Er^{3+} doped Silica-on-Silicon using fs-laser doping process for Integrated Waveguide Amplifier Platforms

'Student Paper'

Paramita Pal[1*], E. Kumi Barimah[1], Benjamin Dawson[2] and Gin Jose[1]

e-mail: pmppa@leeds.ac.uk

[1]School of chemical and process engineering, University of Leeds, LS2 9JT, UK*

ABSTRACT

Rare earth doped waveguide amplifier (EDWA) on silica-on-silicon (SOS) platform are area of great interest for silicon integrated photonics. We report the fabrication of erbium doped silica-on-silicon (SOS) wafer-scale platforms for integrated waveguide amplifier and laser application. We used a method named- ultrafast laser plasma doping (ULPD) process on silica- on-silicon substrates using erbium doped zinc-sodium tellurite glasses (TZN) as targets. The influence of laser energy on the doping process was studied in terms of the refractive index of the waveguides formed and their photoluminescence properties. Planar slab waveguides of refractive index1.64 at 633 nm and characteristic photoluminescence lifetimes of erbium at 1535 nm wavelength emission, varying from 13.38 ms to 10.52 ms were obtained. We used higher repetition rate (10 kHz) amplified Ti-Sapphire laser with pulse duration of 45 fs for faster and efficient growth of active waveguide layer in this research.

Keywords: femtosecond laser, pulsed laser deposition, SOS, erbium, EDWA

1. INTRODUCTION

Formation of active waveguide regions on silicon platforms will be advantageous to introduce, in particular, optical gain elements on silicon. The limited success in doping silicon directly with rare earth ions prompted us to investigate the method developed by Jose et.al [1] for application on silica-on-silicon (SOS) [2]. The ability of the method to produce highly erbium doped SOS could be interesting particularly for engineering miniature optical waveguide amplifier and thin disk lasers in the C-band of optical communication (1530-1565 nm) [3].

In this report, we report the use of erbium doped (0.25 mole%) zinc-sodium-tellurite (TZN) glasses as the ablation targets in our femtosecond pulsed laser deposition (fs-PLD) system consisting of a fs-laser with (wavelength 800nm, pulse duration~ 45 fs and repetition rate -10 kHz). In a previous study, laser with pulsed duration of 100fs and pulse repetition rate of 1 kHz was used [2]. Tellurium oxide (TeO_2) based glasses, as a host material, exhibit high rare-earth ion solubility and hence advantageous as target material in the process. In the ULPD technique, the femtosecond laser generates nanoparticles and ions to form a high energetic, highly forwarded plume which allows near-stoichiometric transfer of the target material into silica substrate surface. The silica heated to upto about 700 ^oC is thus modified to form an erbium doped tellurium containing homogeneous silicate layer (EDTS) [3]. They exhibit characteristic optical properties of erbium doped silicate glass suitable for amplifier and laser engineering. The schematic of planar slab waveguide prepared in this study is shown in Fig.1.

Fig. 1. The schematics for EDTS waveguiding samples produced in the present work

2. EXPERIMENTAL DETAILS

2.1. PREAPARATION OF THE GLASS TARGETS

The zinc-sodium-tellurite glass (TZN) was prepared using the melt quenching technique following the compositions of (79.75) TeO_2–10ZnO10Na_2O-0.25Er_2O_3. The high purity chemicals have been used for batch melting in a furnace at 875 °C in a gold crucible for 1 hour and quenched from ~770°C. The glass is then annealed below the glass transition temperature i.e. 300° C for 3 hours. After that the glasses were cooled down to room temperature. The glass was polished before performing any laser ablation experiments.

2.2. DOPING PROCESS BY LASER ABLATION

Three samples were prepared with EDTS layers on SOS wafers (3 × 2 mm) as shown in Fig.1. with varying laser pulse energies thus varying laser fluences (S1= 0.44 J/cm^2, S2= 0.53 J/cm^2, S3= 0.66 J/cm^2). The samples were prepared at a set substrate temperature of 600 ºC and 4 hours deposition time.

3. MEASURED OPTICAL PROPERTIES OF EDTS PLANAR OPTICAL LAYER

3.1. REFRACTIVE INDEX AND THICKNESS

The refractive indexe and the thickness of the waveguiding EDTS layers formed within the silica-on-silicon were measured using ellipsometry and a prism coupler. The thicknesses obtained for different samples S1, S2 and S3 were 571nm, 480 nm and 1317 nm respectively. The refractive index data obtained for S3 using ellipsometry is shown in Fig. 2. The sample S3 with thickest EDTS layer has the surface refractive index around 1.6540 at 633 nm wavelength and three guided modes at this wavelength were observed. The measured effective indexes of the guided modes were TE0(1.6405), TE1 (1.6003) and TE2(1.5364).

