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Journal of Alloys and Compounds 323–324 (2001) 788–791

Journal of ALLOYS AND COMPOUNDS

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Magnetic field effect in the luminescence of Er^{3+} ion in $(Er_{0.05}Y_{0.95})_2BaZnO_5$

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Abstract

Luminescence of Er^{3+} ion in Y_2BaZnO_5 was measured in the presence of a magnetic field, with the purpose of gathering information about the electronic structure. Luminescence measurements in Y_2BaZnO_5:Er^{3+}, performed at 2 K in a magnetic field up to 4.00 T are presented. Emitted light from the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition (17 800–18 400 cm^{-1}) was detected propagating parallel to the external magnetic field. A $g = 10$ factor for the ground state of the Er^{3+} was evaluated from the splitting of the 18 316 cm^{-1} line. The same result allowed us to evaluate a g factor equal to two for the lowest sublevel of the $^4S_{3/2}$ excited state.

Keywords: Spectroscopy; Er^{3+}; Y_2BaZnO_5

PACS: 78.55 Hx

1. Introduction

The structure of the oxide family Re_2BaCuO_5 (Re = Sm, Eu, Gd, Ho, Er, Tm, Yb and Y) was determined by Michel and Raveau in 1982. The Re occupies two different sevenfold oxygen-coordinated sites with the same symmetry but with slightly different Re–O distances [1]. For the Y_2BaCuO_5 sample, a magnetic order was found in 1988 from the splitting of absorption lines of the Er^{3+} ion [2]. The isostructural family, Re_2BaZnO_5 [3], is transparent to visible radiation, whereas the copper family has only a transparency window at the green region of the spectrum. Therefore, the zinc family is more suitable for the study of optical properties of rare-earth ions in the visible region.

In this work, we present luminescence spectra for $(Er_{0.05}Y_{0.95})_2BaZnO_5$ to estimate a g factor of ten for the ground state and a g factor of two for the $^4S_{3/2}$ excited state for one of the non-equivalent positions occupied by the Er^{3+} ion.

2. Experimental

Samples were produced by conventional solid-state reaction. A mixture of Er_2O_3, Y_2O_3, CuO, ZnO and $BaCO_3$ with nominal composition $(Er_{0.05}Y_{0.95})_2BaZnO_5$ was performed in agate mortar and fired in alumina crucibles at 1323 K for 144 h in air. Two intermediate grindings of the product of the reaction were made at 24 and 48 h after starting the process. After 144 h, the product of the reaction was slowly cooled to room temperature. Then the product was pressed into pellets and sintered at 1073 K over 12 h. The pellets were mounted in an immersion bath cryostat for optical and magneto-optical measurements [4].

Luminescence spectra were obtained using a Lexel CW Ar ion laser pumping the $^4I_{15/2} \rightarrow {}^4F_{7/2}$ transition of the Er^{3+} ion at 20 491 cm^{-1} (line 488 nm). The excitation beam was filtered in a spatial prism filter and by a short pass color filter (500 nm). The luminescence light was filtered by two long pass color filters (495 and 530 nm). The luminescence light was analyzed by a Jarrell-Ash (0.5 m) monochromator coupled to an RCA GsAs 4832 photomultiplier. Care was taken with the geometrical arrangement in order to avoid specular reflected laser light. The

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PII: S0925-8388(01)01146-X

electrical signal was measured with an SR530 lock-in amplifier and the results were stored in a computer.

3. Results and discussions

Fig. 1a displays the luminescence spectrum for the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ optical transition of the Er^{3+} ion in $(Er_{0.05}Y_{0.95})_2BaZnO_5$. At high temperature (240 K), all levels of the $^4S_{3/2}$ multiplet are populated and all transitions occur between these two multiplets. When the temperature decreases to 2 K, only the lowest level of the $^4S_{3/2}$ becomes populated. This observation permits us to identify the higher energy lines [lines indicated by a circle in the 2 K spectrum in Fig. 1a as being transitions between the lowest level of the $^4S_{3/2}$ to the ground state (transition indicated by (1) in Fig. 1b)]. The appearance of two closely spaced lines in the high-energy region of the emission spectra presented in Fig. 1a ($T = 2$ K) is due to the two non-equivalent positions for the Er^{3+} ion in the sample. In each non-equivalent position, the Er^{3+} ion is subject to different crystal-field interactions. This and the fact that there is energy transference between the Er^{3+} ion in the two non-equivalent positions in the sample [5] suggests an explanation for the variation in intensities of lines observed experimentally.

