Optical Investigation of Co Ions Diffusion in Gd$_3$Ga$_5$O$_{12}$ Single Crystals

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Absorption of light on the $^4A_2\rightarrow^4T_1(^4F)$ transition in tetrahedrally coordinated Co$^{2+}$ dopant ions reveals non-linear dependence on the incident light intensity. This phenomenon of Co$^{2+}$ ions saturable absorption is used in practice for Q-switching of solid state lasers of 1.2...1.7 μm spectral range [1]. One of the materials used for Q-switching is Gd$_3$Ga$_5$O$_{12}$ (GGG) crystals doped by Co$^{2+}$. Both the bulk crystals grown by Czochralski method and the LPE GGG:Co$^{3+}$ single crystalline films grown on a GGG substrate can be used for this application [2, 3]. Besides the incorporation of metal ions into some complex oxides crystals can be achieved by high-temperature annealing in the presence of their compounds, particularly the metal oxides [4].

This work presents the results of GGG doping due to diffusion of cobalt ions from the surfaces of the crystals. Two different GGG samples were used for investigations: the first one in the form of plate with dimensions of 7×15×1 mm$^3$, the second one in the form of cylinder with 15 mm diameter and 10 mm height. The plate surface and base surfaces of cylinder were perpendicular to crystallographic directions [111]. These surfaces were polished. Samples were placed in ceramic crucibles, were covered from all sides with Co$_3$O$_4$ powder and were annealed in air in the Naberterm (Germany) oven at 1200 °C for 24 hours. The optical spectra of annealed samples were registered with a spectrophotometer Shimadzu UV3600 (Japan) in the 200...1700 nm spectral range. Transmission spectra of 7×15×1 mm$^3$ plate were studied when light is passed along the [111] direction, i.e. in the direction of diffusion. For determination of the cobalt ion diffusion depth the 2 mm-thick plate was cut from the cylindrical sample and polished so that its largest facet was parallel to the direction [111]. The absorption spectra were registered in the direction perpendicular to the [111] one by a special device that allowed to perform measurements in increments of 20 microns at points along [111]. The absorption spectra obtained after annealing coincides with known data about the absorption of Co$^{2+}$ ions in tetrahedral positions. The spatial distribution of dopants was determined from the measurements of depth-depended Co$^{2+}$ absorption changes. It is shown that the depth of Co$^{2+}$ diffusion in GGG reaches a value about 500 μm.

The results of XRD studies are presented for surfaces that were in contact with diffusant (Co$^{2+}$ ions) source. For plate cut out perpendicular to the (111) plane the changes of chemical composition and structural properties along the direction of diffusion were studied by electron-probe microanalysis and micro-Raman spectroscopy methods. The mechanisms of Co$^{2+}$ ions incorporation into GGG structure are discussed.

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