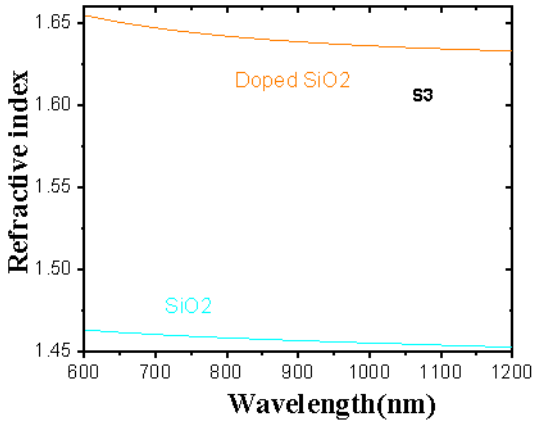

Fig. 2. Refractive index of the EDTS layer for S3 comparing that to silica

3.2. PHOTOLUMINOSCENCE(PL) AND LIFETIME COMPARISON

The PL spectra at room temperature is measured by exciting the samples using a laser diode with wavelength 980nm. The subsequent radiative transition of Er^{3+} ions from $^4I_{13/2}$ -$^4I_{15/2}$ results in PL emission- peaked around 1540 nm which is shown in Fig.3. From the normalised spectra, the full width at half maximum (FWHM) of the PL for each sample is calculated and they range from around 33 nm to 36 nm as reported in Table 1. The photoluminescence decay lifetime is comparable for S1 and S2, and higher than that of S3 as shown in the table.

The emission spectral characteristics of Er^{3+} ion in EDTS depends largely on the doping concentration in the target glass. In a previous research a detailed study of Er^{3+} -ion concentration in the target glass on PLD and PL lifetime of EDTS was undertaken and it showed PL intensity to increase with concentration while the lifetime decreases after about 0.25% Er^{3+} -ion concentration [3]. However, these studies were performed for samples prepared using a 1kHz laser. Two comparable high lifetimes are obtained for samples prepared at lower laser fluences (S1 and S2) while at higher laser fluence of 0.66 J/cm^2 the lifetime decreased to 10.52 ms suggesting concentration of quenching due to energy transfer between Er^{3+}-ions. This can be attributed to change in ablation

dynamics when higher (10kHz) repetition rate laser used in this research. It can be inferred that at higher laser fluence, the generated plume incorporates more Er^{3+} ions into silica, resulting in EDTS layer that has higher Er^{3+} concentration. Further doping optimisation is therefore needed to grow thick waveguiding layer with higher doping concentration to fabricate high gain per unit length waveguide amplifier.

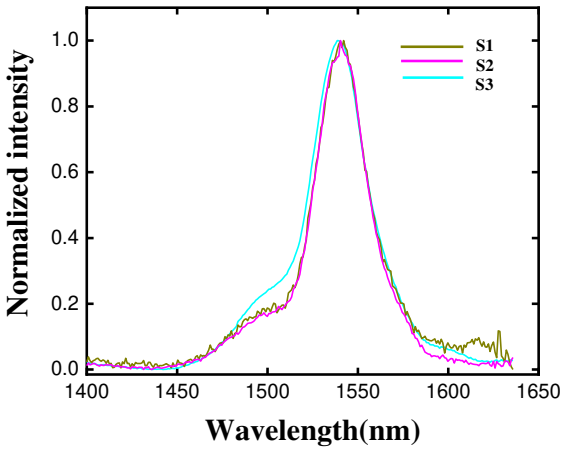

Fig.3.PL spectra of the samples prepared using varying laser fluences

TABLE 1: FLUROSCENCE LIFETIMES AND FWHMS OF THE EDTS SAMPLES

Sample ID	Laser fluences (J/cm^2)	FWHM(nm)	Lifetime (ms)
S1	0.44	36.53	13.38
S2	0.53	33.38	13.40
S3	0.66	33.05	10.52

4. CONCLUSION

We demonstrate preparation and spectroscopic characterisation of high refractive index, high photoluminescence and lifetime of EDTS waveguides on SOS using ULPD technique. We have increased the rate of growth of the waveguides using a high repetition rate repetition rate (10 kHz) fs-laser comparing to those reported previously using 1 kHz fs-laser. Planar slab waveguides with three guided modes at 633 nm were demonstrated. Further work is in progress to fabricate channel waveguide amplifiers with optimum dopant concentrations.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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