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Erbium doped Nanoparticle-Polymer Composite Thin Films for Integrated Photonics

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Abstract: A novel technique of synthesising polymer-Er^{3+}-doped ceria nanocomposite thin films with strong Er^{3+} ions photoluminescence (PL) emission and long lifetime at 1534 nm for applications in optical sensing and waveguide are presented.

Summary: Rare-earth doped cerium oxide (Re_2O_3-CeO_2) has been investigated extensively in the past two decades as an oxide-ion conductive material for solid oxide fuel cell electrolytes [1]. However, doping of ceria with other rare earth (Re^{3+}) ions or glasses [2] has huge potential in various applications such as in biomedical and optical sensors,, scintillators, optical waveguide amplifiers, and lasers in the visible and near-infrared (NIR) wavelengths for optical communications, which have not been fully exploited. It has been proven that the quick expedient transformation of the oxidation state of Ce for Ce^{3+} and Ce^{4+} in phosphors, glasses, and nanoparticles compositions enhances the photoluminescence (PL) properties of the doped rare earth ions in the NIR. Siloxane-based polymers have also been employed to fabricate low-loss optical waveguides directly on printed circuit boards to enable short-reach board-level optical links [3, 4]. This is due to their outstanding thermal, mechanical and optical properties: they exhibit good thermal stability and can withstand temperatures up to about 300°C; they don't suffer from the yellowing phenomenon or thermal aging effects commonly found in polymer materials when exposed to temperature greater than 100^{o}C; they exhibit low loss at the wavelengths of interest and can be easily patterned with a variety of methods. The integration of the Re^{3+} ions doped CeO_2 nanoparticles with siloxane polymers can offer light emitting and amplification functionalities in such polymer-based systems and enable the formation of low-cost compact optical waveguide amplifiers suitable for use in board-level optical interconnects. However, the integration of these two these two dissimilar materials is challenging due to the poor dispersibility of inorganic nanoparticles in polymer matrices and the difference in their thermal expansion coefficients. As a result, we have developed a novel technique of incorporating nanoparticles into siloxane materials using microfiltration membranes. The membranes efficiently remove the agglomerated and large nanoparticles from the polymer-nanocomposite solution resulting in homogeneous dispersion of the nanoparticles within the polymer matrix.

In the study presented here, erbium (Er), gadolinium (Gd) co-doped CeO_2 ($Er_{10}Gd_{10}Ce_{80}O_{19}$) nanoparticles are synthesised with the sol-gel technique [5]. About 12.5 % volume fraction of the nanoparticles is dispersed in the siloxane polymer and part of the polymer nanocomposite solution is filtered through a 1.2 µm pore membrane. The unfiltered and filtered solutions are spin coated onto silica substrates to fabricate polymer nanocomposite thin films. Their surface morphology, cross-sectional analysis using scanning electron microscope with energy dispersive x-ray spectroscopy, X-ray spectroscopy, Raman spectroscopy, and optical transmission properties of both films will be discussed and compared. Their room temperature PL spectrum and lifetime are also evaluated by employing a fluorescence spectrometer furnished with a 980 nm semiconductor laser diode. PL emission at1.5µm with a bandwidth of ~60.0 nm and a lifetime of ~5.5 ms is recorded for the filtered thin film sample which is promising for the formation of optical waveguide amplifiers based on this integration method.

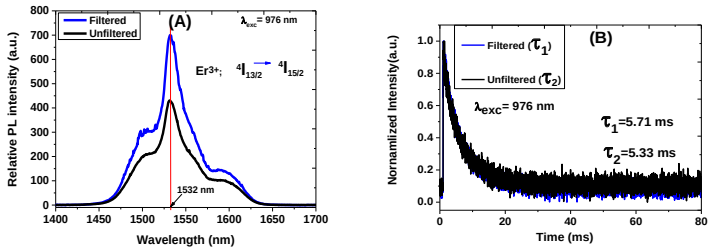

Fig. 1: A) PL spectra of Er ions intra-4f atomic transition $^4\mathbf{I}_{13/2} \rightarrow {}^4\mathbf{I}_{15/2}$ in unfiltered and filter polymer nanocomposite thin films at room temperature under 976 nm excitation source; (B) Corresponding lifetime transients.

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