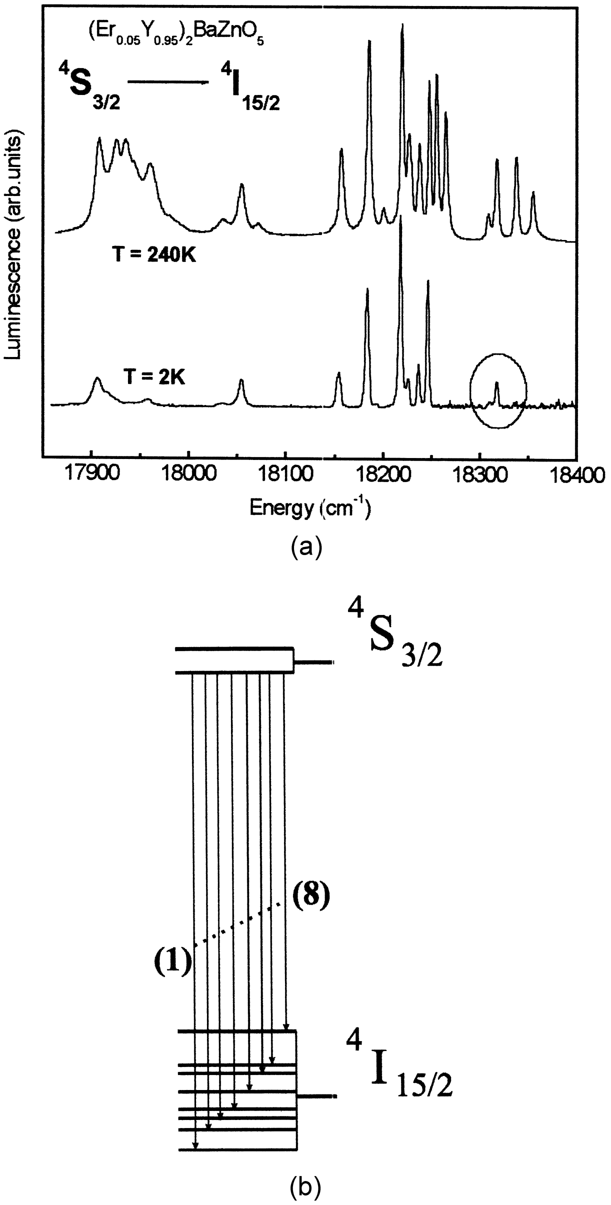

Fig. 1. (a) Emission spectrum for the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition of the $(Er_{0.05}Y_{0.95})_2$ $BaZnO_5$ sample. This spectrum was recorded at 240 and 2 K. The lines inside the circle are transitions between the lowest level of the $^4S_{3/2}$ to the ground state. (b) A simple level scheme to show the transitions observed in Fig. 2a.

In Fig. 2a, we present the behavior of the higher energy line of the emission spectra for magnetic fields between 0.00 and 1.00 T. The higher energy line splits into two lines for magnetic fields greater than 0.40 T. At 1.00 T, this line becomes large. In Fig. 2b, the spectrum obtained for a field of 0.45 T is shown in detail. A good fitting for this spectrum is obtained if two gaussian lines are used with centers at 18 314.1 and 18 316.4 cm^{-1}, respectively. With these numerical values, we can estimate a g factor of 10.6. Therefore, we are not able to declare if this g factor is for the ground state or for the $^4S_{3/2}$ excited multiplet. To understand the behaviour of the spectra in Fig. 2a, we will assume that this estimated g factor is for the ground state of the Er^{3+} ion in one non-equivalent position of the Y_2BaZnO_5 sample.

In Fig. 2c, a diagram with the energy levels is presented. This transition occurs between the lowest level of the $^4S_{3/2}$ and the ground level, separated by an energy E_0. With a magnetic field applied to the sample, the Kramer's degeneration is broken, and transitions between these levels can occur. In Fig. 2c, for fields of 0.45 and 0.80 T, we assigned these transitions the numbers 1, 2, 3 and 4. From Fig. 2c, we can write:

$$E_1 = E_0 - \frac{1}{2} g_e \mu_B H - \frac{1}{2} g_0 \mu_B H \quad \text{(1) less energetic one}$$

$$E_2 = E_0 + \frac{1}{2} g_e \mu_B H - \frac{1}{2} g_0 \mu_B H \quad (2)$$

$$E_3 = E_0 - \frac{1}{2} g_e \mu_B H + \frac{1}{2} g_0 \mu_B H \quad (3)$$

$$E_4 = E_0 + \frac{1}{2} g_e \mu_B H + \frac{1}{2} g_0 \mu_B H \quad \text{(4) more energetic one}$$

where E_i ($i = 1$, 2, 3 and 4) is the value of the photon energy emitted in the transition i, g_e is the g factor for the excited state, g_0 is the g factor for the ground state, μ_B is the Boltzman constant and H is the magnetic field applied to the sample. By measuring $E_3 - E_1$ or $E_4 - E_2$, we can calculate the fundamental factor g_0.

