Supporting Information

Measurement of Optical Properties

PL spectra of the core-shell-shell particle were obtained by an optical microscope with an objective lens with a magnification factor of 100. The particles were spin-coated onto a silica glass. PL intensity from a single particle was obtained by using an aperture which has 50 μm in diameter. The excitation is 405 nm light from a diode laser. The PL was detected by a liquid N_2 cooled Si-CCD diode array (HORIBA UVS-CCD-SS). The spectra were corrected with a reference spectrum of a standard halogen lamp. For the scattering measurement, a halogen lamp was used as a light source and the spectra were detected by a Miniature Fiber Optic Spectrometer USB2000 (Ocean Photonics). All measurements were performed at room temperature.

Calculation Analysis

-Radiative decay rate-

The radiative decay rate of the luminescent dipole inside the core of the multi-shelled particles was calculated by a classical approach described in Ref. [21]. First, a dipole is placed in the core of multi-shelled sphere and the electric and magnetic fields were calculated by a recursive transfer method. Then the time-averaged total radiated power (radiative loss) was calculated by integrating the time-averaged Poynting vector over the surface of a sphere with an infinite radius. The radiative decay rate is proportional to the radiative loss. In Ref. [21], the radiative decay rate is normalized to that of a dipole placed in a free space (Eq. 126 in Ref. [21]). In this work, the ratio of the radiative decay rate in Figure 3 was obtained by dividing the normalized radiative decay rate of a dipole inside the core of the $SiO_2@Y_2O_3@SiO_2$ particles by that of a dipole inside the core of the $SiO_2@Y_2O_3$ particles. Note that the normalized radiative decay rate was averaged over the position of the dipoles assuming that the dipoles are uniformly dispersed inside the core.

-Relationship between radiative decay rate ratio and quantum efficiency ratio -

Generally, the quantum efficiency (*QE*) can be expressed by

$$QE = \frac{W_r}{W_r + W_{nr}}$$

where, W_r and W_{nr} are the radiative and the non-radiative decay rate, respectively. In this work, the quantum efficiency is assumed to be very small, i.e., $W_r << W_{nr}$, because Ce^{3+} doped in Y_2O_3 nanoparticles is known to show very weak luminescence[34]. In this case, the quantum efficiency is obtained by

$$QE = \frac{W_r}{W_{nr}}.$$

In addition, W_{nr} is assumed to be independent of the number of shells. This is valid because the luminescent center (Ce^{3+}) is placed inside the core and the local environment is not changed by the SiO_2 or Y_2O_3 shell coating. Under these assumptions, the ratio of the radiative decay rate of the luminescent dipole inside the core of the SiO_2@Y_2O_3@SiO_2 particle to that of the SiO_2@Y_2O_3 particle is the same as the ratio of the quantum efficiency of the SiO_2@Y_2O_3@SiO_2 particle to that of the SiO_2@Y_2O_3 particle.

