Ultra large amplification bandwidth of Er^{3+} and Tm^{3+} at S and L band from TeO_2-WO_3-Na_2O-Nb_2O_5 glass doped optical fibers

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ABSTRACT

Tellurite glasses optical fibers became promising for optical amplifiers due to its high rare earth ions solubility and very large amplification bandwidth. Among several tellurite glasses the TeO_2-WO_3-Na_2O-Nb_2O_5 system show one of the largest bandwidth. Our previous characterization of lifetime using the Ω_2, Ω_4, Ω_6, Judd-Ofelt parameters indicate a quantum efficiency maximum for 7500ppm Er^{3+} concentration. Therefore we decided to produce jointed Er^{3+} and Tm^{3+} single mode optical fibers with this glass system keeping the 7500ppm Er^{3+} concentration and varying the Tm^{3+} concentration from 2500ppm to 15000ppm. This single mode fiber was pumped by 120mW of the semiconductor laser at 790nm and we observed a flat ASE bandwidth from 1400 to 1570nm for the 5000ppm Tm^{3+} concentration.

Keywords: Broadband emission, tellurite fiber, energy transfer process

1. INTRODUCTION

Tungsten- tellurite glass matrices are ideal hosts for the fabrication of the large bandwidth Er^{3+}-Tm^{3+}-co-doped fiber amplifiers, due to the modern Wavelength Division Multiplexing (WDM) optical communication systems demand the broadest continuous optical amplifiers as possible. The 45 nm bandwidth of Er^{3+} silica doped optical fibers at the C-band (1530-1565 nm) is insufficient for greatest speed of information transmission. Recently, Jeong et al demonstrate an Er^{3+}-Tm^{3+} co-doped 20m long silica fiber amplified spontaneous emission (ASE) with bandwidth over 90nm (1460-1550 nm), without any external filters, when the fiber is pumped at 980 nm [1]. Tellurite glasses, however, known for the enhancement of the amplification bandwidth, should be a better host than silica. In co-doped systems the most important processes are energy transfer (ET) that can either help the amplification or decrease its efficiency. The energy transfer processes between the $^4I_{13/2}$ Er^{3+} and $^3F_4$ Tm^{3+} levels, which are responsible for an ASE intensity reduction 1550nm wavelength around.

2. EXPERIMENTAL

For the Optical Fibers fabrication we used the tellurite glass matrix $70TeO_2$ - $19WO_3$ -$7Na_2O$ - $4Nb_2O_5$ (%mol) as the base glass for the core and the clad. To increase the core refractive index, and, consequently, the fiber Numerical Aperture (NA), we increased the Nb_2O_5 core content by 80000 ppm. The pre-form was made by the rod-in-tube method, using a 7 mm external diameter basic glass for the clad and 0.5 mm Er^{3+}/Er^{3+}-Tm^{3+} doped glass for the core. Good quality optical fibers were obtained after drawn at the 540 -550 ^oC temperature range in a Heathway tower with 3.6 m/min draw speed. The 125 μm external diameter fiber obtained matches the core size of commercial silica fibers with 10 μm core diameter to assure good light coupling. The ASE measurements was made using a Ti:sapphire cw laser (Spectra Physics model 3900S), which is coupled to the tellurite fiber core through of the objective lens at one fiber end while the luminescence was collected on the opposite by another identical objective lens. To avoid the 790 nm second order at 1580 nm we used a Schott RG1000 filter to cut-off all the pump light before the Optical Spectrum Analyzer (OSA) (Agilent HP 86145B). A third objective lens after the filter couples the light into another silica fiber directly connected to the OSA. The ASE intensity measurements were realized with 5nm wavelength resolution, and –50dBm reference level in the OSA.

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3. RESULTS AND DISCUSSIONS

The both luminescence spectra showed in figure 1correspond to emission transitions of Er^{3+}-Tm^{3+} -co-doped tellurite fiber. The luminescence intensity showed in figure 1-a was obtained with an Ocean Optics USB 2000 spectrophotometer in VIS-IR spectral range, while the luminescence intensity in figure 1-b was obtained with an OSA in IR spectral range.

