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Ytterbium-induced energy-transfer upconversion enhancement in Nd^{3+}/Pr^{3+}-codoped $PbGeO_3$–PbF_2–CdF_2 glass excited at 810 nm

A.S. Gouveia-Neto[a,*], E.B. da Costa[a], L.A. Bueno[b], S.J.L. Ribeiro[c], Y. Messaddeq[c]

[a]*Departamento de Física e Matemática, Laboratório de Fotônica, Universidade Federal Rural de Pernambuco, Recife, 52171/900, PE, Brasil*
[b]*UNOESC, ACET, Videira, SC, 89560/000, Brasil*
[c]*Instituto de Química, UNESP, Araraquara, 14800/900, SP, Brasil*

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Abstract

The effect of ytterbium ions upon energy transfer (ET) excited upconversion emission in Nd^{3+}/Pr^{3+}-codoped $PbGeO_3$–PbF_2–CdF_2 glass under 810 nm diode laser excitation is investigated. The results revealed that the presence of Yb^{3+} ions in the Nd^{3+}/Pr^{3+}-doped sample yields a fourfold enhancement in the visible and near infrared upconversion luminescence. The dependence of the upconversion process upon the excitation power, Nd^{3+}, and Yb^{3+} concentrations is examined. The results indicated that ytterbium plays a major role in the ET upconversion process by bridging the 810 nm neodymium excitation to praseodymium ions. The population of the Pr^{3+} ions $^3P_0$ emitting level was accomplished through a multi-ion interaction involving ground-state and excited-state absorption of pump photons at 810 nm by the Nd^{3+} followed by successive ET involving the Nd^{3+}–Yb^{3+} and Yb^{3+}–Pr^{3+} pairs. There is also direct ET Nd^{3+}–Pr^{3+}.

Keywords: Energy transfer; Upconversion; Glass; Rare earth; Luminescence

1. Introduction

The study of multi-ion interaction in rare-earth doped new host materials has recently attracted much interest due to the fact that the interaction mechanisms can be beneficial in the realization of photonic devices based upon rare-earth doped

*Corresponding author. Tel.: +55 81 33021480; fax: +55 81 33021011.
E-mail address: artur@ufrpe.br (A.S. Gouveia-Neto).

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systems. The multi-ion interaction provides conditions for the so-called sensitization process where the species excited by a pump photon transfers its excitation to the other species present in the matrix. The exploitation of this ion-pair interaction referred to as energy transfer (ET) has been extensively investigated in Er^{3+}-, Pr^{3+}-, Tb^{3+}-, and Tm^{3+}-doped samples sensitized with trivalent ytterbium [1–8]. In ytterbium-sensitized hosts one takes advantage of the strong absorption cross-section of Yb^{3+} ions in the region of 980 nm and the efficient ET mechanism involving ytterbium and those rare-earth acceptors. For a number of applications, it is desirable to access the visible wavelength emitting levels of such rare-earth ions employing an excitation source in the wavelength region of 800 nm. This is possible by exploiting the intense absorption cross-section of Nd^{3+} ions in the 800 nm wavelength region in conjunction with a very efficient excitation transfer mechanism involving neodymium and ytterbium ions. In this peculiar situation, the ytterbium ion plays a major role as an ET bridging ion between a donor (Nd^{3+}) and as already demonstrated for acceptor ions such as Tm^{3+}, Tb^{3+}, and Ho^{3+} [9–12], and recently reported by us in Nd/Tm/Yb-doped $PbGeO_3$–PbF_2–CdF_2 glass [13]. Recently, efficient frequency upconversion excitation due to a Nd^{3+}–Pr^{3+} pair ET process was used to produce 800 nm excited blue laser action in a neodymium-sensitized praseodymium-doped fluorozirconate glass fiber [14], and frequency upconversion involving triads and quartets of ions in a Pr^{3+}/Nd^{3+}-codoped fluoroindate glass excited in the 600 nm region, was also investigated [15]. In this work we report on the enhancement of ET excited upconversion processes in a Pr^{3+}/Nd^{3+}-codoped glass sample due to the ytterbium ions which bridge the excitation transfer from neodymium to praseodymium ions in Nd^{3+}/Pr^{3+}/Yb^{3+}-codoped $PbGeO_3$-based glass under 810 nm semiconductor laser excitation.

2. Experimental setup

The preparation process of our samples followed the protocol already described elsewhere [8,13] and it suffices to mention here that they had a composition of 70% $PbGeO_3$:15% PbF_2: 15%CdF_2 and were either double doped with Nd^{3+}/Pr^{3+} or triply doped with Nd^{3+}/Pr^{3+}/Yb^{3+}. The host material presents very good optical quality, is stable against atmospheric moisture, and exhibits low optical attenuation in the 0.4–5.0 μm spectral region. The material also exhibits high solubility allowing the incorporation of high lanthanide concentrations apart from being nonhygroscopic and possesses high thermal stability against crystallization. The sample thickness was ~1.0 mm and the excitation source was a CW diode laser operated around 810 nm delivering a maximum power of 80 mW. The pump beam was focused down onto the samples by a 5 cm focal length lens and the beam waist at the samples location was ~60 μm. Thus, excitation densities in the samples of up to 25×10^6 W/m^2 were achieved for the maximum laser output power of 80 mW. Furthermore, the luminescence signal was collected perpendicular to the pump beam direction in order to avoid pump scattered light into the detection system, and was dispersed by a 0.34 m scanning spectrograph with operating resolution of 0.5 nm and detected by an S-20 uncooled photomultiplier tube. Phase detection was used for data acquisition and storage. The measurements throughout this study were performed at

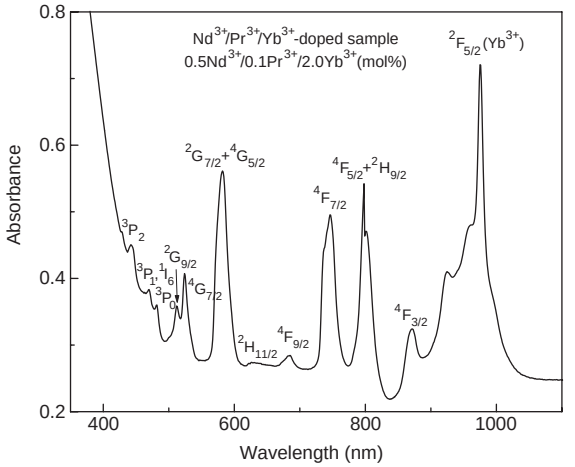

Fig. 1. Absorption spectrum of the $0.1Pr^{3+}/0.5Nd^{3+}/2.0Yb^{3+}$ mol% triply-doped sample.