Investigation of Erbium-doped Tellurite Glasses for a Planar Waveguide Power Amplifier at 1.57μm

J. I. Mackenzie*[1], G. S. Murugan[1], T. Suzuki[2], Y. Ohishi[2], A.W. Yu[3] and J.B. Abshire[4]
[1] Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, U.K.
[2] Research Center for Advanced Photon Technology, Toyota Technological Institute, 2-12-1 Hisakata, Tempaku, Nagoya 468-8511, Japan
[3] Laser & Electro-Optics Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A
[4] Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A
**Corresponding author: jim@orc.soton.ac.uk*

Abstract: Comparing gain in Er-doped tellurite glasses for CO_2 absorption measurements, a maximum gain of 2.2dB/cm with 8 ms fluorescence lifetime has been obtained at 1572 nm using a 974 nm pump with intensity of $8kW/cm^2$.
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1. Introduction

Currently our planet has the highest concentration of atmospheric CO_2 than at any time in the past 0.4M years, in order to make predictions of the future atmospheric composition, and improve climate modelling, a better understanding and full characterization of the nature and processes of CO_2 sinks are needed on a global scale. For this purpose new powerful and efficient sources are required to probe the atmosphere from space to make accurate measurements of the abundance of tropospheric CO_2. In this paper we detail our investigation of erbium-doped tellurite glasses with and without ytterbium co-doping, which can be operated at wavelengths beyond the conventional C-band coinciding with a CO_2 absorption line. These glasses are suited as host media that can be used for a planar waveguide power amplifier gain stage in a MOPA dual channel laser absorption spectrometer system being developed for the ASCENDS space mission [1]. We have measured high gains per unit length reaching $3.5dBcm^{-1}$ at the 1530 nm peak and $2.2dBcm^{-1}$ around 1572nm. A long fluorescence lifetime of >8ms is observed in this glass leading to low saturation intensities and the prospect of excellent performance as the host media in a planar waveguide power amplifier.

2. Glass fabrication and characterization

To ensure a broad gain bandwidth extending beyond the 1570 nm absorption band of CO2, we chose simple tellurite compositions using magnesium as one of the glass modifiers, due its strong cationic field strength, shown to maximise the σ_{em} x τ_f and σ_{em} x FWHM figure-of-merits in similar glasses [2]. Co-doping with ytterbium allows higher gains to be achieved but requires efficient energy transfer from the upper $^4F_{5/2}$ level of the Yb^{3+} ions to the $^4I_{13/2}$ energy level of the Er^{3+} ions. The base tellurite composition has a maximum phonon-energy of $\sim 750cm^{-1}$, therefore B_2O_3/GeO_2 was also included in two glass compositions to increase this value and similarly the non-radiative decay rate from the Er^{3+} $^4I_{11/2}$ level.

The glasses were prepared with 99.99% purity starting materials, fully melted in a platinum crucible in an electric furnace at 800°C with a dry air atmosphere to prevent hydroxal contamination. The melts were cast on preheated steel plates and annealed at 300 °C for 10 hrs, before being cut and polished for characterization. Three compositions have been fabricated and compared; (A) 80TeO2 – 10ZnO – 10MgO, (B) $72.5TeO_2$ – 10ZnO – 10MgO – $7.5B_2O_3$, and (C) $65TeO_2$ – 10ZnO – 10MgO – $7.5B_2O_3$ – $7.5GeO_2$ mol%, which were either singly doped with Er^{3+}, or co-doped with an equal ratio of Er^{3+} and Yb^{3+}, at a rare earth ion concentration of 1.0×10^{20} $ions/cm^3$ for the B and C series, and 1.5×10^{20} $ions/cm^3$for the A series compositions respectively. Refractive index, emission lifetime, DSC, transmission and pump-probe gain measurements were performed on each of the samples.

3. Results and discussion

Optical measurements made with the cut and polished samples measuring ~20 x 20 x 4 mm^3 provided the refractive index for each composition, the absorption cross-section at the signal wavelengths (Fig. 1), and the fluorescence lifetime. A co-linear pump-probe experiment was used to measure the steady state gain in the bulk glass samples at several wavelengths between 1525 nm and 1600 nm. Using a 0.75 W 974 nm OCLARO fibre coupled pump, intensities up to $8kWcm^{-2}$ could be achieved during the 10ms pump pulse, during which time the change in power of a CW tuneable probe source was measured with a broad-area unbiased Germanium photodiode. The probe variation in power around the pump pulse was recorded on a digital oscilloscope and saved for later analysis to determine the internal gain and time taken to reach a steady state condition.