TEM images

-The core of the $Y_2O_3:Ce^{3+}$ particles-

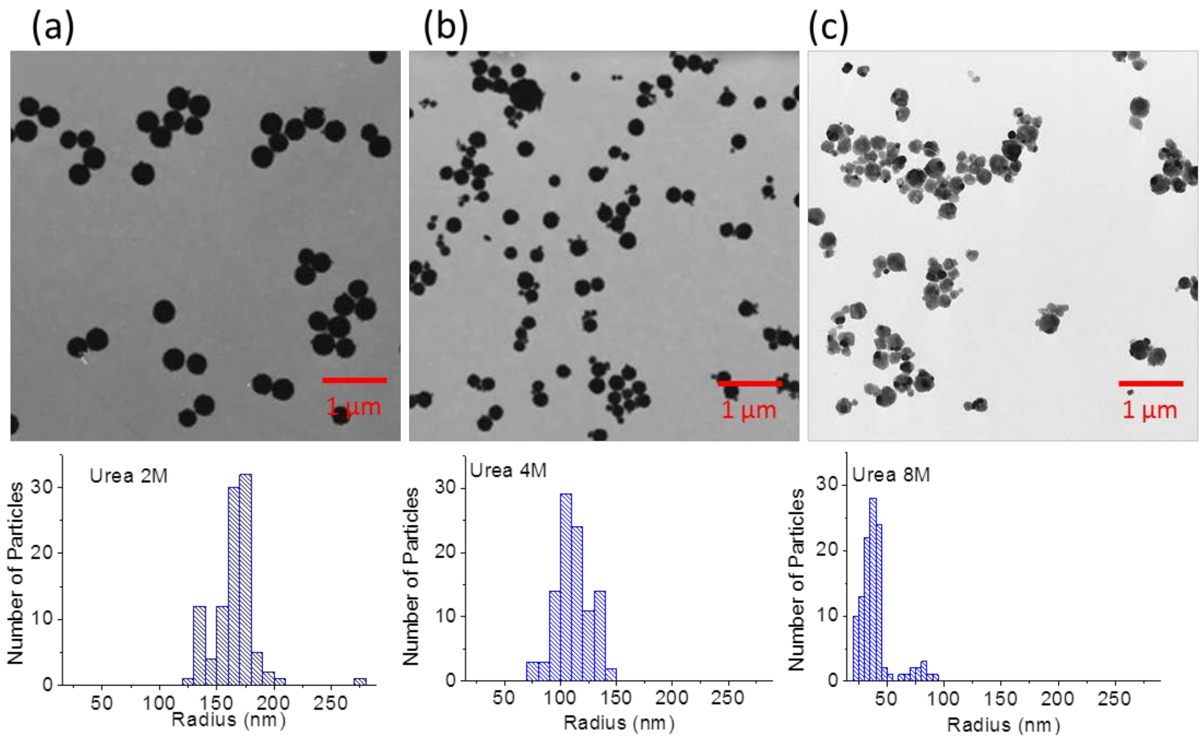

Figure S1. TEM images of the core of the $Y_2O_3:Ce^{3+}$ particles (top figures) and the size distributions (bottom figures). The reaction temperature is 95 °C. The concentration of yttrium nitrate is 0.01 M and the urea concentration is (a)2M, (b)4 M and (c)8 M, respectively. The radius (R) and the standard deviation of the size distribution (σ) are (a) R=164 nm, σ=18 nm, (b) R=110 nm, σ=14.3 nm, and (c) R=35 nm, σ=6.7 nm, respectively.

