Erbium-doped Yttria-stabilized Zirconia thin layers for photonic applications

(Student paper)

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ABSTRACT

Near-infrared (near-IR) integrated photonic devices in silicon-based platforms have been studied over the last decades for applications such as on-chip optical communications and sensing. Driven by the need of more power efficient new photonic systems, the hybrid integration of functional oxides has become an attractive route to explore new physical phenomena. In this regard, Yttria-Stabilized Zirconia (YSZ) stands as an interesting material for its structural, chemical and optical properties. We recently demonstrated YSZ waveguides with propagation losses of 2 dB/cm at a wavelength of 1380 nm [1]. We have recently explored the introduction of active rare-earth dopants into YSZ waveguides to demonstrate on-chip optical amplifier. For that purpose, Er^{3+} ions are preferred due to their luminescence properties within the C-band of telecommunications. In this study, we demonstrate strong luminescence from Er-doped YSZ multilayer stacks around $\lambda = 1.54$ µm, grown by pulsed laser deposition (PLD) technique. The alternation of YSZ thin films and sub-nanometric layers of Er has enabled us to have control of the Er-Er inter-distance in the growth direction, hence being able to strongly decrease the luminescence quenching caused by upconversion processes. Moreover, the optical properties of Er-doped YSZ thin films grown on silicon nitride strip photonic waveguides under resonant pumping will be discussed in this paper.

Keywords: functional oxides, nanophotonics, rare earths, yttria-stabilized zirconia, optical gain, hybrid photonic platform.

1. INTRODUCTION

Latest advances in nanophotonics have triggered the search for low power consumption photonic devices. In this regard, engineering materials has been suggested as a powerful strategy to give birth to new functional materials willing to be implemented in silicon photonics platforms for a vast range of applications including datacom, telecom, sensing, or quantum optics [2]. In this context, functional oxides have been revealed as very interesting class of materials due to their singular characteristics comprising superconductivity, magnetism, ferroelectricity, catalytic activity, resistive switching, electro-optic effects, piezoelectricity, or optical nonlinearities, among others [3]-[6].

Despite the difficulties of hybrid integration on silicon photonics due to lattice constraints imposed by silicon, material engineering has been raised as an elegant solution to epitaxially grow high-quality crystalline functional oxide films on silicon keeping the interfaces light scattering and defect density to minima. This technique requires a buffer layer for lattice adaptation between silicon and the functional oxide and to avoid inter-diffusion between substrate and oxide materials.

An appealing material in this regard is yttria-stabilized zirconia (YSZ), extensively used as a buffer layer for functional oxides in applications as a solid electrolyte, gas sensors and fuel cells. YSZ outstanding properties include thermal and chemical stability and hardness and mechanical durability. Interestingly, YSZ also shows promising optical properties as it belongs the popular mid-index contrast material family (MiDex) [7] that is largely employed in photonics due to its low propagation loss and the absence of nonlinear phenomena, preventing two photon absorption (TPA) to dominate under high pumping conditions in the near and mid-IR; transparency from the ultraviolet to the near-infrared and a good Kerr effect puts this buffer oxide under the scope for photonic integration).

Rare-earth ions have been used as active materials for photonic devices to enhance light emission in integrated photonics to develop new light sources and optical amplifiers. One of the main challenges to confront on rare-earth integration on a host is to keep the doping level as high as possible while avoiding quenching effects and maintaining a good crystalline quality of the host. Moreover, only low phononic materials able to avoid non-radiative effects are suitable to host rare-earth ions efficiently. Light amplification has been demonstrated in functional oxides as $LiNbO_3$ and gain for oxides as Al_2O_3 and Y_2O_3 [8]-[10], and have already demonstrated its potentiality when combined with photonic integrated circuits. Y_2O_3 thin films are good candidates as hosts for rare-earth ions in constructing active waveguides for telecommunication applications operating at 1.55 µm. Among the rare-earth ions, the erbium ion is known to have several transitions in the wavelength range within the near-infrared (near-IR) as a well as a good solubility in YSZ, making this rare-earth a perfect candidate for the development of efficient light emitting functional oxides at telecommunication wavelengths.

