Abstract
$^{151}$Eu Mössbauer spectroscopy was applied to distinguish among different Eu microenvironments and phases in spherical $\text{Y}_2\text{O}_3:$Eu$^{3+}$ and core-shell $\text{Y}_2\text{O}_3@$Eu$^{3+}$ phosphor nanoparticles prepared by using homogeneous precipitation method. $^{151}$Eu isomer shift revealed that Eu atoms exist only in oxidation state Eu$^{3+}$ in all spherical and core-shell phosphors. Significant differences have been found between the Mössbauer parameters (isomer shift, principal component of EFG and linewidth) characteristic of spherical $\text{Y}_2\text{O}_3:$Eu$^{3+}$ and core-shell $\text{Y}_2\text{O}_3@$Eu$^{3+}$ phosphor nanoparticles. The Mössbauer parameters of spherical $\text{Y}_2\text{O}_3:$Eu$^{3+}$ were associated with Eu substituting Y in the $\text{Y}_2\text{O}_3$, while Mössbauer parameters of core-shell $\text{Y}_2\text{O}_3@$Eu$^{3+}$ phosphor were attributed to Eu being in the Eu$_2$O$_3$ shell, proving the structural model and the successful preparation of these phosphors.

Keywords
Phosphors · Eu doped yttrium oxides · Core-shell nanoparticles · Spherical nanoparticles · $^{151}$Eu Mössbauer spectroscopy
1 Introduction

More and more industrial interest was focused on semiconductor-based light-emitting diodes (LEDs). In their preparation the phosphors play a very important role. Among the phosphors Eu doped Y$_2$O$_3$ is one of the best luminophors regarding the emission efficiency of a red light. For the flat-panel display industry it became necessary to obtain nanoparticles with regular morphology and narrow size distribution [1]. Spherical morphology of phosphors is needed to achieve high brightness and high resolution. Spherical nanoparticles can be prepared by solvothermal synthesis [2], spray pyrolysis [3], and homogeneous precipitation [4] method. By forming core-shell particles spherical particles can also be produced [5]. In our recent work [6] we prepared spherical Y$_2$O$_3$:Eu$^{3+}$ and core-shell Y$_2$O$_3$@Eu$^{3+}$ nanoparticles using homogeneous precipitation. The structure model of these phosphor nanoparticles are shown in Fig. 1. Eu incorporation into the yttrium oxide is supposed in the case of the spherical Y$_2$O$_3$:Eu$^{3+}$ nanoparticles with average diameter of 106 nm (Fig. 1 (I)), while Eu is expected to be a constituent of Eu$_2$O$_3$ which forms a shell around the Y$_2$O$_3$ core in the case core-shell Y$_2$O$_3$@Eu$^{3+}$ nanoparticles (Fig. 1 (II)). However, XRD of both spherical Y$_2$O$_3$:Eu$^{3+}$ and core-shell Y$_2$O$_3$@Eu$^{3+}$ nanoparticles showed solely the cubic structure of Y$_2$O$_3$, without any information about the effect of Eu doping on the structure. Therefore the aim of this study was to elucidate the location and microenvironments of Eu atom incorporated both in spherical Y$_2$O$_3$:Eu$^{3+}$ and in core-shell Y$_2$O$_3$@Eu$^{3+}$ phosphor nanoparticles prepared by homogeneous precipitation method. For this study we have used $^{151}$Eu Mössbauer spectroscopy which has been already applied to investigate different europium (II) and (III)-activated phosphors even many years ago [7].

2 Experimental

The spherical Y$_2$O$_3$:Eu$^{3+}$ nanoparticles were prepared by homogeneous precipitation according to Gai et al. method [4]. Y(NO$_3$)$_3$ and Eu(NO$_3$)$_3$ and urea were dissolved in deionized water. The solution was stirred at 90 °C for 4 h and the precipitate appeared. The suspension was separated by centrifugation. The product was washed with deionized water and dried in air at 80 °C for 24 h. The sample was calcined at 800 °C for 3 h.

Preparation of Y$_2$O$_3$@Eu$^{3+}$ core shell nanoparticles: spherical Y$_2$O$_3$ nanoparticles were prepared the same way as above and was dispersed in deionized water creating a suspension. Eu(NO$_3$)$_3$ and urea was given to this suspension separately. The suspension was stirred at 90 °C for 4 h so the Eu$_2$O$_3$ could precipitate onto the surface of the Y$_2$O$_3$ nanoparticles. The suspension was separated by centrifugation. The product was washed with deionized water and dried in air at 80 °C for 24 h. The sample was calcined at 800 °C for 3 h. The doping concentrations of the Eu$^{3+}$ were 2.5, 5, 10, 15 mol%.

$^{151}$Eu Mössbauer spectra of powdered samples were recorded in transmission geometry with a conventional Mössbauer spectrometers (WISSEL, RANGER) working in constant acceleration mode. The γ-rays were provided by a $1 \times 10^{10}$ Bq $^{151}$SmF$_3$ source. The measurements were performed at 300 K. Isomer shifts are given