-The Y_2O_3@SiO_2 particles-

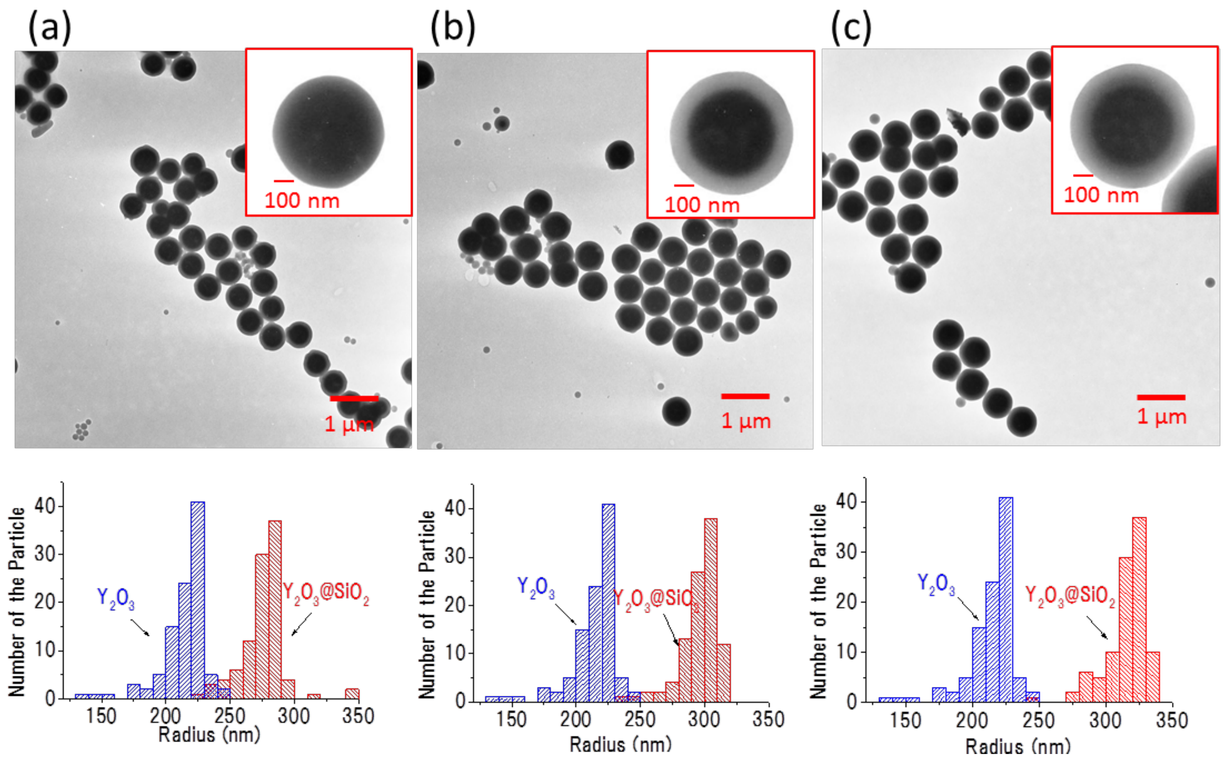

Figure S2. TEM images of the core of the Y_2O_3@SiO_2 particles (top figures) and the size distributions (bottom figures). The TEOS concentration is 0.4 vol%. The NH_3 (aq, 28%) concentration is (a)4 vol%, (b)6 vol%, and (c)10 vol%, respectively. The SiO_2 shell thickness (T_s) and the standard deviation (σ_s) are (a) T_s =61 nm, σ_s = 2.2 nm, (b) T_s =81 nm, σ_s = 1.5 nm, and (c) T_s =100 nm, σ_s = 2.4 nm, respectively.