2. EXPERIMENTAL PROCEDURE

On a first approach, erbium-doped yttria stabilized-zirconia (Er:YSZ) thin films were deposited by pulsed laser deposition (PLD) on silicon dioxide (SiO_2) (0-100nm) encapsulated silicon nitrate (SiN_x) waveguides of 600nm on a silicon platform (Fig.1 (a)) at 800°C in an oxygen atmosphere. Laser ablation of two rotating targets of 8% mol YSZ ceramic target and metallic erbium was carried out by a KrF excimer laser (248-nm wavelength, 3-J/cm² fluence, and 5-Hz repetition rate).

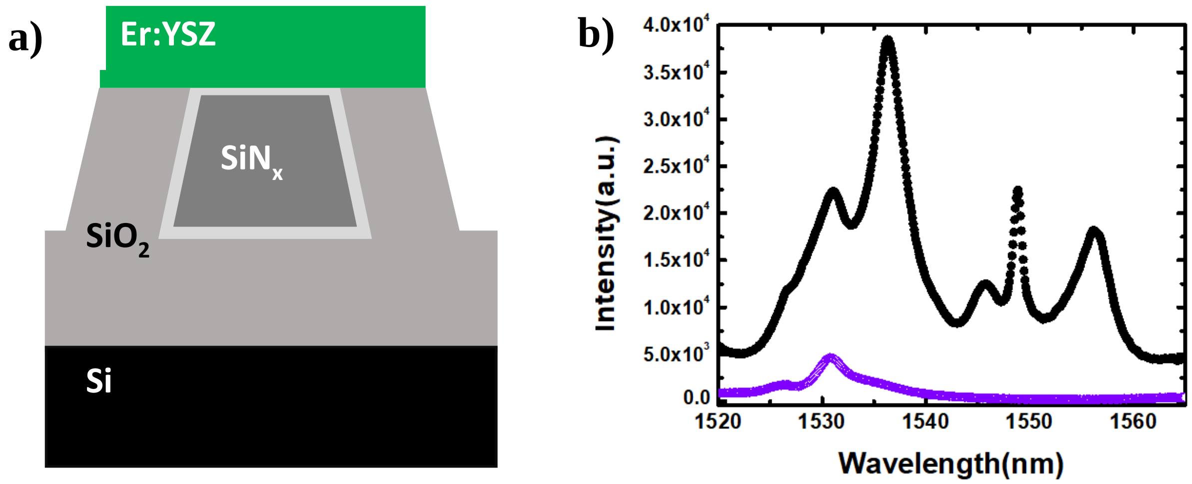

Figure 1. (a) Cross-section of a SiNx waveguide encapsulated by silicon dioxide on a silicon platform. A thin film of Er-YSZ was growth by PLD. (b) PL emission in the near-IR range of Er:YSZ thin film reveals two emissions of different intensities corresponding to the same transition: (black dotted) a locally enhanced signal showing Stark splitting for 1530, 1536 and 1548 nm and (purple dotted) an homogeneous emission with a maximum at 1530 nm.

2.1. Optical characterization

In Fig. 1(b) we observe two photoluminescence (PL) emission profiles corresponding both to erbium $\mathbf{^4I_{13/2}\rightarrow ^4I_{15/2}}$ transition) after exciting erbium-doped YSZ thin film at 980 nm with a continuous wave of a titanium-sapphire (Ti:Sa) laser. PL purple dots signal in Fig. 1(b) is homogeneously distributed on the sample and shows a higher intensity at 1530nm. Moreover, a local emission profile in Fig. 1(b) (black dots) proves Stark effect of the same transition with enhanced emissions at 1530, 1536 and 1548nm. Stark effect in rare-earth transitions is known to be related to the crystallinity of the sample, out of the scope of our study.

