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Ultrafast laser plasma assisted rare-earth doping for silicon photonics

Gin Jose[1], Jayakrishnan Chandrappan[1], Suraya Ahmad Kamil[1], Matthew Murray[1], Zsolt Zolnai[2], Emil Agocs[2], Peter Petrik[2], Paul Steenson[3], Thomas Krauss[4]

1. Institute for Materials Research, School of Chemical and Process Engineering, University of Leeds, LS2 9JT, UK
2. Institute of Technical Physics and Materials Science, Hungarian Academy of Sciences, 1121 Budapest, Konkoly Thege Rd. 29-33, Hungary
3. Institute of Microwaves and Photonics, School of Electronic and Electrical Engineering University of Leeds, Leeds, LS2 9JT, UK
4. Department of Physics, University of York, York, YO10 5DD, UK

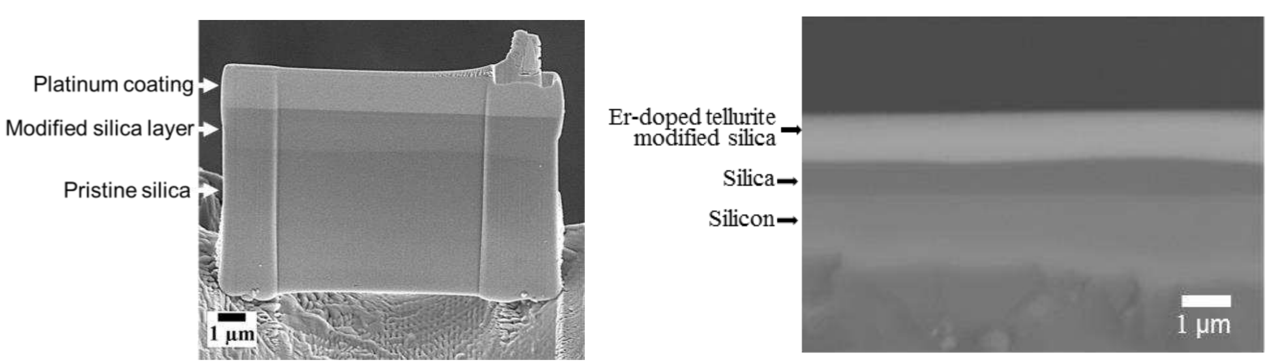
E-mail : g.jose@leeds.ac.uk

Abstract: A novel technique for rare-earth doping in silica is developed with femtosecond laser plasma processing and record high concentration of erbium in silica/ silica-on-silicon platforms to realize compact optical amplifiers for silicon photonics are achieved.

OCIS codes: (130.0130) Integrated optics; (160.0160) Materials; (060.0060) Fiber optics and optical communications; (320.0320) Ultrafast optics

The next generation silicon photonic systems are aiming for Tbps/cm^2 transmission capacity and beyond, which necessitate highly dense optoelectronic integrations [1]. However, the photonic integrated circuits have inherent signal deterioration at each stage of signal processing such as splitting and switching. The hybrid semiconductor optical amplifiers and erbium doped optical fiber amplifiers are only bridging solutions to meet the current system requirements. Therefore, the development of optical loss compensated waveguides and high gain compact amplifiers on silica/silicon are crucial to advance the photonic integrations to realize cost-effective next generation system in packages [2]. Rare-earth doped silica materials are one of the potential platforms to achieve this target, but the current fabrication techniques generate crystallinity in silica even at moderate erbium concentrations (>10^{18} atoms/cm^3) leading to erbium clustering that degrades the optical performances [3–5]. In this paper, we introduce a femtosecond laser plasma assisted rare-earth doping process in silica glass and silica on silicon platforms to fabricate highly dense erbium and ytterbium doped silicates. This novel process yields amorphous silicates with record high (2.8 at.%) doping concentration of rare-earth elements in pure silica with 9.1 ms lifetime.

In this unique process, the rare-earth elements (erbium (Er)/ytterbium (Yb)) were initially dissolved in tellurite base material (TZNE: (80-x)TeO_2-10ZnO-10Na_2O-xEr_2O_3) to prepare the target glass and subsequently ablated using a 100 femtosecond (fs) pulsed laser operating at 800 nm wavelength [6,7]. The complex interfacial reactions between the laser plasma and the hot substrate (silica/silica-on-silicon) produce a tellurite modified dense silica-rich layer with a homogeneous distribution of target glass components as indicated in Fig.1(a) and Fig. 1(b)., which is entirely different from a conventional fs pulsed laser deposition (PLD) process.



(a) (b)

Fig. 1. The high-resolution cross-sectional images of the samples fabricated through fs laser plasma-assisted process. Erbium doped silica layer on (a) silica substrate and (b) silica on silicon substrate.

The optical characterizations reveal the formation of a planar optical layer with higher refractive index (n =1.6) compared to the base silica (n = 1.45). The spectroscopic properties of Er^{3+}-ions corresponding to the intra-4f transition $^4I_{13/2} \rightarrow {}^4I_{15/2}$ in this multi-ion doped platform are investigated. The results indicate desirable emission band at 1535 nm with longer fluorescent decay lifetimes (9-12 ms).

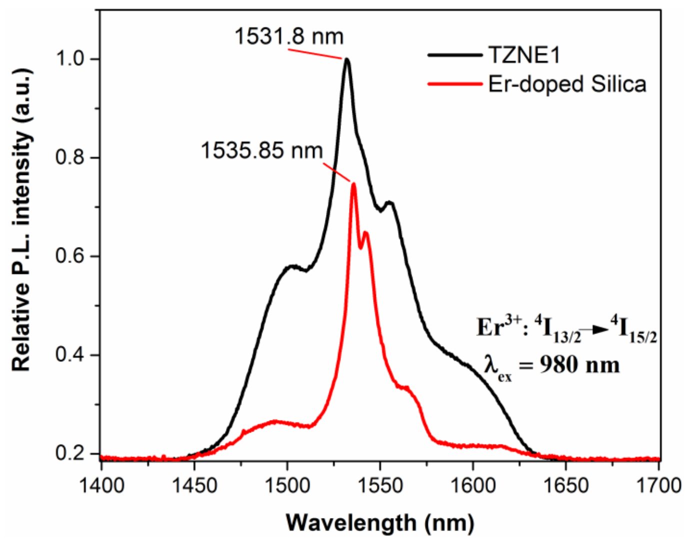


Fig. 2. Emission spectra of erbium in the target tellurite glass (black line) and in the fs laser plasma modified silica sample (red line)

This paper will also present the details of a new co-doping process for the development of Yb-sensitized Er systems based on sequential multi-target ablation process. The exceptional nano-layer mixing to formulate the Er-Yb co-doped systems cannot be achieved through any other standard glass manufacturing technique. This innovative method unlocks a new perspective in rare-earth doping in silica and has the potential to realize the miniature optical amplifiers with >5dB/cm gain to enable dense photonic integrations.

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