Characteristic features of the low-temperature luminescence of $YBa_2Cu_3O_{7-x}$

V. A. Gaĭsin, B. S. Kulinkin, and B. V. Novikov
Leningrad State University

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The photoluminescence spectra of $YBa_2Cu_3O_{7-x}$ ceramics and single crystals in the region 360–400 nm have been studied. The lasing effect has been observed for the first time. A correlation between luminescence and zinc-oxide microinclusions has been established.

The observation of several lines situated in the near-UV region, 367–375 nm, in the spectra of photo- and cathodoluminescence of $YBa_2Cu_3O_{7-x}$ ceramics was reported in Refs. 1–4. A characteristic feature of the temperature dependence is the threshold intensification of the lines as the temperature is lowered. The lines $\lambda = 374.5$ nm and 369.5 nm appear in the luminescence at 170 K and 60 K, respectively.[1,2] The line $\lambda = 367$ nm (the λ line) intensifies in the cathodoluminescence as the ceramic undergoes a transition to the superconducting state at 93 K (Refs. 3 and 4). The α line was interpreted as a manifestation of the intrinsic luminscence of the ceramic. In Refs. 1–4 the authors reported a nonuniform distribution of luminescence along the surface of the ceramic and suggested that there might be a correlation between the luminescence and the microinclusions of a foreign phase.

Ambiguous interpretation and the absence of information about the luminescence of $YBa_2Cu_3O_{7-x}$ single crystals impelled us to carry out a detailed study of the luminescence of this compound in the near-UV region.

In the present letter we report the results of an experimental study of the photoluminescence spectra of the superconducting $YBa_2Cu_3O_{7-x}$ ceramics and single crystals in the temperature interval 1.6–300 K under different conditions of laser pumping (LGI-21 laser). To record the spectra, we used a double grating monochromator which was assembled from two high-transmission MDR-2 monochromators. The use of the spectral apparatus enabled us to record spectra of the emitting regions of up to 50 μm in size. We found that in the ceramics and single crystals only single points emit light. At 300 K the luminescence spectrum consists of a broad, asymmetric band with a peak at 381 nm (Fig. 1a).

The shape of the luminescence band of all the investigated points is the same.

At temperatures $T < 120$ K the luminescence spectra of some regions of the ceramic sample were found to have narrow luminescence lines that grew in intensity (Fig. 2, b and c). These lines are situated inside the luminescence contour line, and the polarization of the lines coincides with the polarization of the excitation lines. These lines were so narrow that we could not determine their half-width with the measurement apparatus we used (their contour coincided with the instrumental function of the apparatus, 0.2 nm). The number of lines detected depended on the point at which

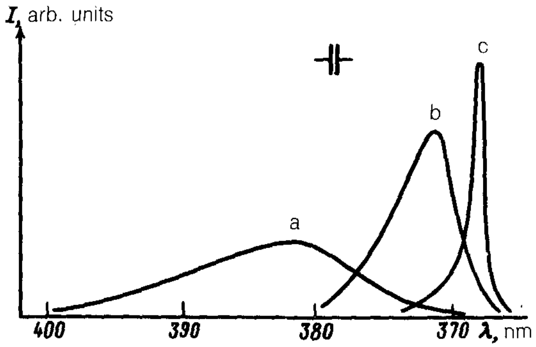

FIG. 1. Luminescence spectra of the UV band excited by a LGI-21 pulsed nitrogen laser (the weak excitation level is $\sim 10^{23}$ phot/s): a—300 K; b—77 K; c—1.6 K.

they were observed. This number varied from 1 to 20. The temperature at which the lines appeared varied with the variation of the power level of the laser. At a constant temperature these threshold excitation lines appeared in the luminescence spectrum as the power level of the laser was increased. The luminescence spectrum for one of the test points is plotted in Fig. 3 as a function of the power level of the laser pumping at $T = 100$ K.

The threshold dependence of the line intensification on the pump power and the presence of polarization are evidence that these are lasing lines. The large variety of lasing spectra and a narrow half-width of the lines stem from the fact that there are

