Heavily doped Er^{3+}/Yb^{3+}planar waveguides on silica for high gain per unit length amplification in the C-band

(Student Paper)

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ABSTRACT

This paper explores potential design and the likely characteristics of an Er^{3+}/Yb^{3+}co-doped waveguide amplifier based on a planar waveguide fabricated using the ultrafast laser plasma implantation method. Using this technique a layer of silica glass is modified by the implantation of tellurite glass particles in a silica glass substrate, resulting in a rare earth rich region with demonstrated concentrations of up to 1.63x10^{27}atoms/m^3. Experimental measurements of a planar waveguide's properties are shown and the theoretical gain achievable is calculated using numerical simulations, resulting in a value of 9.5 dB/cm and a theoretical maximum of 27 dB/cm.

Keywords: Waveguide amplifiers, Erbium/Ytterbium co-doped, modelling, spectroscopy, optical communications

1 INTRODUCTION

The ubiquitous use of silica based optical fibre and Erbium Doped Fibre Amplifiers (EDFA) is due to the low loss in the Er^{3+}emission band and chemical stability. However optical fibre and indeed any other potential silica based application, suffers from low rare earth (RE) ion solubility in the host material, requiring the use of long interaction volumes (>5 metres) to achieve any meaningful degree of amplification, making it impractical for applications where size is a concern [1], [2].

Extensive research efforts have been focused on finding suitable host materials with desirable properties such as high lifetime of the Er^{3+} $^4I_{13/2}$level and capacity to incorporate high concentration of RE ions. Several promising hosts have been studied with a variety of advantages and disadvantages over silica glass [1]. A recurring theme in these efforts is that the investigated hosts are either difficult to fabricate, chemically unstable or incompatible with silica glass, impeding efforts to integrate them into the optical network.

A recently developed technique [3], [4], utilized a femtosecond laser to generate a stream of plasma and nanoparticles [5] from a rare earth (RE) rich tellurite target glass to implant it into a silica glass substrate. This created a highly doped rare earth tellurite silica (RETS) metastable region in the glass with RE ion concentrations of up to 1.63x10^{27} atoms/m^3 with a photoluminescence lifetime of 9.1 ms at a wavelength of 1.5 µm. In contrast the typical achievable concentration without significant clustering in silica is in the order of 10^{24} atoms/m^3 [1].

In order to guide the development of an Er^{3+}/Yb^{3+} doped waveguide amplifier (EYDWA) the emission and properties of a planar RETS waveguide were measured and this data was incorporated in an amplification model [6] in order to estimate the gain of the amplifier.

2 EXPERIMENTAL PROCEDURE

The planar waveguide was created by sequentially ablating 1% mol Er_2O_3 and 1% mol Yb_2O_3 tellurite target glasses, with a 42 fs, 1 kHz pulsed laser (KM Labs, Wyvern). This process was carried out in 12 cycles of 10 minutes Er_2O_3 glass alternated with 20 minutes of Yb_2O_3 glass, for a total of 6 hours. The composition of each target is shown in table 1.

TABLE 1. TARGET GLASS COMPOSITIONS USED FOR THE FABRICATION

mol % concentration				
TeO2	**Na2O**	**ZnO**	**Er_2O_3**	**Yb_2O_3**
79%	10%	10%	1.00%	-
79%	10%	10%	-	1.00%

The refractive index and thickness of the resulting modified layer was measured using a prism coupler (Metricon 2010) with 633 nm laser. The lifetime was measured with a time resolved fluorescence spectrometer (Edinburgh Instruments FLS970) by irradiating the sample with a 976 nm fibre-pigtailed diode laser operating at 100 mW being triggered every 100 ms for 1 ms.

3 RESULTS

The material properties are summarized in table 2

TABLE 2. PLANAR WAVEGUIDE PROPERTIES

Property	Value
Thickness	1.153 µm±0.008 µm
Refractive index	1.6150±0.0002
Lifetime	8.4 ms

Applying Marcatili's method [7] to a buried waveguide with the aforementioned properties and assuming substrate refractive index of 1.45, single mode behaviour is obtained for both 976 nm pump and wavelengths from 1500 nm to 1600 nm typically used in communications. Due to the high refractive index contrast between the core and substrate, a large portion of the energy is contained inside the waveguide as evidenced by Fig.1 the large effective refractive indices of 1.55 and 1.50 for the pump and signal respectively. This results in high overlap between the amplification media and the pump and signal fields further enhancing gain.

