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Green up-conversion luminescence of erbium-doped oxyfluoride germanate fiber under continuous-wave laser-diode excitation

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ABSTRACT

Up-conversion luminescence of Er^{3+}-doped oxyfluoride germanate optical fiber is observed under laser-diode excitation. The enhanced green emission line is due to $^2H_{11/2}$,$^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+}. The integrated luminescence intensity related to $^2H_{11/2}$,$^4S_{3/2} \rightarrow {}^4I_{15/2}$ (green) and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ (red) transitions of Er^{3+} is reduced with increasing temperature. Several spectroscopic parameters of Er^{3+} ions in optical fibers were determined. The spectral linewidth is reduced, whereas the maximum of emission peak is shifted to longer wavelengths with increasing fiber length.

1. Introduction

Rare earth - doped optical glass fibers have a great interest due to numerous applications in medicine, telecommunication, military and laser technology. Lead silicate, germanate and/or tellurite based glasses belong to fundamental sources from which the optical fibers can be also fabricated [1–4]. They possess unique properties such as the ability to accept quite high concentrations of the optically active ions without clustering, high refractive indices and relatively low phonon energies. For that reason, optical fibers obtained from tellurite glass are well adapted to ignite up-conversion luminescence mechanisms [5–8]. Furthermore, Lin et al [9] confirmed that by physical and chemical dehydration technique to remove OH group from raw materials and via built-in casting method to make glass fiber preform, mid-infrared fluorotellurite glass fibers with low loss of 3.61 dB/m at 1550 nm were fabricated.

Recently, the up-conversion luminescence properties of Tm^{3+} and Ho^{3+} ions in germanate glass fibers were examined by us under direct excitation of Yb^{3+} [10–12]. In this work, a new optical results for Er^{3+} doped oxyfluoride germanate fibers are presented and discussed. Enhanced green up-conversion luminescence of trivalent Er^{3+} ions is observed under continuous-wave (cw) 980 nm laser-diode excitation.

2. Material and methods

Precursor glass with the following composition: $5BaF_2$-$25BaO$-$60GeO_2$-$9.5Ga_2O_3$-$0.5Er_2O_3$ (in mol%) was prepared by mixing and melting appropriate amounts of metal anhydrous oxides and fluorides of high purity (99.99%, Aldrich Chemical Co.) as starting materials. The relatively low activator concentration (0.5 mol%) was used in order to eliminate the energy transfer processes between rare earths. Due to the hygroscopicity of the fluorides and, in order to minimize the adsorbed water content, all glass components were weighted and stored in glove box, in a protective atmosphere of dried argon. Then, they were melted at 1200 °C/45 min. In the next step, optical fiber was manufactured using SG Controls drawing tower. Firstly germanate 10 mm diameter glass perform was fabricated by pouring glass mass into form. During drawing process fiber was coated with low refractive index silicone ($n_D = 1.4$) which is the fiber cladding. Temperature of fiber drawing was 850–930 °C. Basic parameters of the manufactured fiber are as follows: cladding diameter = 480 μm, core diameter = 360 μm, numerical apperture NA = ~1. Spectrofluorometric measurements for precursor glass and optical fibers were conducted using a Stellarnet Green-Wave spectrometer and a LIMO32-F200-DL980-LM continuous-wave laser-diode (P = 1 W, λ_p = 976 nm) as a pump

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source. The spectra were collected between 500 nm and 700 nm using accuracy of 0.1 nm. Influence of temperature on up-conversion luminescence of fabricated Er^{3+}-doped optical fiber was measured using tube furnace. Optical fiber was placed inside furnace and pumped from one end. Luminescence signal was transmitted to the spectrometer by transmission fiber. Temperature of furnace was controlled by PID regulator and Pt-Rh thermocouple with accuracy ±1 °C.

3. Results and discussion

Fig. 1 (bottom) presents up-conversion luminescence spectra of Er^{3+} in optical fibers with 3, 4, 5, 10 and 15 cm length. The inset shows cross-section of the fabricated optical fiber.

Moreover, the attenuation spectrum measurement obtained by using the cut-back method is also presented. The cut-back method allows a better quantitative measurement of the fiber attenuation, because the coupling effects between the measured values are neglected [13]. Our oxyfluoride germanate glass fiber doped with Er_2O_3 (0.5 mol%) has attenuation bands maxima around 280, 37, and 75 dB/m respectively, within the spectral range 500–700 nm. Measured by cutback method background losses are 0.7 dB/m (@600 nm).

The up-conversion luminescence spectra were measured under 976 nm excitation (P = 1 W). The experimental data are compared to that one measured for precursor glass. The observed green and red luminescence bands at 550 nm and 670 nm are due to $^2H_{11/2}$,$^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ transitions of Er^{3+}, respectively. However, the green up-conversion emission corresponding to $^2H_{11/2}$,$^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition is dominant independently on fiber length. The photo of the fabricated optical fiber emitting green light under 976 nm excitation is shown in Fig. 1 (top). From the image, the green up-conversion emission can be visually observed by the naked eye. The mechanism of up-conversion process was determined from the log–log dependence of emission intensity on the excitation power. The slopes of 1.78 and 2.04 for both green and red transitions of Er^{3+} indicates that 2-photon mechanism [14] was involved in the up-conversion luminescence process (Fig. 2).