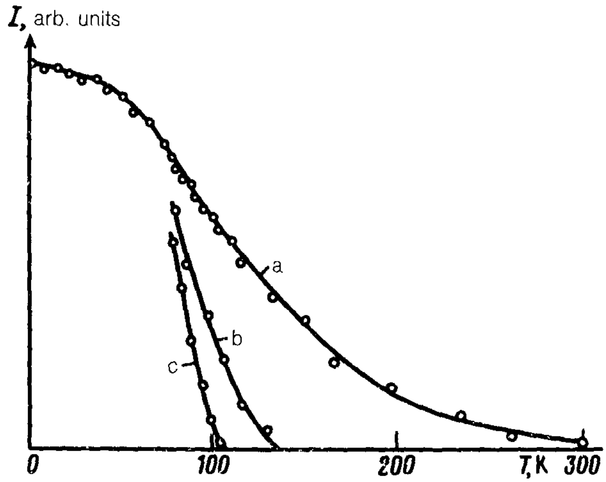

FIG. 2. (a) Temperature dependence of the integrated luminescence intensity of a UV band in the case of weak excitation ($\sim 10^{23}$ phot/s); (b,c) thermal luminescence of the lasing lines $\lambda = 373.2$ nm and 371.8 nm, respectively (the excitation level is $\sim 10^{24}$ phot/s). The luminescence was excited by LGI-21 pulsed nitrogen laser.

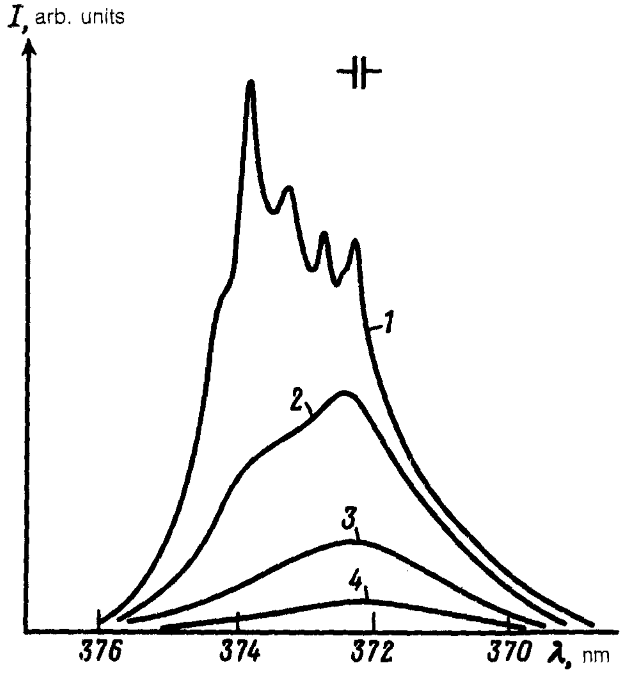

FIG. 3. Luminescence spectrum of the UV band vs the excitation level of the LGI-21 laser. 1—6×10^{23}; 2—4×10^{23}; 3—2.5×10^{23}; 4—1.0×10^{23} phot/s.

individual lasing modes. The band broadened and the maximum shifted toward the long-wave side of the spectrum in those regions where the lasing lines were not seen when maximum pump power was applied. The band broadening is seen most clearly at $T = 1.6$ K.

At a minimum pump level, when the narrow lines did not luminesce, we measured the temperature dependence of the spectral parameters of the luminescence band at temperatures 1.6–300 K. As the temperature of the sample was lowered, the UV band contracted, the maximum shifted toward the short-wave side of the spectrum, and the integrated intensity increased.

At $T = 1.6$ K the spectrum exhibited a narrow line with $\lambda = 368.8$ nm and a half-width of 0.2 nm (Fig. 1c). The temperature dependence of the line intensity is shown in Fig. 2a.

In contrast with the data of Refs. 2 and 3, no anomalies in the transition of the sample to the superconducting state were observed as a result of changing the spectral parameters of the luminescence band.[1)]

The absence of a temperature correlation between the luminescence intensities upon the transition of the ceramic to the superconducting state and the fact that luminescence occurs in only certain parts of the sample lead us to assume that the UV luminescence we have observed is attributable to the microinclusions of a different phase. Such microinclusions, which are transparent microcrystals with a maximum size of $\sim 20\ \mu m$, we were able to extract from the ceramic. A qualitative x-ray spectral microanalysis carried out with a Camebax microanalyzer showed that these microinclusions contain an appreciable amount of zinc. Comparing our results with the published data for various zinc compounds, we concluded that the UV luminescence, which we have observed in the ceramics and single crystals of $YBa_2Cu_3O_{7-x}$, is identical to the luminescence of zinc oxide. The position of the band peaks, the temperature-induced shift, and the lasing effect are in good agreement.[5] The narrow line at 368.8 nm detected at 1.6 K is probably the M-band luminescence. It can be assumed that zinc-oxide microcrystals form in the synthesis of the superconducting $YBa_2Cu_3O_{7-x}$ materials upon oxidation of zinc which is contained in the initial components as an impurity.

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[1)] The curves of the temperature dependence exhibited structural features only when lasing the effect occurred upon changing the temperature. The lasing effect was sometimes observed near the superconducting transition temperature (Fig. 2, b and c). We assume that the lasing effect should be taken into account in evaluating the results of Refs. 1–3.

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