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Photoluminescence of Er^{3+} ions in Bi_2TeO_5 single crystals

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Abstract

Optical absorption and emission spectra of Er^{3+} ions in Bi_2TeO_5 single crystals have been studied at room temperature. Besides the $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$, and $^4F_{9/2} \rightarrow {}^4I_{15/2}$, emission, that were typically strong under excitation to higher energy manifolds than the actual emission, the $^4S_{3/2} \rightarrow {}^4I_{13/2}$ luminescence was also intense. The visible transitions were assigned, and Judd–Ofelt calculation was performed by fitting the experimental data set. The calculated Ω_t Judd–Ofelt intensity parameters ($\Omega_2 = 6.98 \pm 0.57 \times 10^{-21}$ cm^2; $\Omega_4 = 1.74 \pm 0.05 \times 10^{-21}$ cm^2; $\Omega_6 = 1.23 \pm 0.12 \times 10^{-21}$ cm^2) were consistent with the Bi_2TeO_5 crystal structure and the Er^{3+} substitution for Bi sites. The radiative transition probabilities, the branching ratios and the radiative lifetime of the transitions of Er^{3+} ions in bismuth tellurite were also calculated. The results are analyzed for potential application of Bi_2TeO_5:Er^{3+} as a new laser material.

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Keywords: Er^{3+}-luminescence; Laser material; Judd–Ofelt theory

1. Introduction

During the last few years Er^{3+}-doped materials have been widely investigated for possible laser applications, especially in spectral ranges around 1517 nm ($^4I_{13/2} \rightarrow {}^4I_{15/2}$) and 860 nm ($^4S_{3/2} \rightarrow {}^4I_{13/2}$), which have low loss in optical waveguide and are safe to human eyes [1]. Also, Er^{3+} is an attractive candidate as a dopant for infrared-pumped visible luminescence and laser emission. Particularly, lasing at the green transition $^4S_{3/2}$–$^4I_{15/2}$ has led to fruitful results with fiber

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and bulk structures [2]. Within the Er manifolds several luminescence transition occur to the $^4I_{13/2}$ level that is not populated at room temperature (RT), and this provides several possible laser channels [3]. Therefore, up-conversion luminescence in several Er-doped materials has also been investigated for laser fabrication to optical communication systems [1,2,4].

Bi_2TeO_5, crystal is a new optical material, which exhibits interesting non-linear properties. For example, its photorefractive properties look attractive for holographic memory application [5]. Also, the crystal can be doped with rare earth ions, like Er^{3+}, in homogeneous, high concentration [6]. Bi_2TeO_5 has an orthorhombic crystal structure with Abm2 symmetry. A large number (17%) of structural oxygen deficiency is characteristic to the Bi_2TeO_5 crystals, which is related to the charge compensation of the Bi^{3+} ions in the CaF_2-based lattice. This makes Bi_2TeO_5 a special host for dopants having three slightly different Bi^{3+}sites (with 8 and 7 oxygens in the coordination spheres, respectively) and a Te^{4+} lattice site (with 3 covalent and 2 ionic bondings to oxygens). The basic absorption spectra of Er in Bi_2TeO_5 were presented in Refs. [6,7] for the infrared and visible transitions.

The aim of this work is to study the luminescence of the Er^{3+} ions in Bi_2TeO_5 single crystals. In the present work the Judd–Ofelt model was employed to estimate the oscillator strength, radiative probabilities, radiative rates and the total lifetime of transitions between multiplets of the Er^{3+} ion in Bi_2TeO_5 crystal matrix. Results are compared with the experimental observations, and the potential of Bi_2TeO_5:Er^{3+} as laser material was discussed.

2. Experimental

Single crystals of bismuth tellurite were grown from the melt by the balance-controlled Czochralski technique in air, using resistance heating and platinum crucible. The detailed growth conditions can be found in Ref. [8]. Er dopant was added to the melt in the form of Er_2O_3 in a concentration of 10^{-3} Er atom per mole of host. The built-in Er concentration was determined by atomic absorption spectroscopy (AAS). More details of the analytical process can be found in [6,9]. The crystals were typically X-ray oriented, cut and polished, but for the [1 0 0] orientation optical quality surfaces could be obtained by cleaving. The typical sample dimensions for the spectroscopic investigations were $6 \times 6 \times 7\,mm^3$. The refractive indices of the biaxial Bi_2TeO_5 single crystal were reported in [10]. To perform Judd–Ofelt calculation we used the average of the n_b and n_c values that corresponded to the given crystal orientation for the absorption measurements.

The absorption spectra were measured by a Cary 14 type spectrophotometer in the whole IR and VIS spectral range at RT. All the luminescence measurements were also done at RT. Fluorescence excitation and emission spectra with continuous excitation were obtained with a Hitachi F-4500 spectrofluorimeter equipped with a 150 W Xenon lamp. The high resolution luminescence setup consisted of a Spectra-Physics Argon laser (200 mW at the 488 nm output used) as excitation source, and a Spex double monochromator for dispersion with a photon-counting readout system using a cooled RCA C31034 phototube for detection. The whole system was arranged in the conventional 90° scattering geometry. The data collection was performed with a Datamate microprocessed controller. Pulsed excitation photoluminescence measurements were carried out by a Perkin–Elmer LS-5 fluorescence spectrophotometer. The light source was a 10 W Xenon lamp with 0.01 ms pulse duration at half peak intensity. For shorter luminescence lifetime an EGG 2100 tunable Dye laser was used as excitation source. In these measurements, the fluorescence was monitored by a 0.45 m Czerni–Turner monochromator, detected by a cooled Hamamatsu R-943-03 photomultiplier tube and processed by an EGG/Par 162 Boxcar averager.

3. Judd–Ofelt theory

Judd–Ofelt approach [11,12] has been employed to describe the absorption and photoluminescence properties of the radiative transitions of trivalent