Characterization of yttria nano structured material for radiation dosimetry

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The use of rare earths (RE) as dopant of materials has supplied the development of advanced materials for many applications such as optical markers, special alloys, semiconductors, as well as radiation dosimetry. The development of new dosimetric materials is a great challenge in innovation of materials. Yttria (Y_2O_3) presents luminescent proprieties and can be considered a potential material for radiation dosimetry. In this study Y_2O_3 nanoparticles were characterized by Photon Correlation Spectroscopy (PCS), Specific Surface Area by BET method (SSA), X ray diffraction pattern (XRD) and Scanning Electron Microscopy (SEM) and Thermally Stimulated Luminescence (TL). According results yttria powders with mean particle size of d_{50}=304nm, pycnometric density of ρ=4.84g.cm^{-3}, specific surface area SSA=13.5m^2.g^{-1} presents TL signal response at 150°C and λ=550nm when exposed to ^{60}Co gamma radiation.

Key words: yttria, rare earths, thermoluminescence, radiation dosimetry.

1. INTRODUCTION

The development of new dosimetric materials with luminescent and spectrometric/paramagnetic response higher than established dosimeters is a great challenge in innovation of materials. From RE, yttria (Y_2O_3) is a promising material for radiation dosimetry due to its intrinsic chemical and physical proprieties as melting point of 2400ºC, refractive index of 1.9, thermal and chemical stability. Y_2O_3 is used for enhancement of sintering[1], catalysis[2], luminescence[3], electrical[4], electronic[5], mechanical[6] and thermal[7] behavior of many advanced materials. YAR et al.[8] by chemical reaction highly uniform nano-sized yttrium doped tungsten oxide particles (WO_2:Y_2O_3) were synthesized. Samples sintered at 1400ºC showed higher relative density (R_D=95%) and finer grain size as compared to those sintered at 1500ºC and 1600ºC. LI et al.[9] produced yttrium doped zinc oxide nanofibers (ZnO: Y_2O_3) by electrospinning method followed by calcination. As a result, doping with yttrium was useful to form particles with uniform morphology, higher specific surface area (40.2m$^{2\cdot}$g^{-1}) and gas sensing as compared to those ZnO. Europium doped yttria (Y_2O_3:Eu^{3+}) is noted for its excellence in luminescence[10]. ZHANG et al.[11] reported the synthesis of single-layer yttrium oxide nanosheets doped with Eu^{3+} and Tb^{3+} by the exfoliation method. The promising results such as transparency, strong red and green emissions show that nanosheets have potential to be used as building blocks and other functional materials. Based on yttrium oxide proprieties and its promising applications the present work aims to characterize yttrium oxide powders as a first step for future application in radiation dosimetry.

2. EXPERIMENTAL

In this work yttria powder (Y_2O_3; Johnson Matthey) was used as raw material. Powder characterization was performed as follow: X-ray diffraction (XRD; Rigaku Multiflex), scanning at $1^{\circ}.min^{-1}$, $\Delta\theta$ = 10-80°(2θ) and radiation Cu-kα; scanning electron microscopy (SEM, Oxford); X-ray fluorescence (XRF, Rigaku RIX 3000); photon correlation spectroscopy (PCS, ZetaPALS Analyzer, BrookhavenInstruments); specific surface area by BET method (SSA, Micrometrics ASAP 2010); determination of the theoretical particle size (d_{BET}) from BET model[12] and agglomeration factor (F_{AG}); helium pycnometry (Pycnometer Micrometrics 1330). Thermoluminescence response (TL) was carried out after irradiating the samples with γ dose of 10KGy from a ^{60}Co source and using the TL reader Risø (TL/OSL-DA-20) and the spectrometer Ocean Optics (QE65 Pro) with spectral sensibility from 200 to 950 nm. The samples were heated at a heating rate of $10^{o}C.s^{-1}$ up to 400°C.

3. RESULTS AND DISCUSSION

Figure 1 shows XRD pattern of Y_2O_3 powders. According to result is observed that diffraction peaks corresponded to body-centered cubic yttria (C-type) fitting PDF (70-603) and a peak of high intensity in 29º which is related with the crystallographic plane (222). HOEKSTRA et al.[13] reported that the rare earths sesquioxides belong to C-type as Dy_2O_3, Th_2O_3, Ga_2O_3 and In_2O_3. In addition, literature has shown that Y_2O_3 can present other polymorphs. GOURLAOUEN et al.[14] reported the monoclinic structure (B-type) at 997°C under 2.0 GPa during plasma spray coating. NAVROTSKY et al.[15] showed that the C-type becomes fluorite type at 2308°C and hexagonal A-type at 2325°C. QUIN et al.[16] observed structural changes from C-type to B-type for particles smaller than 10 nm.

