Characterization of an Er^{3+}/Yb^{3+} Codoped Two Core Integrated Waveguide Femtosecond Laser written in a Phosphate Glass

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INTRODUCTION

Integrated dual core waveguides have been fabricated in Er^{3+}/Yb^{3+} co-doped phosphate glasses by femtosecond laser writing. A technique is proposed to determine their dimensions and core-substrate refractive index differences, based on asymmetric excitation of the dual core waveguide and mesurements of its output distribution. On the other hand, also a single core waveguide has been written for characterization purposes: gain measurements carried out with it have allowed determination of the glass active properties. Then, enhancement measurements with the two-core waveguides for different signal and pump powers have been carried out, together with simulations of the experiments with the parameters determined in the previous characterization. A good agreement between measurements and simulations has been found, which supports validity of the characterization methods employed.

FABRICATION

Fs-laser writting

Irradiation of phosphate glasses with femtosecond laser pulses allows the inscription of 3D integrated waveguides with high refractive index contrast by ion migration mechanisms [1]. Waveguides written in phosphate glasses with high La_2O_3 content present high refractive index differences in the guiding region mainly due to the incoming migration of La accompanied by the out-diffusion of K.

Sample

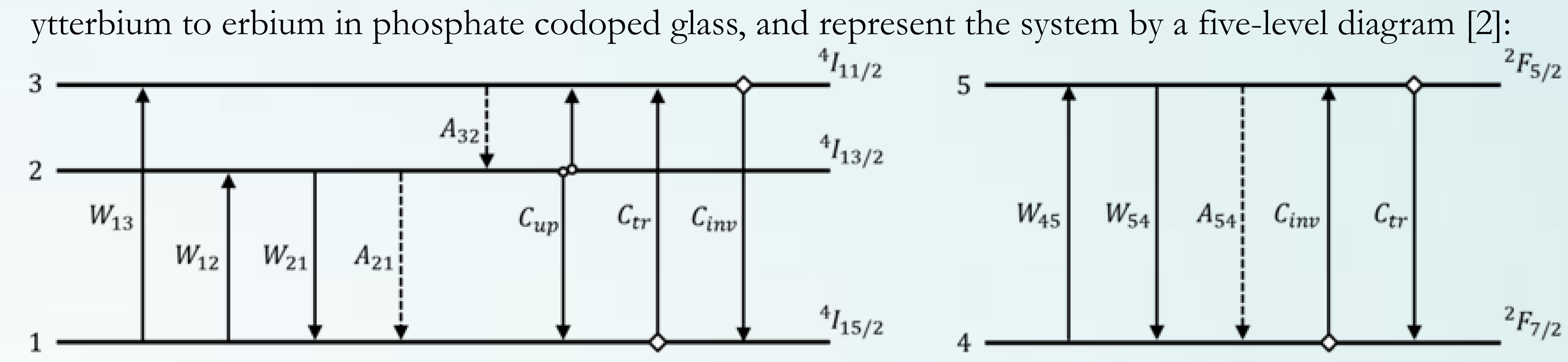
The sample under study, fabricated by the Laser Processing Group of the Institute of Optics in Madrid, has several two-core waveguides with different core-to-core separations. Dimensions of each isolated core would make them single mode for third telecommunication window wavelengths. For characterization purposes, also a single core waveguide has been written.

Composition (%)	
P_2O_5	58.72
La_2O_3	18.4
Al_2O_3	5.82
Yb_2O_3	5.42
K_2O	4.89
SiO_2	4.24
Er_2O_3	2.53

Wavelength 1030 nm
Repetition rate 350 kHz
Pulse energy 520 nJ
Pulse duration 320 fs