To further optically characterize our sample he have performed visible spectroscopy by pumping Er:YSZ on Si_3N_4 waveguides at a wavelength of 1480 nm. It has been evidenced strong up-conversion luminescence of erbium ions at 525, 544 and 562 (Fig. 2(a)), 656 and 679 nm (Fig. 2(b)) corresponding to $^2H_{11/2}\rightarrow ^4I_{15/2}$, $^4S_{3/2}\rightarrow ^4I_{15/2}$, $^2H_{9/2}\rightarrow ^4I_{13/2}$, $^4F_{9/2}\rightarrow ^4I_{15/2}$ and $^2H_{9/2}\rightarrow ^4I_{11/2}$ transitions, respectively . Similar strong up-conversion has been previously observed in other material platforms displaying optical gain, hence providing an interesting scenario to further explore the gain characteristics of this new gain material for integrated photonics [11].

3. CONCLUSIONS

To sum up, high quality crystalline erbium-doped YSZ thin films were epitaxially grown on sapphire substrate and polycrystalline thin films on SiNx waveguides. Optical characterization by means of photoluminescence at 980 nm reveals erbium $\mathbf{^4I_{13/2}\rightarrow ^4I_{15/2}}$ transition for all the substrates and platforms and it has been noticed a local multiple emission corresponding to Stark splitting with enhancement of luminescence. $^2H_{11/2}\rightarrow {}^4I_{15/2}$, $^4S_{3/2}\rightarrow {}^4I_{15/2}$, $^2H_{9/2}\rightarrow {}^4I_{13/2}$, $^4F_{9/2}\rightarrow {}^4I_{15/2}$ and $^2H_{9/2}\rightarrow {}^4I_{11/2}$ transitions have been measured by visible spectroscopy revealing strong erbium up-conversion when pumping at 1480nm.

Future work will focus on the study of gain in Er:YSZ on the hybrid SiN_x platform at 1.53 µm to unveilon-chip optical amplification at telecom wavelengths**.**

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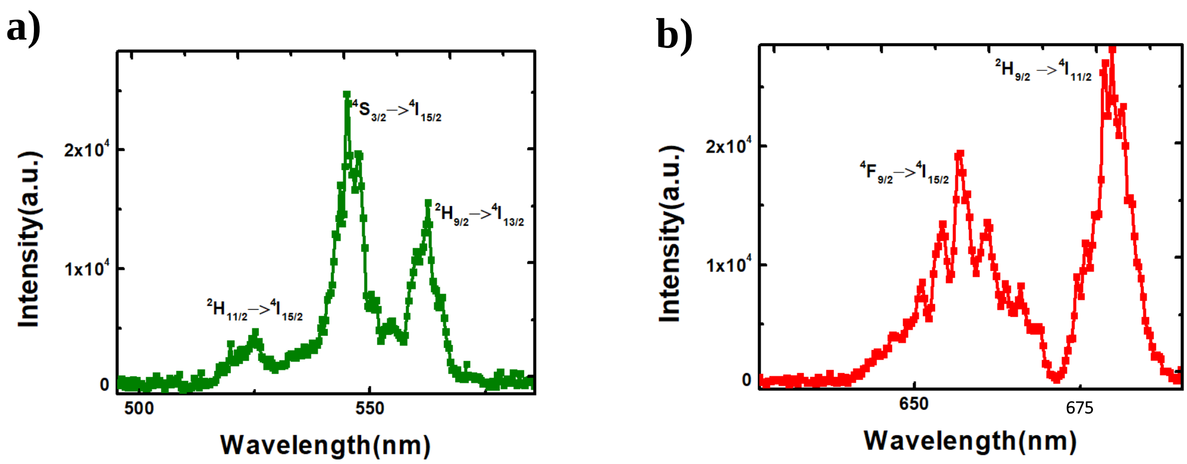

Figure 2. Spectroscopy in the visible range of wavelengths proves erbium up-conversion at different transitions corresponding to the green (a) and red (b) range of wavelengths.

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