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Effects of yttrium codoping on fluorescence lifetimes of Er^{3+} ions in SiO_2–Al_2O_3 sol–gel glasses

P.T. Nga [a,c,*], C. Barthou [b], P. Benalloul [b], P.N. Thang [a], L.N. Chung [a], P.V. Hoi [a,c], L.V. Luat [c], P.T. Cuong [d]

[a] *Institute of Materials Science of VAST, Optic and Spectroscopy, 18 Hoang Quoc Viet, Cau Giay Dist., Hanoi 84, Viet Nam*
[b] *Universités Pierre et Marie Curie et Denis Diderot, Institut des Nanosciences de Paris, CNRS-UMR7588, France*
[c] *College of Technology- VNUH, Hanoi, Viet Nam*
[d] *Thai Nguyen Pedagogical University, Viet Nam*

Abstract

In order to find a new glass host and optimize erbium doping for IR glass optical amplifiers in photonic applications, a study on the optimization of the emission of erbium ions in the SiO_2–Al_2O_3 glass by codoping with Y_2O_3 is performed. It is first attempted to make a new sol–gel glass host based on SiO_2, Al_2O_3, and Y_2O_3 doped with Er^{3+} ions of the composition $(1-x)SiO_2$–xAl_2O_3–yY_2O_3:$0.65Er_2O_3$ (in mol%), x varies from 0 to 65, and y from 0 to 4. The optimal proportion in mol% of SiO_2 and Al_2O_3 for the Er^{3+} emission (at a fixed optimal concentration of 0.65) was 65 – 35. The effect of Y_2O_3 content on photoluminescence, decay curve profiles and lifetime of the $^4I_{13/2}$ level of Er^{3+} in SiO_2–Al_2O_3 glass is observed. The largest quantum efficiency and the higher emission intensity are observed in the sample with $65Al_2O_3$ and $4Y_2O_3$. The emission intensity at 1530 nm is two times higher than in glasses without Y_2O_3. A shift of 3 nm to shorter wavelengths is observed. The emission spectral profiles are flatter and broader for the glasses containing Al and Y (bandwidth of 59.5 nm). The decay curves show strong difference profiles for the different samples. The increase of the lifetime value τ (about ms) of the $^4I_{13/2}$ level of Er^{3+} in the SiO_2–Al_2O_3 with the Y_2O_3 is discussed.

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1. Introduction

Sol–gel erbium-doped glasses are of interest for various applications including solid state micro-sphere lasers, optical waveguides, and optical amplifiers. The erbium-doped fiber amplifier (EDFA), utilizing the emission transition $^4I_{13/2} \rightarrow {}^4I_{15/2}$ of Er^{3+} ions, is a key element of the 1.5 μm telecommunication systems. Due to the rapid increase of information capacity and the need for flexible networks, there is an urgent demand for optical amplifiers with a wide and flat gain spectrum in the telecommunication window, to be used in the dense-wavelength-division-multiplexing (DWDM) networks. Expansion of DWDM systems thus makes the capacity and bandwidth of fiber-optic amplifiers key aspects of the system. The EDFA is made by Er^{3+}-doped silica glass, which shows a narrow emission band at 1.53 μm resulting in narrow gain spectra with a bandwidth around 30 nm. The study on spectral broadening of the 1.53 μm emission of Er^{3+}-doped various glasses, therefore, has been paid great attention [1–5]. For the purpose of broadening the bandwidth, to flatten the gain, we realized a study on the properties of Er^{3+} ions in the novel sol–gel multi-component glass based on SiO_2–Al_2O_3–Y_2O_3.

* Corresponding author. Address: Institute of Materials Science of VAST, Optic and Spectroscopy, 18 Hoang Quoc Viet, Hanoi 84, Viet Nam. Tel.: +84 4 7564333/11 61; fax: +84 4 7341872.
E-mail address: phtnga@ims.vast.ac.vn (P.T. Nga).

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Up to now, there is not yet any systematic investigation on the glasses of the composition $(100-x)SiO_2$–xAl_2O_3–yY_2O_3:$0.65Er_2O_3$, where x varies from 0 to 65 mol%, and y from 0 to 10 mol%, in comparison with the existing results; the sample up to 10 mol% of Al_2O_3 was investigated by Nogami et al. [6] and for 50 mol% by Nedelec et al. [7]. Recently, results on Er/Yb co-activated silica–alumina monolithic glasses increasingly were published, but the advantage of a specific Er/Yb/Al glass composition for the spectroscopy properties at 1.53 μm is not yet identified [8].

In this work, at first we study the optimal proportion of SiO_2 and Al_2O_3 for the Er^{3+} emission in the glasses doped with 0.65 mol% of Er_2O_3 (≈4 wt%), which is considered as the optimal concentration in pure SiO_2 sol–gel glass [9,10]. The introduction of Al_2O_3 improves rare earth dilution and prevents the micro clustering for silica glass hosts with Er^{3+} and therefore the luminescence intensity can be increased. With high concentration of alumina in glass, an exceptionally flat gain characteristic can be obtained. Y_2O_3 is added to the glass to form the composition of $(100-x)SiO_2$–xAl_2O_3–yY_2O_3:$0.65Er_2O_3$ (mol%). Yttrium (Y^{3+}) is chosen since it has a similar ionic radius and the same valence as Er^{3+} ion, therefore it can easily substitute itself and can increase the distance between two Er^{3+} ions. In this study, with only very small amount of Y_2O_3 added to the glass, a good behavior of the decay time of Er^{3+} is observed. Therefore, we will emphasize on the analysis of the decay curves and lifetimes of $^4I_{13/2} - {}^4I_{15/2}$ transition of Er^{3+} ions and the role of Al_2O_3 and Y_2O_3 concentrations in the glass host. The non-exponential nature of the fluorescence decay will be discussed.