For fields greater than 0.50 T, the lines become larger

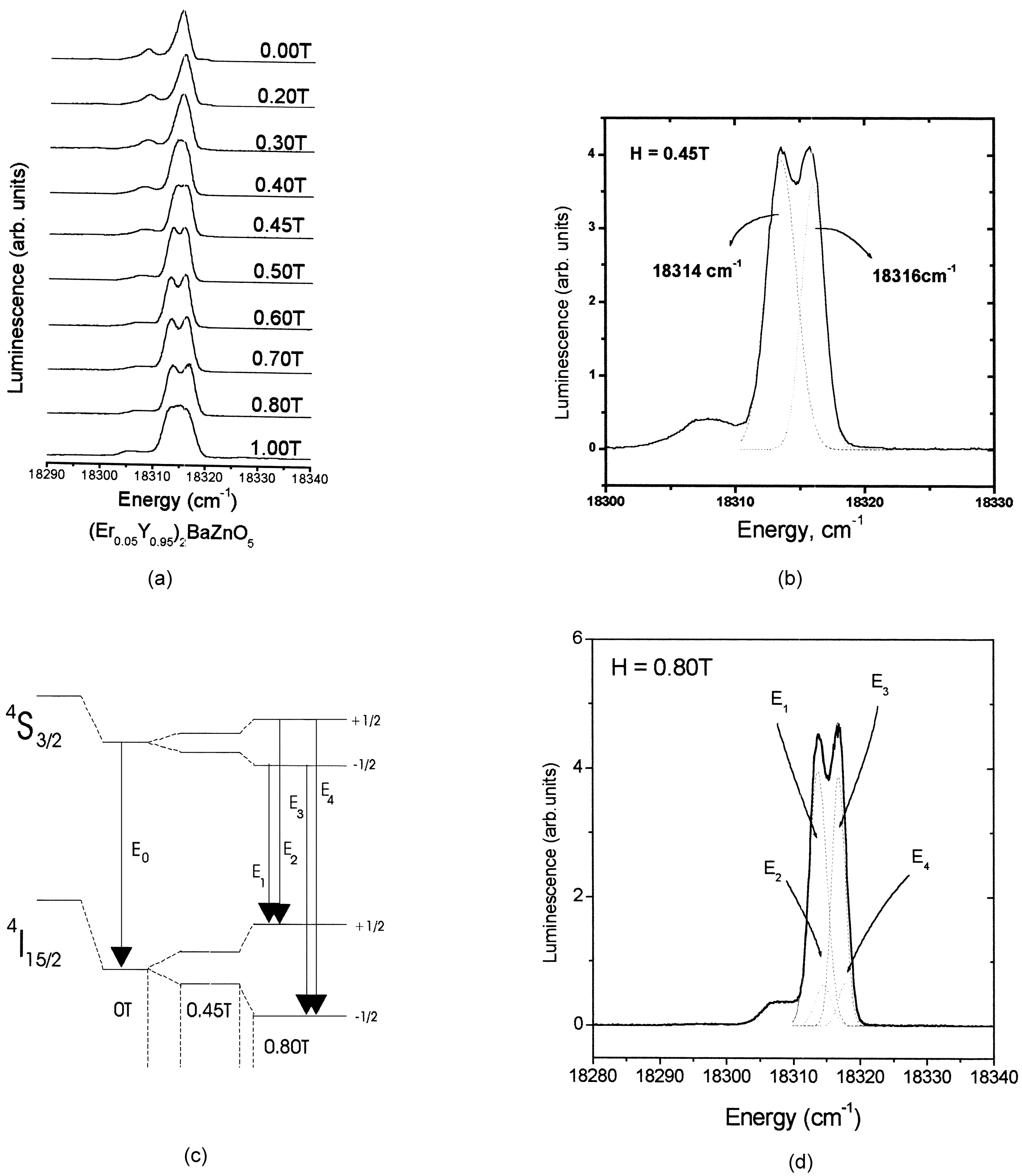

Fig. 2. (a) Behavior of the higher energy line of the emission spectra for magnetic fields between 0.00 and 1.00 T. (b) Experimental result recorded for a field of 0.45 T. Two gaussians centered at 18 314.1 and 18 316.4 cm^{-1} are used to make a good fitting for this spectrum. (c) The energy level diagram for the transitions observed. For fields of 0.45 and 0.80 T, we assigned these transitions the numbers 1, 2, 3 and 4. (d) Experimental result recorded for a field of 0.45 T. Four gaussians centered at $E_1 = 18\,313.7$ cm^{-1}, $E_2 = 18\,314.5$ cm^{-1}, $E_3 = 18\,316.8$ cm^{-1} and $E_4 = 18\,317.8$ cm^{-1} are used to determine a good fit for this spectrum.

and the splitting of the $^4S_{3/2}$ doublet becomes large enough to influence the energy positions of the lines. So, we can estimate the separation between the two levels of the fundamental Kramers doublet, for a field of 0.80 T, using the g_0 factor calculated before. We can then evaluate a separation of 3.9 cm^{-1} between the fundamental Kramers levels doublet, for this magnetic field intensity. Remember that this action is based on a guess.

Fig. 3c permits us to explain why the most energetic line became large at a field of 1.00 T. From this figure, we can see that the E_1 transition became the smallest line. The E_2 transition is the second in energy. The E_3 transition is the third while the E_4 transition became the most energetic. As the separation between lines E_1 and E_2 and between E_3 and E_4 grow linearly with the field at 1.00 T, the lines E_2 and E_3 are in about the same position (see Fig. 3d). This explains the disappearance of the splitting observed for fields smaller then 1.00 T.

