INTRODUCTION

At present, transparent ceramics have been widely known as a material for laser matrices [1]. Their main advantage over single crystals is a relative simplicity of making samples of any necessary shape and size. Methods of formation of transparent ceramics are constantly improved and, even now, make it possible to obtain samples optical properties of which are barely worse than those of crystalline analogs [2]. However, as far as scintillation properties are concerned, transparent ceramics still cannot be considered to be unequivocally competitive with crystals. For some compounds, the luminescence specific light yield is somewhat lower than that for single crystals [3], whereas, for other compounds, it is higher [4]. The objective of this work is to study the luminescence properties of transparent ceramics of yttrium aluminum garnets (YAGs) $Y_3Al_5O_{12}$ doped with Yb.

Ytterbium doped oxide matrices are traditionally used as laser materials [5]; however, they are also interesting from the viewpoint of existence of radiative transitions from the charge transfer state—charge transfer luminescence (CTL). This type of luminescence is characterized by decay times from a few nanoseconds (at room temperature) to hundreds of nanoseconds (at liquid helium temperatures), and, at temperatures of ~100 K, has a light yield that is sufficient for registration (more than 10% of the light yield of BGO [6]), which is attractive for various applications. The objective of this work was to analyze spectral characteristics of transparent YAG ceramics doped with ytterbium, which allowed us to study particular features of different types of luminescence in these structures.

OBJECTS OF STUDY AND MEASUREMENT TECHNIQUE

We studied YAG ceramics doped with Yb$^{3+}$ ions at different concentrations: 0.3, 1, 2, 9.8, 12, and 15%, as well as an undoped sample. All ceramics were prepared at the Konoshima Chemical Co., Ltd by the vacuum sintering and nanocrystalline technology (VSN) [7, 8]. For comparison, we also measured spectra of YAG single crystals. A YAG crystal with a concentration of ytterbium of 0.4% was grown by the Czochralski method at the Institute of Laser Physics, Hamburg University (Germany), and a crystal with 13% Yb was obtained at the FEE, Idar-Oberstein (Germany). From a series of experiments, we measured luminescence and luminescence excitation spectra in the energy range 4–30 eV at room temperature, 100 K, and liquid helium temperatures, as well as temperature dependences of luminescence and of its decay kinetics. The measurements were performed at the SUPERLUMI setup at DESY–HASYLAB (Hamburg, Germany) [9].
RESULTS AND DISCUSSION

Figure 1 presents the luminescence spectra of YAG crystal and ceramics doped with ytterbium. In the visible spectral range, two charge transfer bands are clearly observed, the maxima of which are peaked around 340 and 490 nm. These bands correspond to the transitions from the charge transfer state to the $2F_{5/2}$ and $2F_{7/2}$ levels of the Yb ion [10]. In the infrared range, an intense $4f-4f$ luminescence band of Yb$^{3+}$ ions is observed, which is used in lasers.

At 8 K, the decay kinetics of the two CTL bands is fast with characteristic decay times varying from 50 ns for the ceramics with an Yb concentration of 15% to 95 ns for the sample with an Yb concentration of 0.3%. The luminescence band at 340 nm decays nearly exponentially, while the behavior of the decay time in relation to the Yb concentration is characteristic of the concentration quenching. The CTL decay curves of ceramics and crystal with closer ytterbium contents (12 and 13%, correspondingly) are almost indistinguishable; i.e., kinetically, the CTL observed in ceramics is analogous to the luminescence in crystals.

The excitation spectra of the CTL band at 340 nm for ceramics and crystal are shown in Fig. 2. The excitation spectra of samples with a low Yb concentration (0.3 and 1%) exhibit a pronounced maximum at 6.1 eV, which is caused by the absorption with charge transfer. This peak is followed by a dip at 6.8 eV, which arises due to near surface losses in the range of exciton absorption. For remaining samples, in which the Yb concentration was higher, apart from the mentioned features at 7 eV, another local maximum is observed. The spectra presented in Fig. 2 are normalized to the intensity of the peak at 6.1 eV. We can see from these spectra that, for ceramics, the magnitude of the peak at 7 eV decreases with increasing Yb concentration (from 9.8 to 15%); however, the highest intensity with respect to the main maximum in the range of 7 eV was observed for a single crystal with an Yb concentration of 13%.

It seems that the occurrence of a characteristic plateau in the range of the maximum in the excitation spectra of samples with high Yb concentrations (9.8—15%) is caused by the saturation effect. The luminescence intensity $I_{\text{lum}}$ depends on the intensity $I_{\text{ex}}$ of the excitation radiation incident on the sample as

$$I_{\text{lum}} \sim (1 - e^{-\alpha d}) \eta I_{\text{ex}},$$

where $\alpha$ is the absorption coefficient, $d$ is the thickness of the sample, and $\eta$ is the luminescence quantum yield [11]. Therefore, when the difference in the parentheses tends to unity, $I_{\text{lum}}$ is governed only by the quantum yield $\eta$, which manifests itself in the luminescence excitation spectrum as a plateau. Hence, thickness of the sample of ~100 µm proves to be sufficient in order to absorb all excitation radiation with the energy of 5.7—6.2 eV in the charge transfer band.

As the temperature increases from 8 to 100 K, the relative intensity of the peak at 7 eV in the excitation spectrum increases, as well as the higher-energy spectral range, which corresponds to the creation of electron—hole pairs (see the inset of Fig. 2); i.e., the probability of energy transfer from electron—hole pairs to