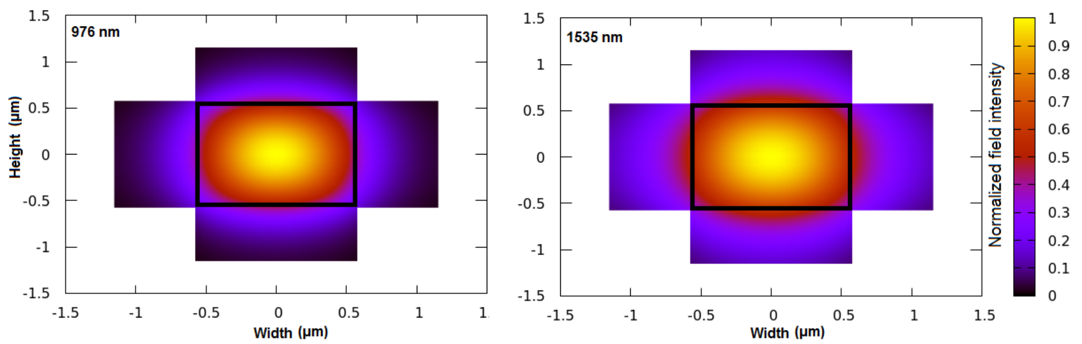

Figure 1. Normalized electric field propagation inside the waveguide

Based on previous studies [3] the expected total RE concentration is approximately 1.61x10^{21} ions/cm^{-3} for a two target process, using target glasses with 1% RE concentration. Time was partitioned in a 1:2 ratio between Er^{3+}rich and Yb^{3+}rich tellurite target glass, assuming a similar concentration partition Er^{3+} ions of 0.537x10^{21} cm^{-3} in the sample, with the remaining fraction as ytterbium ions. By using the absorption and emission cross-sections of germanium-aluminium silicate glasses found in [8], the simulated gain for a signal of 100 signals with -60 dBm power and 20 dBm of 976 nm pump power at this Er^{3+}concentration is shown in Fig.2

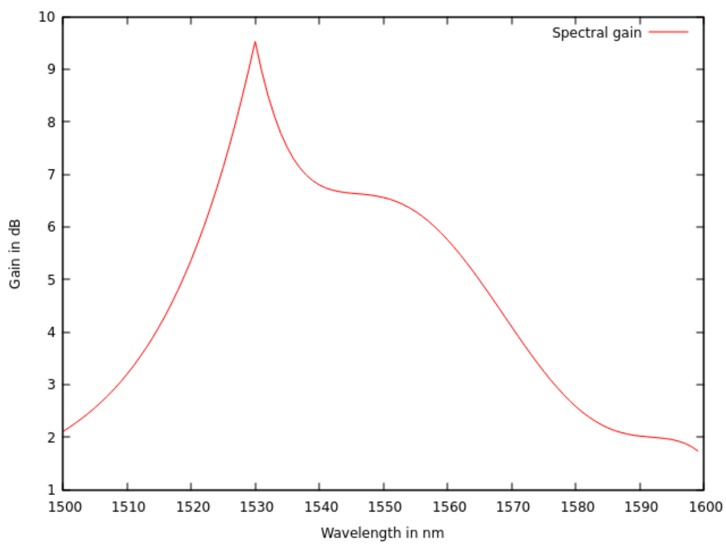

Figure 2. Theoretical gain per wavelength for low signal power

A maximum value of 9.5 dB/cm is achieved at 1530 nm and drops down to 5.2 dB/cm at 1564 nm which corresponds to the behaviour of the cross section data used for Ge-Al-Si glass amplifiers, however the RETS layer can potentially extend the amplification window to 1600 nm as is the case with tellurite only amplifiers [9]. An upper theoretical gain limit of 27 dB/cm at 1530 nm is achievable using 1.61x10^{21} ions/cm^{-3} of pure erbium ions, however experimentally this value is unlikely due to significant Er^{3+}-Er^{3+}interactions at this concentration level as noted by Quimby et al. [10] and losses due to waveguide imperfections.

4 CONCLUSION

A 9.5 dB/cm gain is theoretically possible via femtosecond aided RETS layer formation with high refractive index contrast, enabling the fabrication of small format waveguide amplifiers with large effective index and consequently lower losses in complicated geometries (bends, splits, etc). It is likely gain values closer to the upper bound of 27 dB/cm may be achievable by judiciously co-doping with Yb^{3+} to enhance absorption of 976 nm pump light and reduce detrimental Er^{3+}-Er^{3+} interactions.

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