Femtosecond-Pulsed Laser Deposition of Erbium-Doped Glass Nanoparticles in Polymer Layers for Hybrid Optical Waveguide Amplifiers.

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Tellurium oxide (TeO_2) based glasses are widely used in many applications such as fibre optic, waveguide devices and Raman gain, and are now being considered for use in optical waveguide amplifiers. These materials exhibit excellent transmission in the visible and near IR wavelength range (up to 2.0 µm), low phonon energy, and high rare-earth solubility [1-3]. Siloxane polymer materials on the other hand, have remarkable thermal, mechanical and optical properties and allow the fabrication of low-loss optical waveguides directly on printed circuit boards. In recent years, various low-cost optical backplanes have been demonstrated using this technology [4-7].However, all polymer optical circuits used in such applications are currently passive, requiring therefore amplification of the data signals in the electrical domain to extend the transmission distance beyond their attenuation limit. The combination of the TeO_2 and siloxane technologies can enable the formation of low-cost optical waveguide amplifiers that can be deployed in board-level communications. However, there are significant technical challenges associated with the integration of these two dissimilar materials mainly due to the difference in their thermal expansion coefficients.

In this paper therefore, we propose a new approach for incorporating erbium (Er^{3+})-doped tellurium-oxide glass nanoparticles into siloxane polymer thin films using femtosecond pulsed laser deposition (fs-PLD).. Erbium-doped sodium zinc tellurite (Er-TZN) nanoparticles (NPs) are embedded into siloxane polymer films spin-coated on silica substrates using fs-PLD at low temperatures (100 °C) and under two different pulse energies. The surface morphology, and the compositional and structural characteristics of the samples fabricated are evaluated using scanning and transmission electron microscopy (SEM and TEM), TEM- energy-dispersive X-ray spectrometry, X-ray diffraction (XRD), and Raman spectroscopy. Additionally, photoluminescence (PL) and lifetime measurements are carried out at 1534 nm at room temperature under a 980 nm laser diode excitation. The SEM results show that average particle size of the Er-TZN NPs incorporated into polymer layer decreases with decreasing fs-pulse laser energy, while the PL measurements reveal a full-width at half-maximum (FWHM) of about 39 nm. The respective FHWM value obtained from the bulk glass is 51 nm. The obtained luminescence lifetime of the samples is in the range 3.52 to 4.18 ms, which is slightly lower than the value obtained from the bulk glass target of 4.37 ms.

References:

1. J. C. Sabadel, P. Armand, D. Cachau-Herreillat, P. Baldeck, O. Doclot, A. Ibanez and E. Philippot, Structural and Nonlinear Optical Characterizations of Tellurium Oxide-Based Glasses: TeO2–BaO–TiO2, Journal ff Solid State Chemistry, 1997, 132, 411-419.
2. A.K. Singh and S. B. Rai in: "Up conversion and optical thermometry in HO^{3+}:TeO_2 glass, effect of addition of PbO2 and BaCO3 Laser and Spectroscopy Laboratory", Department of Physics BHU, Varanasi 221005, India 2007.
3. Ravi Kumar V.V., Bhatnagar, Anil K.; Jagannathan, R. In: "Structural and optical studies of Pr^{3+}, Nd^{3+} and Eu^{3+} ions in tellurite based oxyfluoride, TeO2-CiF glasses"2001
4. R. Dangel, F. Horst, D. Jubin, N. Meier, J. Weiss, B. J. Offrein, B. W. Swatowski, "Development of versatile polymer waveguide flex technology for use in optical interconnects", Journal of Lightwave Technology, 31(2013), 3915
5. N. Bamiedakis, A. Hashim, R. V. Penty, and I. H. White, "A 40 Gb/s Optical Bus for Optical Backplane Interconnections," *Journal of Lightwave Technology*, vol. 32 (2014), 1526-1537.
6. J. Beals, N. Bamiedakis, A. Wonfor, R. Penty, I. White, J. DeGroot, K. Hueston, T. Clapp, and M. Glick, "A terabit capacity passive polymer optical backplane based on a novel meshed waveguide architecture", *Applied Physics A: Materials Science & Processing*, vol. 95 (2009), 983-988.

7. R. C. A. Pitwon, W. Kai, J. Graham-Jones, I. Papakonstantinou, H. Baghsiahi, B. J. Offrein, R. Dangel, D. Milward, and D. R. Selviah, FirstLight: “Pluggable Optical Interconnect Technologies for Polymeric Electro-Optical Printed Circuit Boards in Data Centers”, *Journal of Lightwave Technology*, vol. 30(2012), 3316-3329.