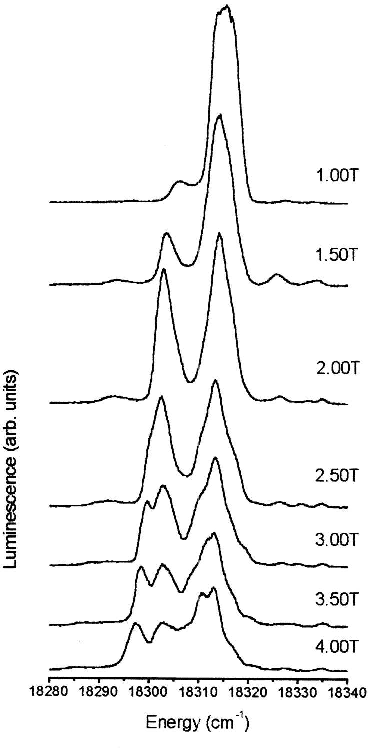

Fig. 3. Results obtained for fields between 1.00 and 4.00 T.

Using this speculative result, we can fit the experimental spectra recorded at 0.80 T. This was done in Fig. 2d. In this figure, we have fitted the experimental result including four gaussians and have tried to maintain the separation of 3.9 cm^{-1} between gaussians E_1 and E_3 and between gaussians E_2 and E_4. Good fittings were obtained, maintaining a separation of approximately 3.2 cm^{-1}. Gaussians lineshapes centered at $E_1 = 18\,313.7$ cm^{-1}, $E_2 = 18\,314.5$ cm^{-1}, $E_3 = 18\,316.8$ cm^{-1} and $E_4 = 18\,317.8$ cm^{-1} were obtained. From this result, we can calculate the separation between lines E_4–$E_2 = 3.3$ cm^{-1}; E_3–$E_1 = 3.1$ cm^{-1}; E_4–$E_3 = 1$ cm^{-1} and E_2–$E_1 = 0.8$ cm^{-1} and estimate a $g_0 \simeq 8.5$ and $g_e \simeq 2.4$.

For fields greater than 1.00 T, the spectra are presented in Fig. 3. As can be seen, the intensities of all lines change with the magnetic field. New experiments are being done in order to understand this behavior.

4. Conclusions

In this work, we have studied the emission $^4S_{3/2} \to {}^4I_{15/2}$ as a function of the magnetic field applied to the $(\mathrm{Er}_{0.05}\mathrm{Y}_{0.95})_2\mathrm{BaZnO}_5$ sample. From this study, we were able to estimate $g_0 \simeq 10$ for the ground state of the Er^{3+} ion in one of the non-equivalent positions occupied by this ion in the sample. We also estimated a $g_e \simeq 2$ for the lowest Stark sublevel of the $^4S_{3/2}$ excited state.

Acknowledgements

This work was supported in part by FAPESP and UEPG.

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