-The Y_2O_3@SiO_2@SiO_2 particles

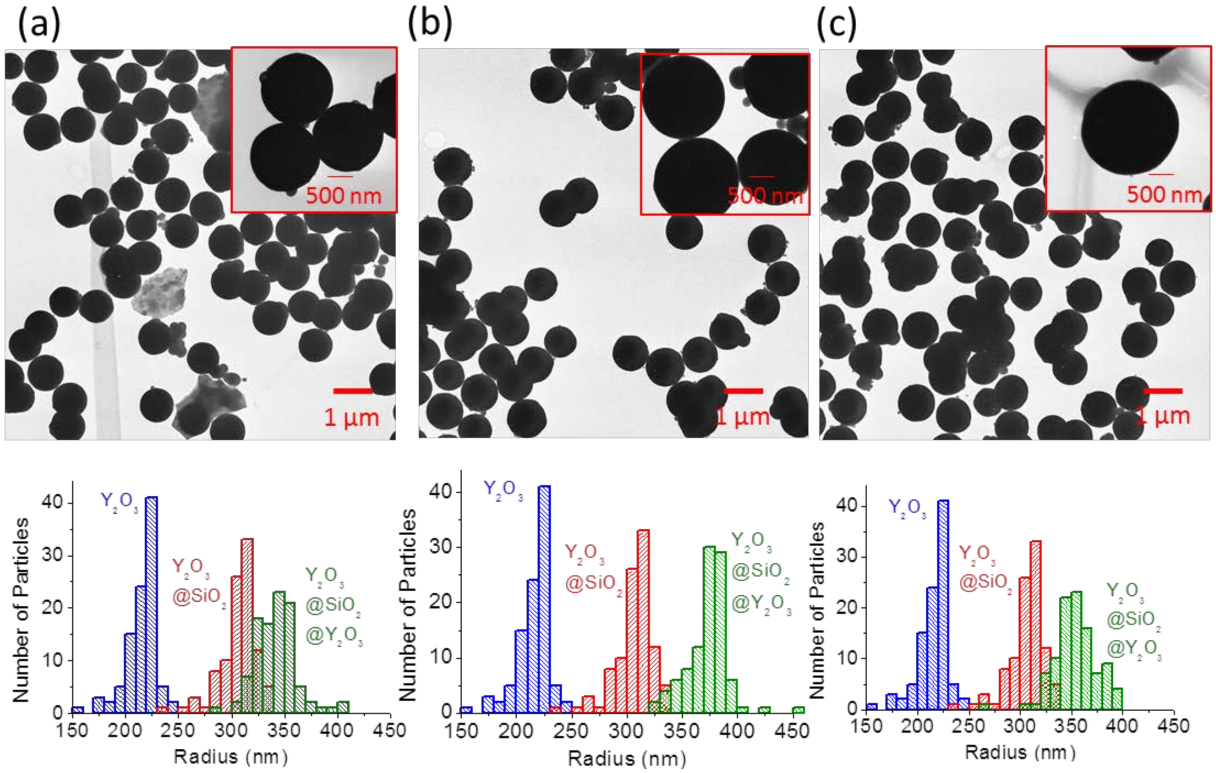

Figure S3. TEM images of the core of the Y_2O_3@SiO_2@Y_2O_3 particles (top figures) and the size distributions (bottom figures). The reaction temperature is 65 ^{o}C. The yttrium nitrate concentration is 0.01 M. The urea concentration is (a)0.10 M (b)0.20 M, and (c)0.30 M, respectively. The Y_2O_3 shell thickness (T_y) and the standard deviation (σ_y) are (a) T_y =35 nm, σ_y = 1.9 nm, (b) T_y =66 nm, σ_y = 1.7 nm, and (c) T_y =47 nm, σ_y = 7.7 nm, respectively.

