A NOVEL IR-TRANSPARENT Ho^{3+}:Y_2O_3–MgO NANOCOMPOSITE CERAMICS FOR POTENTIAL LASER APPLICCATION

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The work is devoted to obtaining of transparent nanocomposite materials as low loss, highly thermally conductive materials for potential laser applications. We report Ho^{3+}:Y_2O_3–MgO nanocomposite ceramics with excellent mechanical and optical properties by combining glycine-nitrate process and spark plasma sintering. Morphology, structural-phase state, infrared transmittance and luminescence depending on the holmium concentration (0…12 at.%) were studied for the first time. It was found that optical transmittance reaches 75% at 6000 nm for 3 at.% Ho^{3+}:Y_2O_3–MgO ceramics.

Keywords: transparent ceramics, nanocomposite, spark plasma sintering, eye-safe lasers, luminescence

Introduction. Lasers emitting in the mid-infrared (mid-IR) spectral range (2–6 μm) are of great interest for use in a wide variety of applications including industry, atmospheric sensing, LIDARs and medicine. General trend in creation of such lasers is a search for the most promising high thermal conductivity host materials. The key to solve the problem of low loss, highly thermally conductive transparent ceramics for potential laser applications may be the development of transparent nanocomposite materials. The advantages of transparent nanocomposites include high optical quality inherent to single crystals, higher thermal conductivity and mechanical properties compared to the constituent oxides. The basic strategy for the synthesis of composite nanoceramics is to control their structural-phase state at the nanoscale by using consolidation methods that suppress the diffusion mass transfer such as spark-plasma sintering (SPS), hot isostatic pressing (HIP), etc. The optical transparency of nanoceramics in the IR range of the spectrum occurs due to the low light scattering on defects and interphase boundaries with characteristic dimensions of several nm. Fabrication of composite nanoceramics involves the creation of a nanocomposite of two or more non-soluble components in the solid state. In this case, grain growth can be suppressed due to the fact that the grains of each phase pin the boundary of the other phase [1–3]. At the same time, the requirement to ensure transparency of nanocomposite in a wide range of wavelengths requires the use of materials with a cubic structure and wide transparency windows. The optical transmission of composite nanoceramics will be realized for average grain sizes of less than 150–200 nm, whereby the contribution of light scattering at the interphase boundaries will be minimal. Recently, fabrication of Y_2O_3–MgO transparent nanocomposite ceramics has been reported [4–6]. The aim of this work is to determine the influence of Ho^{3+} ions on the structural-phase state of the Ho:Y_2O_3–MgO ceramic.

Experimental part. 50:50 vol.% 3, 6, and 12 at.% Ho^{3+}:Y_2O_3–MgO nanocomposite ceramics were prepared by means of GNP and SPS techniques. The phase identification was performed by X-ray diffraction method (XRD) using a SIEMENS D-500 X-ray diffractometer (CuKα-radiation, graphite monochromator). The optical properties of ceramics were studied using a Fourier-Transform Infrared (FTIR) spectrometer (Vertex-80, Bruker Optik GmbH, Germany) in the wavelength range of 1000–10000 nm.

Results. The obtained ceramics are characterized by a biphasic structure with a uniform grain distribution of both phases in the sample, which allow effectively stabilize the average grain size of ceramics of about 200 nm. Holmiumcontaining secondary phases with dimension of 1–15 nm were revealed at the grain boundaries of nanocomposite due to the sintering features of ceramics by the SPS in graphite tooling.

XRD shows that holmium ions enter only Y_2O_3 structure with the formation of $(Y_{1-x}Ho_x)_2O_3$ substitutional solid solutions in the whole concentration range of Ho^{3+} ions studied. The highest in-line transmittance of 75% at 6000 nm was obtained for ceramics doped with 3 at.% of Ho_{3+} ions, which is 5% higher compared to undoped Y_2O_3–MgO. This fact is connected with smaller ionicity degree of Ho–O bonds compared to that of Y–O, leading to enhanced diffusion in yttrium sublattice.

All nanocomposite ceramics show dominant luminescence in the green and infrared domains, as well as a weak emission in the red domain. The 6% Ho^{3+}:Y_2O_3–MgO nanocomposite demonstrates the strongest emission intensity in the 1925–1975 nm wavelength range. It has been shown that increase of holmium concentration decreases the luminescence intensity at 1200 nm ($^5I_6 \rightarrow {}^5I_8$) and 2000 nm ($^5I_7 \rightarrow {}^5I_8$) due to the cross-relaxation processes. The absorption cross-section at 1931 nm and the emission cross-section at 2118 nm were determined to be $\sigma_{abs}=0.51\times10^{-20}$ cm^2 and $\sigma_{em}=0.29\times10^{-20}$ cm^2, respectively, proving that Ho^{3+}:Y_2O_3–MgO nanocomposite could be a promising material for high-power eye-safe lasers operating at wavelengths ~2 μm.

Conclusions. It is shown that the consolidation of glycine-nitrate nanopowders of Ho:Y_2O_3–MgO (50:50 vol.%) using spark plasma sintering allows obtaining a homogeneous two-phase nanoceramic by suppressing recrystallization through grain boundary collisions of mutually insoluble phases. The optical transparency of the composite can be achieved under the conditions of forming a homogeneous two-phase structure, spatial confinement of the recrystallization processes of components, and maintaining grain size at the level of 200-250 nm, at which the contribution of light scattering at interphase boundaries is minimal.

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