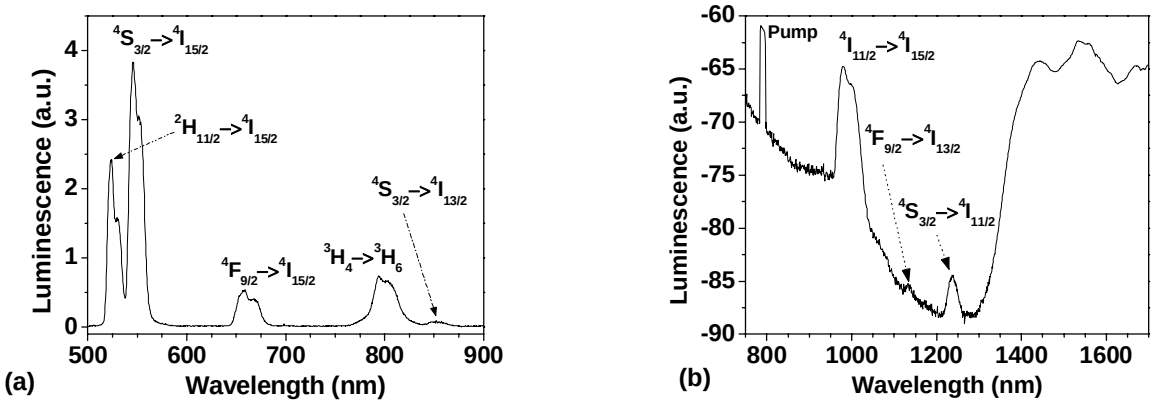

Fig. 1 Luminescence spectra in (a)VIS-IR and (b) IR spectral range for a 7500ppm Er_2O_3-5000ppm Tm_2O_3-co-doped tellurite fiber.

In both luminescence spectra there are eleven emission transitions in all, of these, tree transitions are not were named due to that these are overlapped in one band only, and these transitions are $^3F_4 \rightarrow {}^3H_6$, $^3H_4 \rightarrow {}^3F_4$, and $^4I_{13/2} \rightarrow {}^4I_{15/2}$. Of the same form tree transitions correspond to intermediate excited levels transitions, and these transitions are $^4S_{3/2} \rightarrow {}^4I_{11/2}$, $^4F_{9/2} \rightarrow {}^4I_{13/2}$, and $^4S_{3/2} \rightarrow {}^4I_{13/2}$. From these results, its possible construct an Er^{3+}-Tm^{3+}-ions energy level diagram that shows all the important transitions between ground and excited levels, as well as energy transfer processes for an Er^{3+}-Tm^{3+}-codoped tellurite fiber. In the figure 2 we showed all important mechanism based in absorption and emission processes.

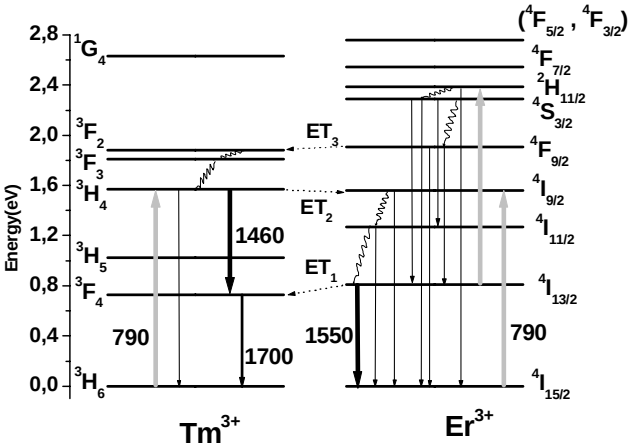

Fig. 2 Energy levels diagram for Er^{3+} and Tm^{3+} ions showing absorption, emission, and energy transfer processes. Gray arrows represent ground state absorption and excited state absorption.