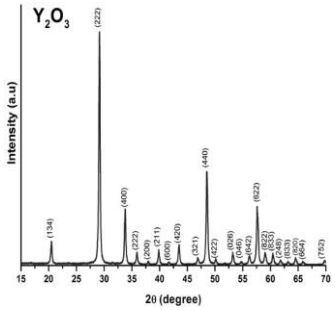

Figure 1. XDR curve of Y_2O_3 powders according to PDF 70-603.

Powder characterization of Y_2O_3 by PCS and SEM is shown in Figure 2. From results, Y_2O_3 presents narrow particle size distribution with a mean particle diameter d_{50} = 304nm (Figure 2a). Besides, the difference of size (span) between minor (d_{10}) and major (d_{90}) distributions was less than 7nm, which confirms the uniformity of particle size distribution, and the relative span was only 0.02. Therefore, Y_2O_3 showed a monomial particle size distribution.

Particles of nano sized scale are ruled by surface forces and as a consequence tend to agglomerate easily as shown in Figure 2b. From SEM image is observed that Y_2O_3 powders are composed of agglomerates of particles in which size is smaller than 1µm. Furthermore, specific surface area by BET method SSA= 13.59 m^2g^{-1}, pycnometric density ρ=4.84g.cm^{-3} and as comparing theoretical particle diameter (d_{BET}) from BET equation with experimental result from

PCS (d_{50}) the difference of size is 214nm and agglomeration factor (*F*ag) was very small 3.33, which means that particles were weakly agglomerated. For radiation dosimetry the configuration of particle size plays an important role. GUIDELLI et al.[17] reported that radiation sensitivity of silver-alanine nanocomposites increases as a function of particle size. FEOFILOV[18] showed that life time of excited trivalent rare earth ions tend to enhance as a function of decreasing of particle size. BOLSHUKHIN[19] reported that the luminescent behavior and light persistent of $Sr_4Al_2O_3:Eu^{3+}$ is longer for particles of nano scale size.

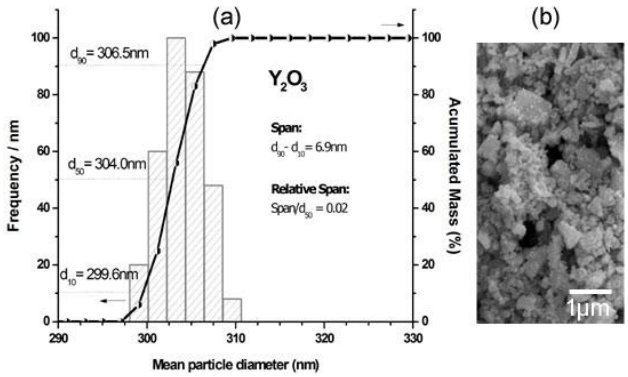

Figure 2. Size and shape characterization of Y_2O_3 powders (a) particle size distribution by PCS and (b) SEM micrograph.

The thermoluminescence (TL) response of yttrium oxide nanoparticles is shown in Figure 3. From the figure, yttrium oxide exhibited a TL peak at 150°C and with light emission quanta at λ=550nm. For yttrium oxide nanoparticles evaluated in this study the light emission at λ=550nm (green light) is new in literature. The TL response may be due to particle characteristics as chemical composition, crystalline and surface defects. These factors can produce charge transport vacancies and luminescence centers. Many contributions on rare earth luminescence response have presented yttrium oxide as matrix for formation of phosphors[20-25]. RAUSKAS et al.[26] reported that yttrium oxide nanoparticles exhibited white light luminescence at λ=330nm like $Y_2O_3:Ce^{3+}$.

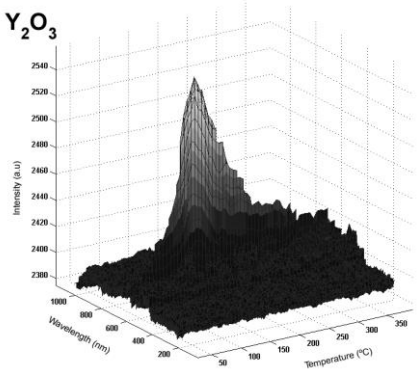

Figure 3. Thermally stimulated luminescence response of Y_2O_3 powders in which TL peak was observed at 150ºC and λ=550nm.

4. CONCLUSION

Characterization of yttria powders for future application in radiation dosimetry was performed. Body-centered yttria powders exhibited uniform particle size distribution, mean diameter d_{50}=304nm, specific surface area around 6.4$m^2.g^{-1}$, pycnometric density ρ=4.84$g.cm^{-3}$. Thermally stimulated luminescence response of yttria was observed at temperature around 150ºC and wavelength λ=550nm. The emission of light in visible spectra is new in literature, considering that yttria has been used as matrix for others rare earth activator ions which exhibit visible luminescence. Therefore, complementary characterizations will be performed in order to understand this behavior.

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