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Micro-crystallization and spectroscopic properties of Er, Yb:*R*Al-borates (*R*=Y, Gd) obtained in $RAl_3(BO_3)_4$–$K_2Mo_3O_{10}$–B_2O_3–R_2O_3 and $RAl_3(BO_3)_4$–B_2O_3 systems

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ABSTRACT

The spontaneous $YAl_3(BO_3)_4$ (YAB) and $GdAl_3(BO_3)_4$ (GdAB) crystals (of nominal composition and co-doped with Er and Yb) up to 4–5 mm in length were grown from high-temperature solutions using $K_2Mo_3O_{10}$ based fluxes in the temperature range of 1120–900 °C. Glass–ceramic composites based on the YAB and GdAB micro-crystals have been prepared by quenching YAB–B_2O_3 and GdAB–B_2O_3 melts and characterized by X-ray diffraction and spectroscopic methods. The vitrified melt was shown to contain micro- and nano-crystalline rare-earth borate phases. Their distribution over the composites has been investigated by electron microscopy and three-dimensional X-ray tomography. The absorption spectra of these materials co-doped with erbium and ytterbium as well as luminescence spectrum were demonstrated.

1. Introduction

Lasers emitting at 1.5–1.6 μm spectral range are of great interest for several industrial applications. This interest is first of all caused by the eye-safety of its radiation. Other advantage of this wavelength is high transparency in atmosphere and fused-silica waveguides. All this makes 1.5–1.6 μm lasers very attractive for applications in eye-safe laser range-finders, LIBS systems, optical location and telecommunications.

The $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of erbium ions is a simple and reliable method for obtaining 1.5–1.6 μm laser operation. However, erbium ions suffer from low pump absorption at the wavelength of commercially available laser diodes near 980 nm. This fact obliges to use additional co-doping with ytterbium ions that strongly absorb pump radiation and transfer it to the erbium ions. For efficient operation of such Er–Yb co-doped lasers, two main spectroscopic conditions should be satisfied. The first is a short lifetime of the $^4I_{11/2}$ energy level that prevents up-conversion processes and depopulation of this level by means of energy back transfer. The second condition is high enough $^4I_{13/2}$ level lifetime to keep quite low laser threshold. These conditions are well satisfied in Er, Yb:RAl-borates, which leads to the high interest in investigating the laser properties of these hosts [1–5]. However, the growth of these crystals with high optical quality and sufficient sizes ($\sim 20 \times 10 \times 10$ mm^3) for such applications remains a comparatively expensive process [6]. By this way the search for new relatively low-cost optical glass–ceramic composites with micro-crystals well-recommended before is promising [7–9].

2. Experimental

Complex fluxes based on potassium trimolybdate $K_2Mo_3O_{10}$ with an addition of boron and rare earth oxides were used in all $YAl_3(BO_3)_4$ (YAB) and $GdAl_3(BO_3)_4$ (GdAB)-crystal growth experiments. Starting chemicals (at least 99.99% and 99.999% purity for rare earths and other materials, respectively) were Y_2O_3, Gd_2O_3, Yb_2O_3, Er_2O_3, Al_2O_3 and B_2O_3, but $K_2Mo_3O_{10}$ was previously sintered from K_2MoO_4 and MoO_4 according to reaction:

$$K_2Mo_3O_{10} = K_2MoO_4 + 2MoO_3.$$

K_2MoO_4 was obtained by calcination of $K_2MoO_4 \cdot 10H_2O$ in a Pt crucible at about 500 °C during 24 h, and MoO_3 was prepared of H_2MoO_4 on the same scheme.

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