levels are indicated in cm^{-1}, and the transitions between them in Å.

(1930°), simplifies the synthesis conditions. In this connection, the preparation of $YAlO_3$ crystals activated by TR^{3+} is of unquestionable interest.

In this communication we present preliminary results of a study of some spectroscopic properties of $YAlO_3$ crystals activated by Nd^{3+} ions, which were synthesized from the melt by a method developed at the Institute of Crystallography of the USSR Academy of Sciences. For the experiments, use was made–

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single crystals of $YAlO_3$—Nd^{3+} of good optical quality with dimensions 12×8×6 mm were formed. The concentration of the active impurity was 1.5 and 3 wt.%. Identification of the obtained specimens by X-ray structural analysis showed that they consist entirely of the $Y_2O_3 \cdot Al_2O_3$ phase.

The experimental technique used to study the spectroscopic characteristics of $YAlO_3$—Nd^{3+} crystals did not differ in any way from that described in work ([2]). Figure 1 shows the absorption spectra of $YAlO_3$—Nd^{3+} crystals and, for comparison, $Y_3Al_5O_{12}$—Nd^{3+}, corresponding to the transition $^4I_{9/2} \rightarrow {}^2P_{1/2}$, obtained at 300° K; Fig. 2 shows their luminescence spectra associated with transitions between the terms $^4F_{3/2}$ and $^4I_{11/2}$. As can be seen, the spectral properties of these crystals differ substantially. Thus, the splitting of the term $^4F_{3/2}$ at 77° K in $Y_3Al_5O_{12}$—Nd^{3+} crystals is ~ 84 cm^{-1}, whereas for yttrium aluminate with Nd^{3+} ions it is 129 cm^{-1}. For a more detailed comparison, Fig. 3 gives schemes of the crystal-field splitting of the terms $^2P_{1/2}$, $^4F_{3/2}$, $^4I_{11/2}$, and $^4I_{9/2}$ of these compounds. It is evident that the splitting of the term $^4I_{9/2}$ in the $YAlO_3$—Nd^{3+} crystal is considerably smaller and has a different character (it is also seen that in the garnet the fifth Stark component, 859 cm^{-1}, of the term $^4I_{9/2}$, and the two upper levels, 2463 and 2517 cm^{-1}, of the term $^4I_{11/2}$, are significantly removed from the others).

Spectroscopic studies also showed that at concentrations of Nd^{3+} ions of ~ 3 wt.% the spectra of yttrium aluminate crystals are characterized primarily by

one type of optical center. The accuracy of the measurements was ± 3 cm^{-1}.

The results of our spectroscopic studies of $YAlO_3$ crystals and their comparison with analogous data for garnet crystals indicate that yttrium aluminate can be used as an active medium in optical quantum generators, and induced emission should be expected on one (or several) of three lines: 10640, 10723, and 10795 Å (transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$). It should also be noted here that, for rapid analysis of the synthesized phases in the Y_2O_3—Al_2O_3 system, as our experiments have shown, the method of studying absorption or luminescence spectra can be successfully applied, since the X-ray structural characteristics, in particular of the phases $3Y_2O_3 \cdot 5Al_2O_3$ and $Y_2O_3 \cdot Al_2O_3$, differ little from one another ([1]).

Measurement of the lifetime of the excited state ($^4F_{3/2}$) of Nd^{3+} ions (3.0 wt.%) in $YAlO_3$ crystals gave a value of τ_{em} at 65° K of about 300 μsec.

In conclusion, we express our gratitude to G. A. Bogomolova and V. N. Shpakov for their participation in the spectroscopic measurements, and to B. P. Sobolev for carrying out the X-ray structural analysis.

Proof note. We have recently obtained induced emission from an optical quantum generator with $YAlO_3$—Nd^{3+} crystals (1.5 and 3 wt.%) both at 77° K and at 300° K. At room temperature the optical quantum generator emits on the line 1097 Å with an excitation threshold below 0.5 J, and at 77° K on the line of 10725 Å.

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Note: Figure translations are in progress. See original paper for figures.