Numerical investigation of emission properties of a quadruply-doped germanate glass

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Riccardo Ballarini[a], Marcin Kochanowicz[b], Antonella Maria Loconsole[c], Dominik Dorosz[d], Francesco Prudenzano[c], and Stefano Taccheo[a]

[a]Politecnico di Torino, Corso Duca degli Abruzzi 24, IT-10129, Turin, Italy
[b]Bialystok University of Technology, 45A Wiejska Street, PL-15-351, Bialystok, Poland
[c]Politecnico di Bari, Via Amendola 126/b, IT-70126, Bari, Italy
[d]AGH University of Krakow, al. Adama Mickiewicza 30, PL-30-059, Kraków, Poland

ABSTRACT

In this paper, we numerically investigated the emission and gain properties of an Yb^{3+}:Er^{3+}:Tm^{3+}:Ho^{3+} co-doped germanate glass. We optimized the relative rare-earth concentrations to achieve homogeneous and efficient emission over 650 nm by merging the emission bands of erbium at 1550 nm, thulium at 1800 nm, and holmium at 2050 nm. Then, we carried out a preliminary investigation of its potential as a fiber amplifier, achieving a theoretical gain higher than 14 dB over a 280-nm-band.

Keywords: Ytterbium, Erbium, Thulium, Holmium, Emission Spectrum, Gain Spectrum, Numerical Model, Optical Amplifier

1. INTRODUCTION

Rare-earth doped glasses are the core for many fiber lasers, fiber amplifiers, and Amplified Spontaneous Emission (ASE) sources. The several different properties of the active glass depend from the rare-earth used for the doping. Multiple doping allows to merge properties from different rare-earths, and thus to increase the emission or gain bandwidth.[1,2] Moreover, some rare-earths can improve the efficiency of other rare-earths (e.g. ytterbium improves erbium pumping).

In this paper, we numerically investigated the emission and gain properties of an Yb^{3+}:Er^{3+}:Tm^{3+}:Ho^{3+} co-doped germanate glass pumped at 980 nm. In such a complex system, the pump interacts directly with ytterbium and erbium, and the energy transfer processes transfer the pump from ytterbium and erbium to the two other rare-earths. The relative rare-earth concentrations is the main parameter to be optimize in order to control the processes between the different rare-earths. A rate-equations numerical model has been used to study such a complex quadruply-doped glass. The optimization of the concentrations has been performed in order to optimize the emission and gain spectra. Then, we preliminary investigated the performance of a fiber amplifier with these concentrations.

2. NUMERICAL MODEL

The numerical model is based on eleven rate equations, one for each energy level considered. The eleven energy levels and the main transitions and energy transfers are represented in Fig. 1. The rate equation system and the detail of the parameters used can be accessed from a previous work.[3] The equations to model the power propagation along a fiber are taken from literature.[4] As can be seen from Fig. 1, the 980-nm-pump absorption involves the erbium $^4I_{15/2}\rightarrow^4I_{11/2}$ and ytterbium $^2F_{7/2}\rightarrow^2F_{5/2}$ transitions. The emission and amplification properties are carried by erbium $^4I_{13/2}\rightarrow^4I_{15/2}$, thulium $^3F_4\rightarrow^3H_6$, and holmium $^5I_7\rightarrow^5I_8$ transitions, located in a wavelength range from 1450 nm to 2150 nm.

Further author information: (Send correspondence to R.B.)
R.B.: E-mail: riccardo.ballarini@polito.it

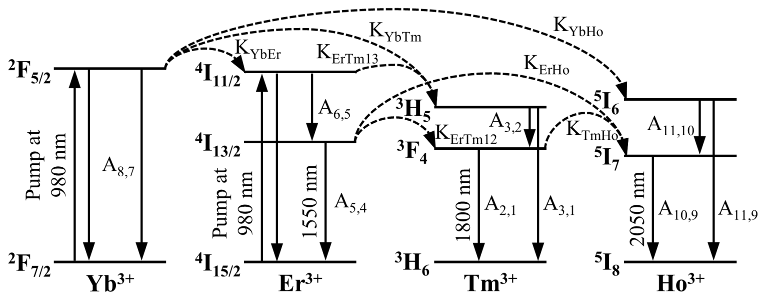

Figure 1. Numerical model scheme, with the energy levels and transitions considered.

3. RESULTS

3.1 Glass Spontaneous Emission

We started from the model of a bulk glass and investigated spontaneous emission with different rare-earth concentrations. While ytterbium was kept fixed at 6.0×10^{25} ions m^{-3}, erbium, thulium, and holmium were changed from 1.0×10^{24} ions m^{-3} to 6.0×10^{26} ions m^{-3}. In order to have only two degrees of freedom, the thulium over holmium ratio was kept fixed to 1. Figure 2 shows an example of the power spectral density of the spontaneous emission with an optimized set of concentrations (6.0×10^{25} ions m^{-3} of ytterbium, 6.0×10^{25} ions m^{-3} of erbium, 4.0×10^{25} ions m^{-3} of thulium and 4.0×10^{25} ions m^{-3} of holmium). The power spectral densities of the different rare-earths are balanced, resulting in an overall spectrum with a -10-dB-flatness of 650 nm, from 1471 nm to 2121 nm.