THEORETICAL MODEL

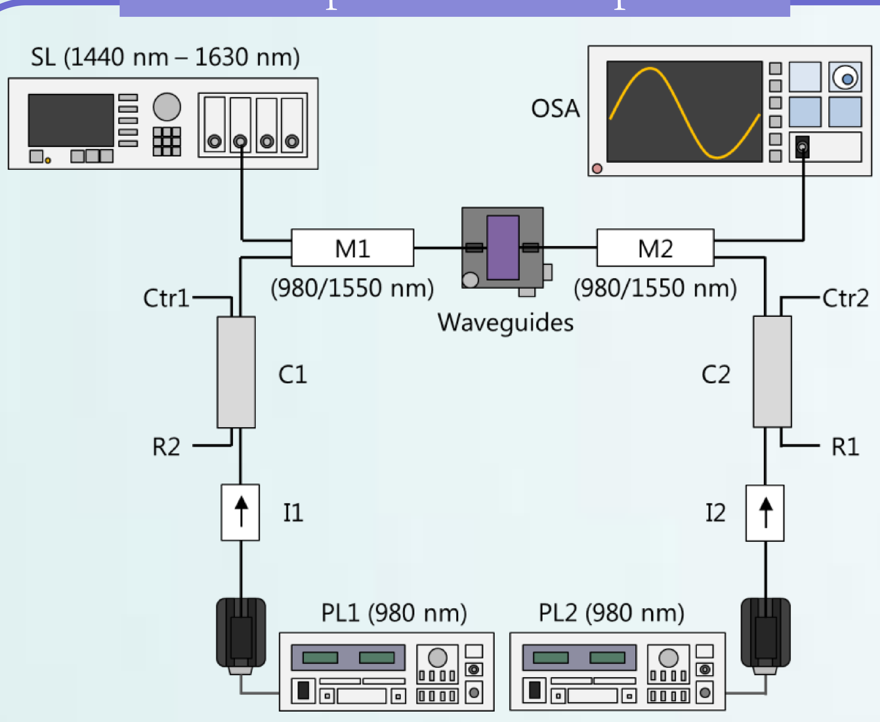
In order to model the amplification of an optical signal along a rare earth doped waveguide, both the **rate equations** system (describing the time evolution of the population densities of the involved active ions energy levels) and the coupled **optical power equations** system (describing the propagation of the optical powers), are required. We follow the conventional diagram of cooperative energy transfer from ytterbium to erbium in phosphate codoped glass, and represent the system by a five-level diagram [2]:



being W_{ij} the stimulated transition rates and A_{ij} the relaxation rates between *ith* and *jth* levels, C_{tr} and C_{inv} the direct and inverse energy transfer rates and Cup the homogeneous upconversion coefficient. Some of the parameters needed in the theoretical model must be obtained experimentally. In order to do that, we first characterize an isolated waveguide written in the same bulk glass.

CHARACTERIZATION

Experimental setup

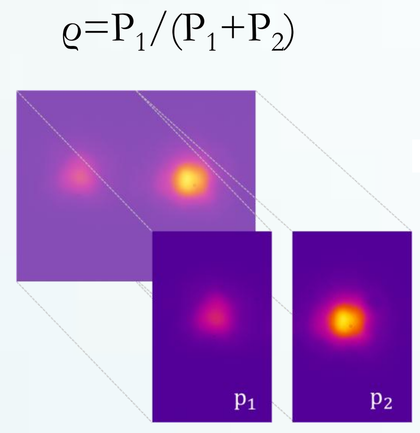


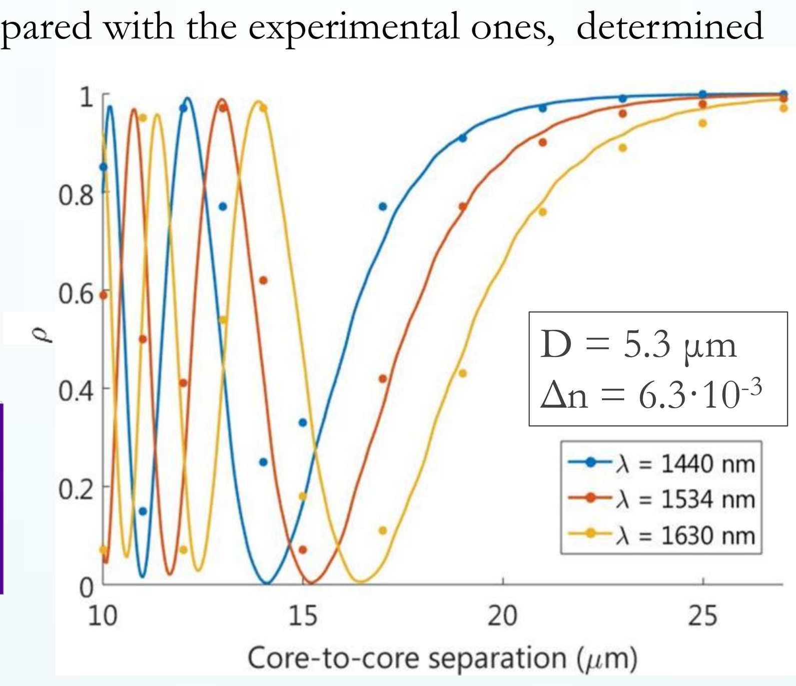
PL: Pump Laser, I: Isolator, R: Residual Pump, C: Coupler, Ctr: Pump Control, M: Multiplexer, SL: Signal Laser, OSA: Optical Spectrum Analyzer.