The 1550 nm around transitions is very important in the optical communication due to that this band represent the optical communications window in silica fiber based. All mechanism and processes treated in front will be related to 1550nm transitions around. When the tellurite fibers are doped with Er^{3+} and Tm^{3+} ions, is known that exist an inherent energy transfer processes between ER^{3+}-$^4I_{13/2}$ and Tm^{3+}- $^3F_4$ levels that play an important role in amplification processes. We observe that for large Tm^{3+} concentration in co-doped systems, the energy transfer between $^4I_{13/2}$ Er^{3+}- $^3F_4$ Tm^{3+} levels is very efficient and as consequence the ASE power 1550nm around decrease. For small Tm^{3+} concentration in co-doped systems, the energy transfer between (Er^{3+}) $^4I_{13/2}$ - (Tm^{3+}) $^3F_4$ levels is not efficient and as consequence the ASE power 1550nm around increase as well as $^3H_4 \rightarrow {}^3F_4$ transition is very predominant. Figure 3 show the ASE intensity spectra for (7500ppm) Er^{3+}-doped tellurite fiber and (7500ppm) Er3+- (5000ppm) Tm^{3+} -co-doped tellrurite concentrations. Pumping with 790 nm we only observed the $^4I^{13/2} \rightarrow {}^4I_{15/2}$ transition for Er^{3+}-only doped tellurite fiber, while all the $^4I_{13/2} \rightarrow {}^4I_{15/2}$, $^3H_4 \rightarrow {}^3F_4$ and $^3F_4 \rightarrow {}^3H_6$ transitions are present in the Er^{3+}-Tm^{3+} co-doped tellurite fibers. In the Er^{3+}-Tm^{3+} co-doped tellurite fiber, the $^3H_4 \rightarrow {}^3F_4$ transition appear in the left side of the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition, and the $^3F_4 \rightarrow {}^3H_6$ transitions appear in the right side of the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition. The bandwidth, measured at –3dB points, in (7500ppm) Er^{3+}-doped tellurite fiber is 74nm, while in (7500ppm) Er^{3+}- (5000ppm) Tm^{3+}-co-doped tellurite fiber is 187nm. Figure 4 show the ASE intensity spectra for two different Tm^{3+} concentration, and in this figure we observed that the ASE intensity decrease for a higher Tm^{3+} concentration. This fact is due to the separation between Er^{3+}-donor and Tm^{3+}-acceptor ions diminish when the Tm^{3+} concentration increase.

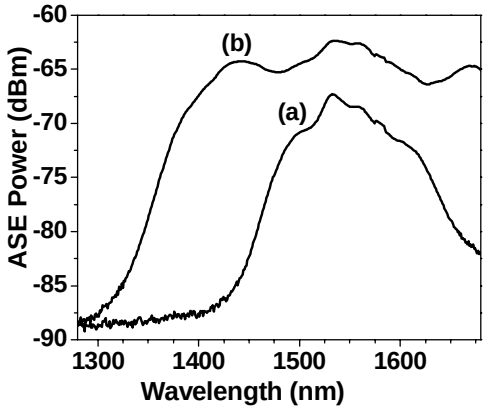

Fig. 3 The fibers characterized have 15cm length. The (a)-curve corresponds to Er^{3+}-doped tellurite fiber and (b)-curve corresponds to Er^{3+}-Tm^{3+} -co-doped tellurite fiber.

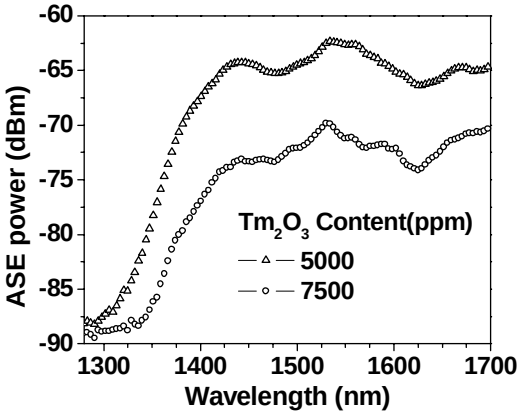

Fig. 4 The fibers characterized have 15cm length. The ASE power decreases due to increase of Tm^{3+} concentration.

The separation between Er^{3+}-donor and Tm^{3+}-acceptor is possible to calculating from energy transfer transition probabilities (W_{TE}^{Er-Tm}). To perform the W_{TE}^{Er-Tm} calculated as a function of Tm^{3+} content we co-doped the same 7500ppm wt% Er_2O_3 doped tellurite glass matrix with Tm_2O_3 concentrations varying from 2500ppm up to 15000ppm wt%. With the previously calculated lifetime experimentally and calculated lifetime trough Judd-Ofelt parameters, we can calculate the W_{TE}^{Er-Tm} using the expression:

$$W_{TE}^{Er-Tm} = \tau_e^{-1}(1-\eta) - W_{NR}^{Er}$$

Here, $\eta = \tau_e / \tau_c = W_R \tau_e$ represents the quantum efficiency and $\tau_c^{-1} = W_R$ is calculated by the Judd-Ofelt parameters, and W_{NR}^{Er} represents all nonradiative transition probabilities for Erbium only doped glasses. Figure 5 shows the results obtained. The lifetime represented at the left axis decreases as the Tm^{3+} concentration increases, and the ET_1 process becomes more efficient.