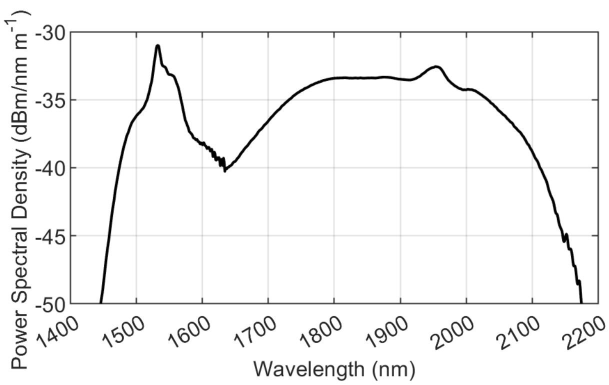

Figure 2. Spontaneous emission from the bulk model with: 6.0×10^{25} ions m^{-3} of ytterbium, 6.0×10^{25} ions m^{-3} of erbium, 4.0×10^{25} ions m^{-3} of thulium and 4.0×10^{25} ions m^{-3} of holmium.

3.2 Glass Gain

Although the gain parameter is not really meaningful in a bulk sample, we also optimized the gain spectrum. Figure 3 shows an example of the gain spectrum with an optimized set of concentrations (6.0×10^{25} ions m^{-3} of ytterbium, 6.0×10^{25} ions m^{-3} of erbium, 2.5×10^{25} ions m^{-3} of thulium and 2.5×10^{25} ions m^{-3} of holmium). Unlike the previous case, achieving the flatness all over the spectrum is not possible. Moreover, the concentrations of ytterbium and erbium are the same of the previous case, while thulium and holmium require lower concentrations in order to keep the peaks almost at the same intensity.

3.3 Fiber Amplifier

As a preliminary investigation, we used the optimized concentrations from the bulk model to analyze a fiber amplifier case. Figure 4 shows the optical gain and the noise figure of a fiber amplifier with the optimized

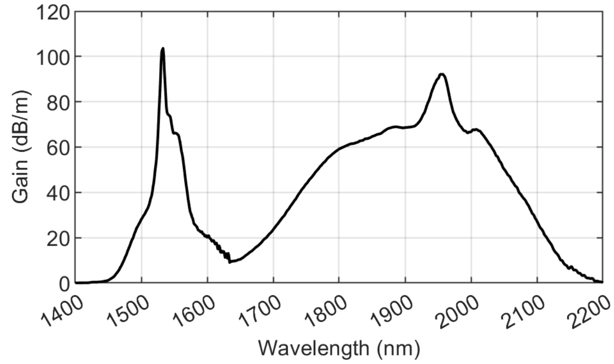

Figure 3. Gain from the bulk model with: 6.0 × 10^{25} ions m^{-3} of ytterbium, 6.0 × 10^{25} ions m^{-3} of erbium, 4.0 × 10^{25} ions m^{-3} of thulium and 4.0 × 10^{25} ions m^{-3} of holmium.

concentrations. In this example, there are 160 signals with a power of -20 dBm each: 40 in the erbium band (from 1525 nm to 1565 nm), 120 are in the thulium and holmium band (from 1800 nm to 2040 nm). The total signal input power is 2 dBm, -4 dBm in the erbium band, and 0.8 dBm in the thulium and holmium band. This theoretical amplifier covers a bandwidth of 280 nm, with a gain higher than 14 db and a noise figure lower than 3.25 dB for every signal.

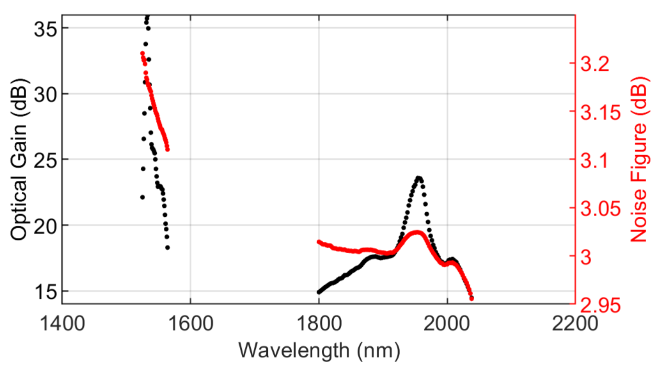

Figure 4. Optical gain and noise figure of 160 channels of -20 dBm each, with a counter-propagating pump of 1 W and a fiber length of 36 cm.

4. CONCLUSION

In this work, we presented a numerical study on the emission and gain properties of an Yb^{3+}:Er^{3+}:Tm^{3+}:Ho^{3+} co-doped germanate glass. From the model, such a glass could be able to generate a broadband emission over a -10-dB-bandwidth of 650 nm, by merging the emission bands of erbium at 1550 nm, thulium at 1800 nm and holmium at 2050 nm. Moreover, from a preliminary analysis, a fiber amplifier made from this glass could be able to achieve a gain higher than 14 dB over a 280-nm-band, with a noise figure lower than 3.25 dB. In future work, we will further study the behavior of the Yb^{3+}:Er^{3+}:Tm^{3+}:Ho^{3+} fiber amplifier, with the aim of designing and developing a device based on this glass.

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