Guiding parameters

The parameter ϱ is numerically calculated for each double waveguide, by means of the BeamPROP tool from the RSoft CAD software. Different combinations of core diameter and refractive index difference are tried and the results are compared with the experimental ones, determined through the output intensity distribution

$$\varrho = P_1/(P_1+P_2)$$

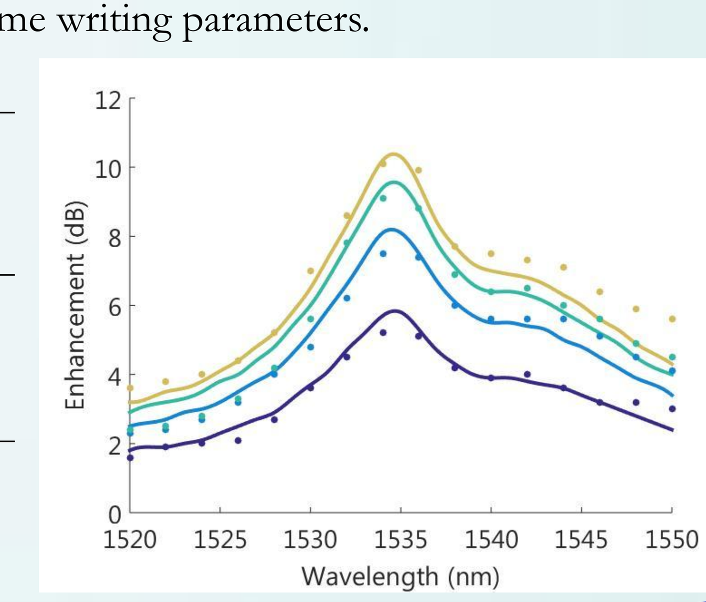




Active parameters

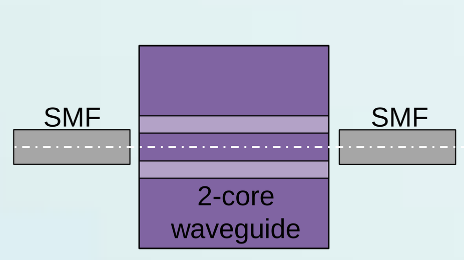
The parameters have been determined by fitting the model results with the absorption spectrum and signal enhancement of the monomode, single core waveguide. We assume that the parameters determined in this stage for the single core are also valid for the rest of cores. This single core is similar to the others composing the double core waveguides, as all of them have been inscribed with the same writing parameters.

Propagation losses (m^{-1})	
Signal (1534 nm)	30
Pump (980 nm)	215
Cross section (m^2)	
$^4I_{15/2}\rightarrow{}^4I_{13/2}$	$9.70\cdot10^{-25}$
$^2F_{7/2}\rightarrow{}^2F_{5/2}$	$1.25\cdot10^{-24}$
Energy transfer rates (m^3/s)	
Direct	$5.0\cdot10^{-24}$
Inverse	$1.5\cdot10^{-23}$
Upconversion Coef.	$5.5\cdot10^{-24}$