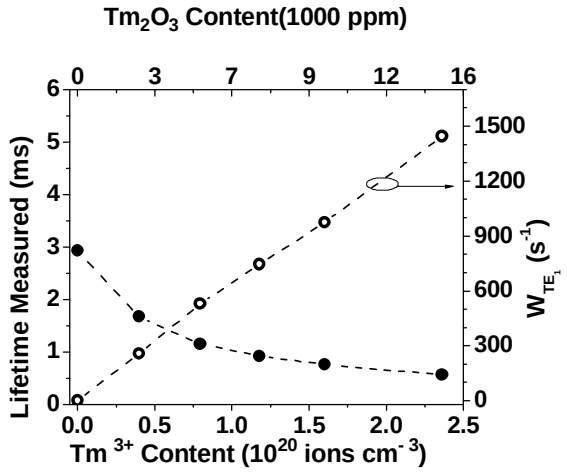

Fig 5 Lifetime experimental and energy transfer transition probabilities.

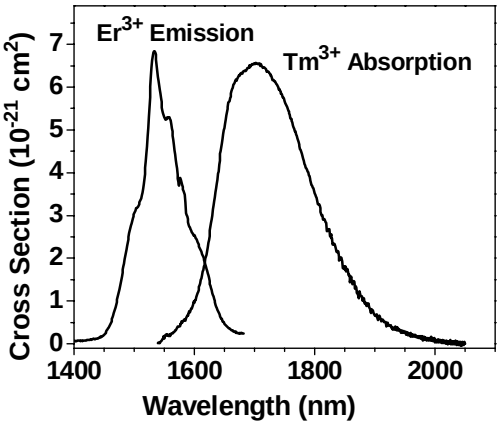

Fig. 6 The Tm^{3+} -absorption and Er^{3+} -emission crosses sections in the tellurite glass.

Using the results obtained before, and the overlap of the Tm^{3+} Absorption and Er^{3+} emission crosses sections showed in the figure 6, its possible to calculating the donor-acceptor separations considering the dipole-dipole interactions for dilute systems [2]. Using the Forster-Dexter energy transfer model for dipole-dipole interactions [3], should be calculated the transitions probability rate between $^4I_{13/2}$ level of Er^{3+}-ion and $^3F_4$ level of the Tm^{3+}- ion. The critical interaction distance (R_0) defined in [3] is calculated in this case, and the result obtained was nearly 4nm. In heavy-metal fluoride glass the result obtained by Chen et al was 1.48nm. The discrepancy of both results should be due to materials host principally. The calculus of the emission cross section was found using the expression guided by Miniscalco et al [4]. The donor-acceptor separation is finally calculated, from previous calculus, for each Tm^{3+} concentration in the co-doped system. The result is showed in the figure 7 and is possible to observing that the behavior of the donor-acceptor separation decrease while the Tm^{3+} concentration increase. This result coherent, explain the fact that the energy transfer process is very efficient when the Tm^{3+} concentration is very high in co-doped systems.

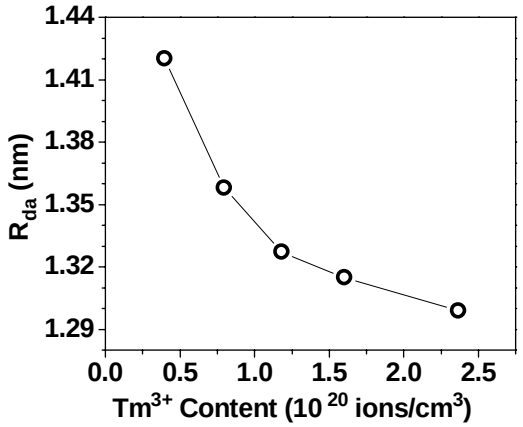

Fig. 7 Donor-acceptor separation (R_{da}) as function of the Tm^{3+} concentration in a co-doped system.

4. CONCLUSION

In conclusion, we obtained 187nm ASE bandwidth at -3dB points using Er^{3+}- Tm^{3+} co-doped tellurite optical fibers pumping at 790 nm. Luminescence intensity and lifetime measurements show that the ET_1 process between $^4I_{13/2}$ to $^3F_4$ levels in Er^{3+}- Tm^{3+} co-doped fiber is the mechanism responsible for the ASE decreasing as the Tm^{3+} concentration pass 5000 ppm (%wt) and that we should avoid it in order to keep the ultra large amplification bandwidth at higher concentrations and gain. The behavior of the separation distance between Er^{3+} and Tm^{3+} ions in function of the Tm^{3+} concentration, indicate that the energy transfer probability increase for higher Tm^{3+} concentration in the Er^{3+}-Tm^{3+} co-doped tellurite fiber.

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6. REFERENCES

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