Several spectroscopic parameters for Er^{3+} in optical fibers such as shift of emission peak wavelength λ_p and spectral linewidth $\Delta\lambda$ were also determined and shown on Fig. 3. The spectroscopic results for $^2H_{11/2}$,$^4S_{3/2} \rightarrow {}^4I_{15/2}$ (green) and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ (red) transitions of Er^{3+} are similar. The spectral linewidth is reduced, whereas the maximum of emission peak is shifted to longer wave-

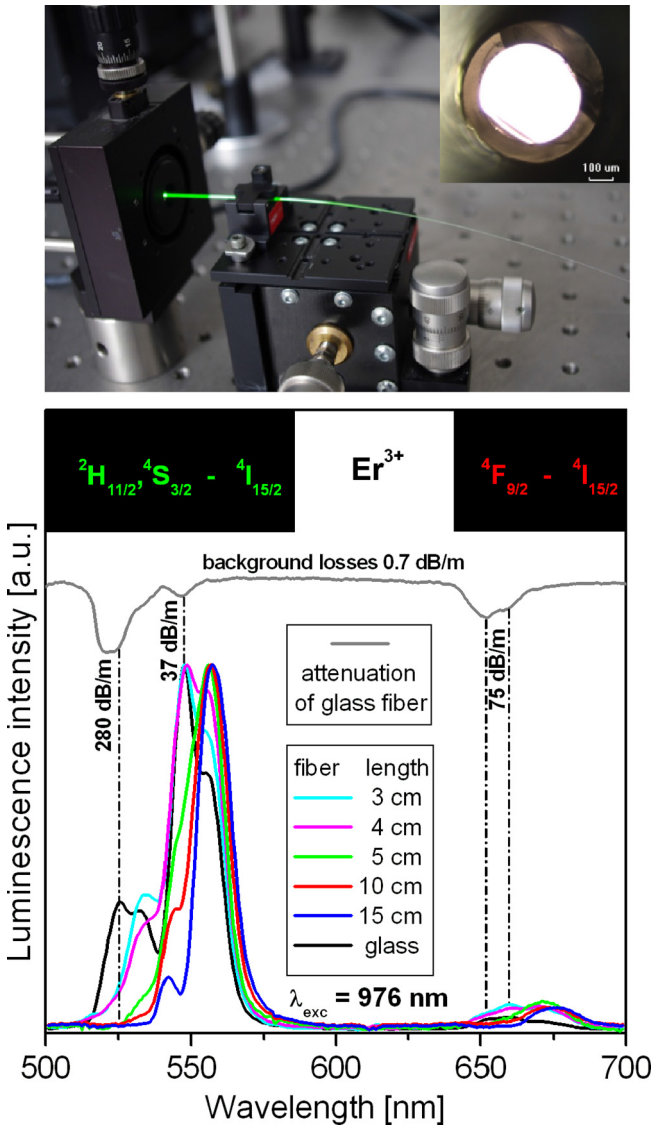

Fig. 1. Up-conversion emission of Er^{3+} in fibers (bottom). The inset shows the photo of green up-conversion emission and cross-section of the fabricated fiber (top).

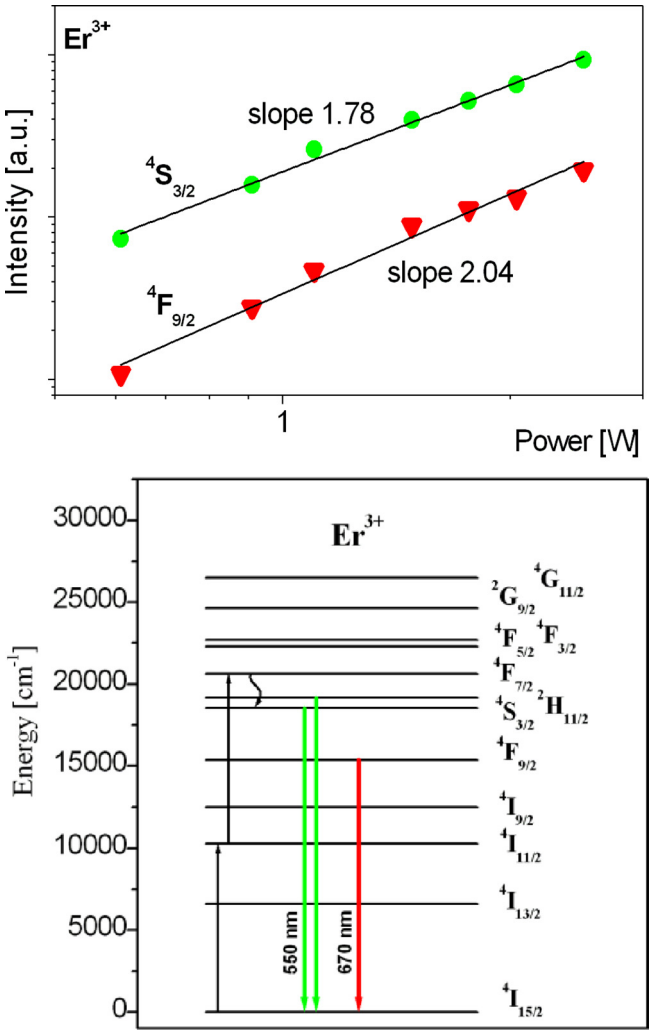

Fig. 2. The log-log dependence of up-conversion emission intensity on the excitation power (top) and the energy scheme (bottom).