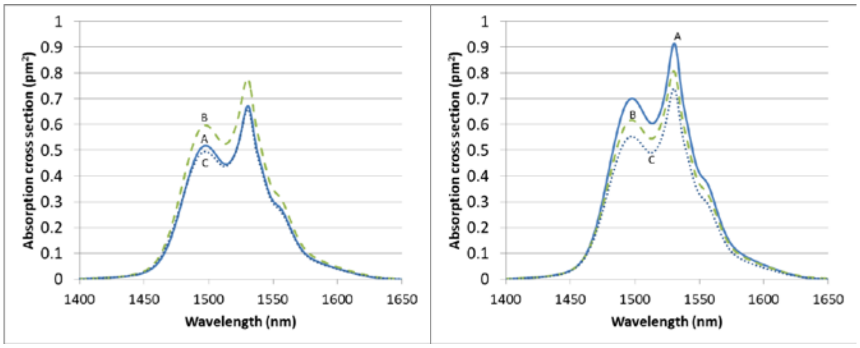
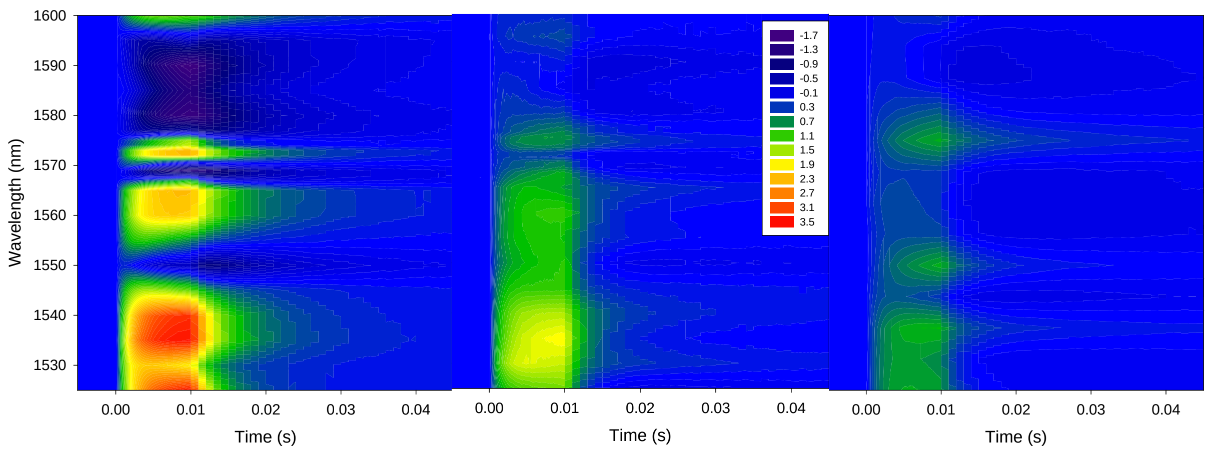


Fig. 1. Absorption cross-section spectra for (a) Er-doped and (b) Er/Yb-doped A, B, and C series compositions respectively.

Table 1: summary of the key measured values for the respective compositions.

Glass	n (@1544nm)	τ_f (ms)	Peak σ_{em} (pm^2)	FWHM σ_{em} (nm)	T_g (C)	ΔT (C)
A-Er	2.028	8.42	0.91	49.7	329	72
A-Er/Yb	2.03	8	0.66	49.4	-	-
B-Er	1.988	2.93	0.79	50.1	338	73
B-Er/Yb	1.986	3.04	0.81	51.8	339	72
C-Er	1.937	2.97	0.66	49.8	364	95
C-Er/Yb	1.936	2.91	0.75	49.8	367	96

The measured gain as a function of time was found to be strongly dependent upon the probe wavelength as illustrated for the co-doped samples in Fig. 2. Non-resonant phonon-assisted excited state absorption is believed responsible for the rapidly varying gain profile, particularly emphasised in the A-Er/Yb sample due to the much longer lifetime of the Er^{3+} $^4I_{11/2}$ in this low phonon-energy material. It should be highlighted that the A-Er/Yb glass had a 50% higher Er/Yb concentration than the other two compositions, notwithstanding it is evident that this glass has higher gain.



(a) (b) (c)

Fig. 2. Measured gain (dB/cm^{-1}) at an incident pump intensity of 8kWcm^{-2} for the (a) A-Er/Yb (b) B-Er/Yb, and (c) C-Er/Yb glasses.

4. Summary

We have made and tested three tellurite glasses suitable for a planar waveguide gain element, a maximum gain of 2.2 dBcm^{-1} around the CO_2 absorption band was realised. The best glass (A-Er/Yb) has an excellent figure-of-merit and potential for meeting the stringent demands for the power amplifier in the ASCENDS mission MOPA system.

5. References

[1] J.B. Abshire, H. Riris, G.R. Allan, C.J. Weaver, J. Mao, X. Sun, W.E. Hasselbrack, M. Rodriguez, E.V. Browell, "Pulsed airborne lidar measurements of CO2 column absorption," NASA Earth Science Technology Forum, B8P1, Pasadena, CA (2011).

[2] C. Yu, D. He, G. Wang, et al. "Influence of cationic field strength of modifiers on the 1.53 lm spectroscopic properties of Er3+-doped tellurite glasses", J Non Cryst Solids **355**, 2250-2253, (2009).