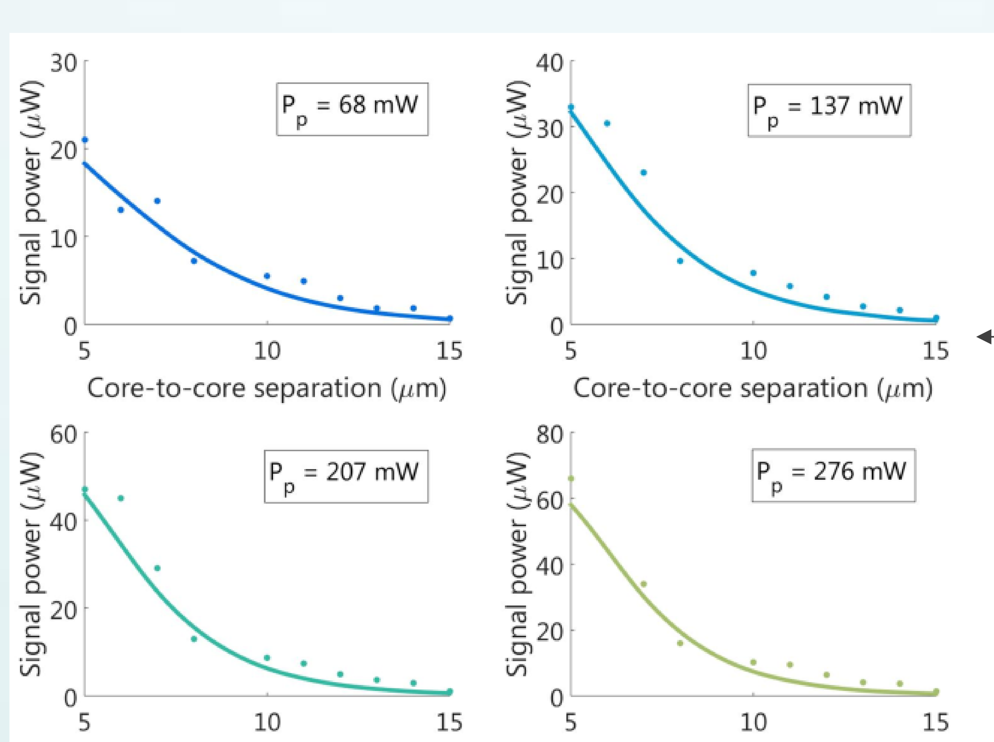


RESULTS

In order to check the characterization procedure usefulness, experimental and numerical output signal results on pumped double core waveguides have been compared. For each double core waveguide, both adjacent SMFs are aligned symmetrically:

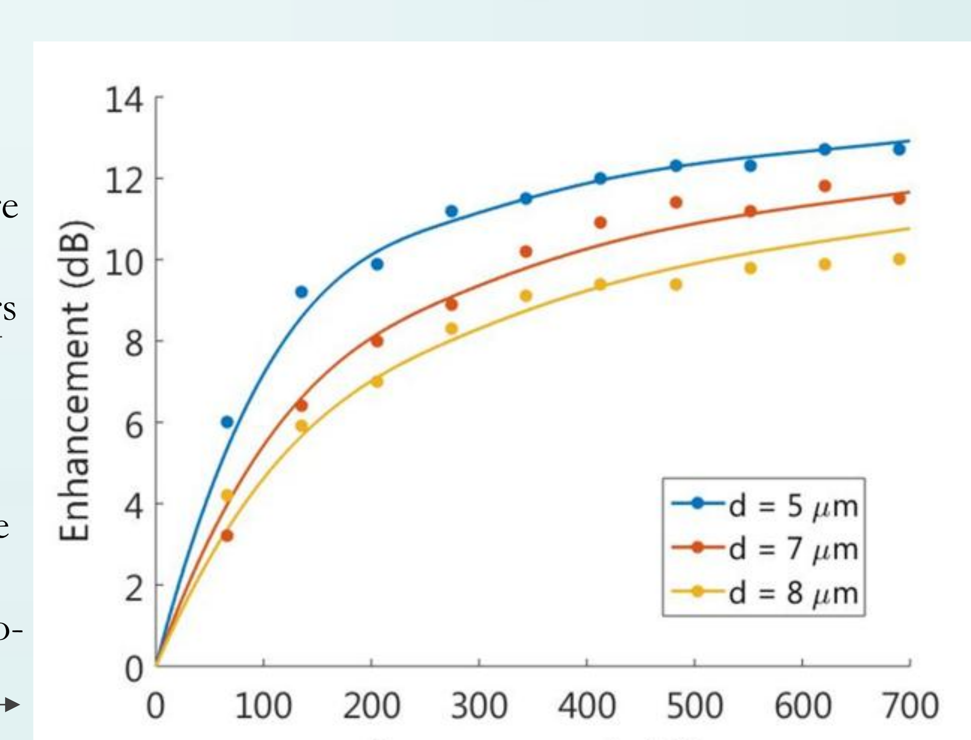


Series of measurements are carried out with 100 μW input signal power at λ=1534 and different pump powers. The same way, numerical calculations have been carried out, with characterization parameters employed as the model parameters. Following figure shows several comparisons between measurements and calculations.



Output signal power dependence on core-to-core separation, for different unidirectional pump powers

Enhancement dependence on bidirectional pump power, for different core-to-core separations



CONCLUSIONS

A complete analysis on dual-core active waveguides including fabrication and characterization has been carried out. Inscription of a single core waveguide together with a set of dual core ones, with different core-to-core distances, has been essential for the procedure. Parameters concerning the active ions have been determined with measurements on the single core waveguide. Their good performance in the prediction of the double-core experimental results shows that the model chosen is suitable for propagation calculations in double-core active waveguides and that the designed characterization procedure allows one to obtain all the parameters necessary to perform calculations with this model, with sufficient precision. Besides, the whole analysis is based on accuracy of the writing technique, which should guarantee enough control on the writing conditions, so that all the cores engraved present similar features. The agreement obtained also confirms trustworthiness of the waveguide fabrication technique employed.

REFERENCIAS:
[1] Toney TEDDY FERNANDEZ, et al., "*Ion migration assisted inscription of high refractive index contrast waveguides by femtosecond laser pulses in phosphate glass,*" OL, 38, 24, 2013.
[2] Juan A. VALLÉS et al., "*Performance of ultrafast laser written active waveguides by rigorous modeling of optical gain measurements*," OME, 1, 4, 2011.

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