2. Experimental

Using the sol–gel method as reported in previous studies [8,11], we have prepared a series of glass samples of the composition $(100-x)SiO_2$–xAl_2O_3–yY_2O_3:$0.65Er_2O_3$ (mol%), x varies from 0 to 65, $y = 0$, 2, 4, to 10. Volume ratios of reactants were chosen in order to realize a known total of Al (mol%SiO_2 + mol%Al_2O_3 = 1). The used chemical precursors were $Si(OC_2H_5)_4$ (TEOS) 98% and $Al(OC_4H_9^{sec})_3$ 98% from Merk. The rare earth salts were $ErCl_3 \cdot 6H_2O_3$, $Y_2(CO_3)$ 99.9% from Aldrich. The hydrolyzed mixture solution was stirred for 1 h, and then left for about 10 days to form a stiff gel of 26 × 230 mm. The stiff gel was dried at room temperature for 15 days, after that, it was heated in air for 2 h at 900 °C to form glass. All used glass samples in this study are transparent.

The glass samples were excited by a diode laser in the near IR range ≈980 nm, with an output power up to 200 mW. For the decay analysis, the laser diode was pulsed with a generator at a frequency of 10 Hz and 100 μs in width with a power energy up to 340 mW (34 μJ per pulse). The rise time is of the order of 6 μs and the fall time of the order of 4 μs. The IR emitted light from the sample, collected by an optical fiber located at 10 mm perpendicular to the surface, was analyzed on the same side as the excitation with a TRIAX 320 Spectrometer and a near IR array detector Hamamatsu (256 pixel). This setup has a resolution of 1 nm/point for a slit ⩽ 50 μm. The decays were analyzed by an InGaAs detector and a Nicolet 400 scope. This experimental setup has a time constant of the order of 50 μs. All measurements in this study were performed at $T = 300$ K.

3. Results on the effect of Y_2O_3 concentration on the lifetime of the $^4I_{13/2}$ level of Er^{3+} ions

In our previous work [11], we have analyzed the influence of the different glass compositions on the emission of Er^{3+} ions in the Near-IR region. In the glasses of $(100-x)SiO_2$–xAl_2O_3, with a fixed Er^{3+} concentration at 0.65 mol%, the higher emission intensity of $^4I_{13/2} - {}^4I_{15/2}$ transition at 1530 nm is reached for the samples containing 50 to 65 mol% in Al_2O_3. We observed also an increase in emission intensity in all glass samples containing a low amount of Y_2O_3 compared with the samples without Y_2O_3. The highest emission intensity of Er^{3+} ions is observed in the glass sample with $Al_2O_3 = 65$ mol% and $Y_2O_3 = 4$ mol%. Fig. 1 presents the influence on the Er^{3+} emission of the Al_2O_3 concentration for an Y_2O_3 content $y = 4$ mol%. We analyzed the emission intensities at 1530 nm for the different compositions of Al_2O_3 and Y_2O_3. The strongest emission intensity is observed for the sample $35SiO_2$–$65Al_2O_3$–$4Y_2O_3$:$0.65Er_2O_3$. The emission intensity at 1530 nm is two times higher than in the glass without Y_2O_3. A shift of 3 nm to shorter wavelengths is observed. The emission spectral profiles are flatter and broader than those in SiO_2 glass. The spectral bandwidth is 59.5 nm. The same situation is observed for the series of glass samples with 2, 6, 8 and 10 mol% Y_2O_3.

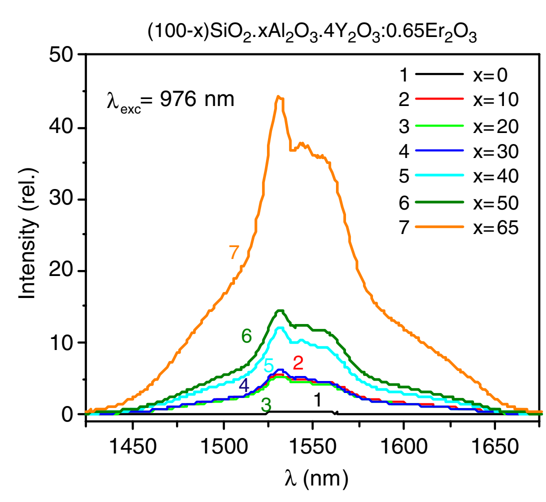

Fig. 1. Photoluminescence spectra (PL) of Er^{3+} in the glasses of the composition of $(100-x)SiO_2$–xAl_2O_3–$4Y_2O_3$: 0.65 Er_2O_3 $x = 0$, 10, 20, 30, 40, 50, 65 in mol%) under 976 nm excitation at 300 K, for comparison of relative fluorescence intensity of Er^{3+} ions at 1530 nm.