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Fabrication of a novel nano-engineered glass based optical fiber for radiation sensor application

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Abstract

The fabrication of a new class of cerium (Ce) and Ce/Au co-doped nano-phase separated alumina-phospho-silica glass based optical fibres through modified chemical vapour deposition (MCVD) process coupled with solution doping technique is presented along with study of their radiation response behavior under ^{60}Co-gamma radiation source at 635nm wavelength. The sensitivity of both Ce doped and Ce/Au co-doped fibres are found to be 0.4643dB/m/Gy and 0.4360dB/m/Gy, respectively. The experimental results show that Ce doped and Ce/Au co-doped optical fibres have good response to radiation exposure which can be useful as a radiation sensor for fibre optic based personal dosimetry applications.

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Keywords: Optical fibre, Ce and Au doped glass, Segregation, Defect centers, Induced loss, Radiation sensor.

1. Introduction

Optical fibre based dosimeter allows remote radiation monitoring and has potential application in highly radiation environment such as nuclear reactors, hazardous place and space application. It can find application in the field of diagnostic or radiotherapy irradiations for a careful control of the dose imparted to patients. Optical fibre dosimeters are being intensively investigated and recently a few systems were proposed based on different physical radiation effects in radiation sensitive glass fibres, suitable to be exploited for dosimetric purposes; Houston et al (2001). Dosimetry can be based on the formation of radiation induced defects leading to glass coloration; Paul et al (2009) and Ghosh et al (2011), or on the filling of pre-existing traps, measured by thermally or optically stimulated luminescence (TSL or OSL) Jones et al (1993), Roy et al (1997). All these systems are used to monitor the total imparted dose after irradiation is complete.

The important issues for prospective use of optical fibres as radiation sensor in fibre optic dosimetry systems are

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an acceptable level of radiation sensitivity, low recovery and the linear optical response. At present, much attention is paid to the development of specialty optical fibre with incorporation of suitable co-dopants to increase the radiation sensitivity. The radiation sensitivity of silica based fibres with incorporation of different co-dopants such as Ge, Al, P etc already reported; Ghosh et al (2011), Jones et al (1993), Paul et al (2009), Friebele et al (1980). Germanium doped fibre does not show much more sensitivity than that of Al and P doped fibres; Paul et al (2009). P doped fibres become good candidate for use as a radiation sensor though its radiation sensitivity is not very high. Our purpose is to develop very high sensitive optical fibre than that of P doped fibres, which will be very effective for use in personal dosimetry system using the low cost light source just like to He-Ne laser of wavelength 635nm. In this connection we have developed Ce and Au doped nano-engineered alumina-phospho-silica glass based specialty optical fibres based on the following information about the properties of Ce and Au doped glasses.

Ce/Au co-doped glass host is expected to enhance efficiency of energy transfer from the host glass matrix to the emissive centers. Furthermore, Ce-doped glass with minor amount of phosphorous (P) inhibits both CeO_2 segregation and oxidation of isolated Ce^{3+} ions to Ce^{4+} ones; Canevali et al (2005). Such properties of alumina-phospho-silica glass doped with Ce and Ce/Au should apply for optical fibres made on its base. In the meantime, the use of Ce doped silica fibres for dosimetry through a measurement of induced loss produced by different kinds of irradiation is still a matter to study.

The purpose of the present paper is also to stress the development of Ce and Ce/Au co-doped nano-engineered alumina-phospho-silica glass based optical fibres through the Modified Chemical Vapor Deposition (MCVD) technique coupled with solution doping process along with study of their radiation response behaviour under ^{60}Co-gamma irradiation at room temperature. The material characterization results of the doping host of Ce and Ce/Au co-doped nano-engineered glass through SEM, TEM and EDX was described. The segregation effect of Ce ion, formation of radiation induced color centre and the radiation response behavior of a composite fibre under the presence of a γ-ray is presented along with relevant discussion. The EPR study has been performed in gamma radiated fibre sample in order to correlate the responsible defect centers. The radiation response characteristics of Ce doped nano-phase separated alumina-phospho-silica glass based optical fibre shows high radiation sensitivity, good linearity with the accumulated dose and very low fading behaviour exhibiting low dose-rates dependency whereas Ce/Au codoped fibre show lower sensitivity having good linearity with the accumulated dose and dose rate independent behavior, suggesting potential application in personal dosimetric application.

2.0 Experiments

2.1 Fiber sample preparation

The MCVD process coupled with the solution doping technique has been used to fabricate special type of nano-engineered glass based optical fibre preform. The process comprises deposition of the porous core layer containing SiO_2 doped with P_2O_5 at 1500 ± 10^0C over the pure silica cladding layer inside a quartz tube (Suprasil F-300 grade) of outer dimension 14 mm with tube thickness of 1.5 mm. The deposition temperature was precisely controlled and monitored through an online IR pyrometer (Model PRO-44-50C-FOV15in/100-21-SB-AP-40C, Williamson Corp., USA) with an temperature accuracy of $\pm 5^0$C synchronously moved with the oxy-hydrogen burner to minimize the variation in porosity of the deposited core layer. The deposited porous core layer next removed from the glass working lathe and impregnated in an aqueous solution containing suitable halide salts of different dopants Al, Ce and Au for fixed time span of 45 minutes. For preparation of Ce-doped preform sample, solution comprises suitable strength of $AlCl_3$ $6H_2O$ and $CeCl_3$ $7H_2O$ salt, while for Ce/Au co-doped sample require amount of $AlCl_3$ $6H_2O$, $CeCl_3$ $7H_2O$ and $AuCl_3$ are dissolved in water. The addition of aluminum as co-dopant is well studied and potentially prevents the clustering of the rare earth (RE) elements; Nguyen (2007), Ishii et al (1987), beside enhancing RE luminescence properties due to uniform RE dispersion. In addition, the co-dopant Al can control the valence of Ce and its ligands; Arai et al (1986).

The silica tube with deposited soaked soot layer was then remounted in glass working lathe followed by dehydration and oxidation in a step-wise manner by increasing the temperature from 900 to 1700^0C. Finally, the tube has been slowly collapsed to achieve the solid rod called preform and the fibres of dimension 125 ± 0.5 μm has been drawn from the fabricated preforms. The vapor phase composition, solution composition, and different process