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Numerical Analysis of an $\text{Yb}^{3+}:\text{Er}^{3+}:\text{Tm}^{3+}:\text{Ho}^{3+}$ Wideband Optical Fiber Amplifier

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Abstract. In this work, we numerically investigate the gain properties of an $\text{Yb}^{3+}:\text{Er}^{3+}:\text{Tm}^{3+}:\text{Ho}^{3+}$ co-doped optical fiber amplifier. The numerical simulations show that a gain higher than 15 dB in a wavelength range of 300 nm can be achieved. The erbium amplifies in the well-known C-band, while thulium and holmium amplify from 1760 nm to 2030 nm.

1 Introduction

Rare-earth doped glasses are at the base of many optical amplifiers. The most widely known is the Erbium Doped Fiber Amplifier (EDFA) for the C-band. However, erbium alone cannot amplify a wider wavelength range. Multiple doping is the key to achieve a broad gain bandwidth, by merging different rare-earth emission peaks at different wavelength ranges [1], [2]. Moreover, multiple doping has proven to improve efficiency (e.g., ytterbium can improve erbium pump absorption).

In this work, for the first time to our knowledge, we numerically analyze the gain properties and the noise figure of an $\text{Yb}^{3+}:\text{Er}^{3+}:\text{Tm}^{3+}:\text{Ho}^{3+}$ co-doped germanate optical fiber amplifier, pumped at 980 nm. In such a glass, the amplification is carried by erbium $^4\text{I}_{13/2} \rightarrow ^4\text{I}_{15/2}$, thulium $^3\text{F}_4 \rightarrow ^3\text{H}_6$, and holmium $^5\text{I}_7 \rightarrow ^5\text{I}_8$ transitions, located in a wavelength range from 1450 nm to 2150 nm [1], [2].

2 Numerical Model

Figure 1 shows the eleven energy levels and the relevant transitions on which the numerical model is based. Eleven rate equations are used to solve the population distribution in stationary condition [3]. The power contributions of the pump, signals and ASE, as well as the gain and noise figure formulae, are taken from the literature [4].

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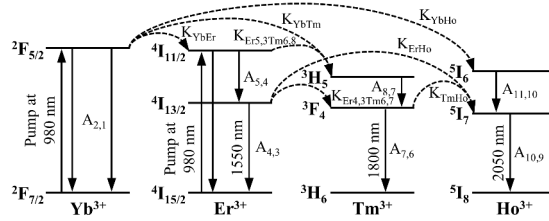


Figure 1. Energy levels and transitions considered in the model.

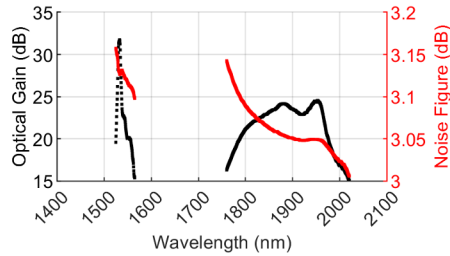


Figure 2. Gain (black, left) and noise figure (red, right) of a sample case with 752 channels of $1 \mu\text{W}$ and spaced 0.4 nm , or 0.75 mW distributed over 300 nm .

3 Results

Figure 2 shows the gain and the noise figure of a sample configuration. In this example, the gain is higher than 15 dB and the noise figure lower than 3.2 dB over a wide wavelength range of 300 nm . In detail, the result has been obtained with an optimized set of concentrations, a fiber 1-m -long and with a diameter of $10 \mu\text{m}$, and both co- and counter-propagating pumps with 600 mW each. The overall input signal power is 0.75 mW distributed over 101 channels in the erbium C-band and 651 channels in the thulium and holmium $1760\text{-}2030\text{-nm}$ -band. The overall output power is 137 mW , with a gain of 22.6 dB .

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