Scattering spectra

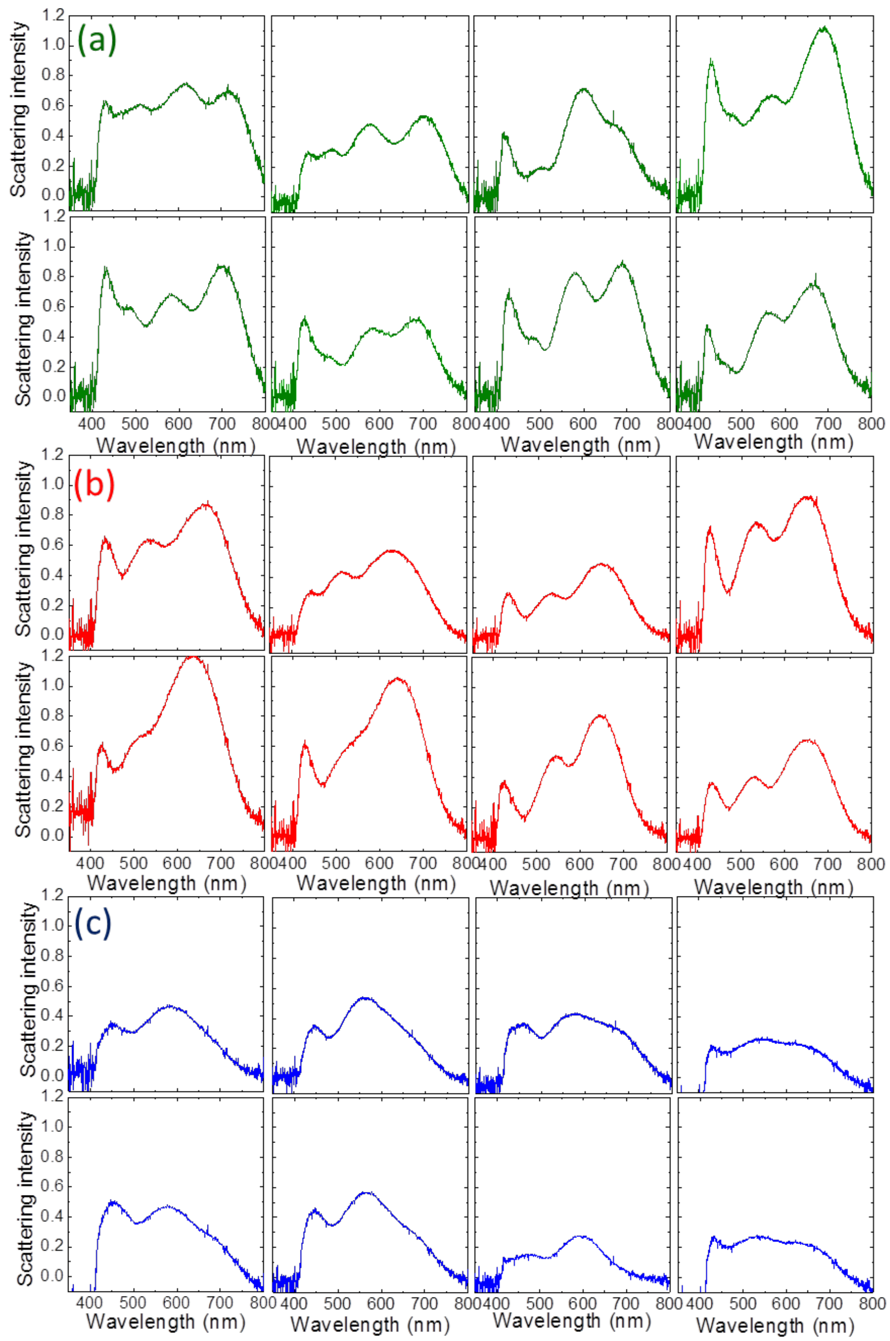

Figure S4. Scattering spectra of a single particle of the (a)Y_2O_3@SiO_2@Y_2O_3, (b)Y_2O_3@SiO_2, and (c)Y_2O_3:Ce samples. The results for 8 different particles are shown for the each sample.

PL spectra

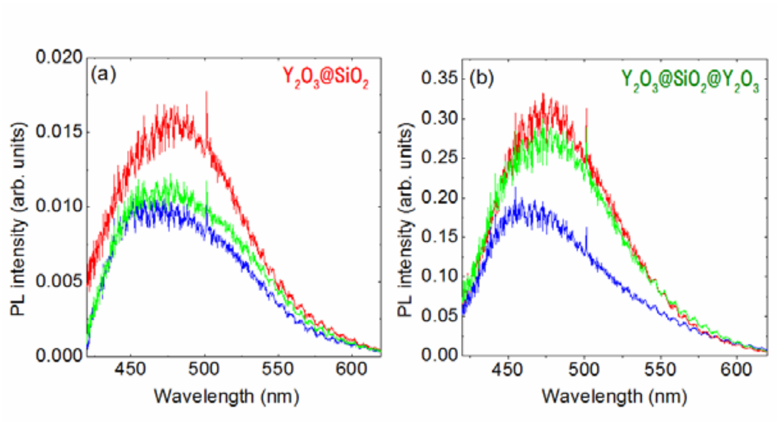

Figure S5. PL spectra of a single particle of the (a) $Y_2O_3@SiO_2$ and (b)$Y_2O_3@SiO_2@Y_2O_3$ samples. Different colors are used for different particles. The PL intensity varies depending on the individual particles.

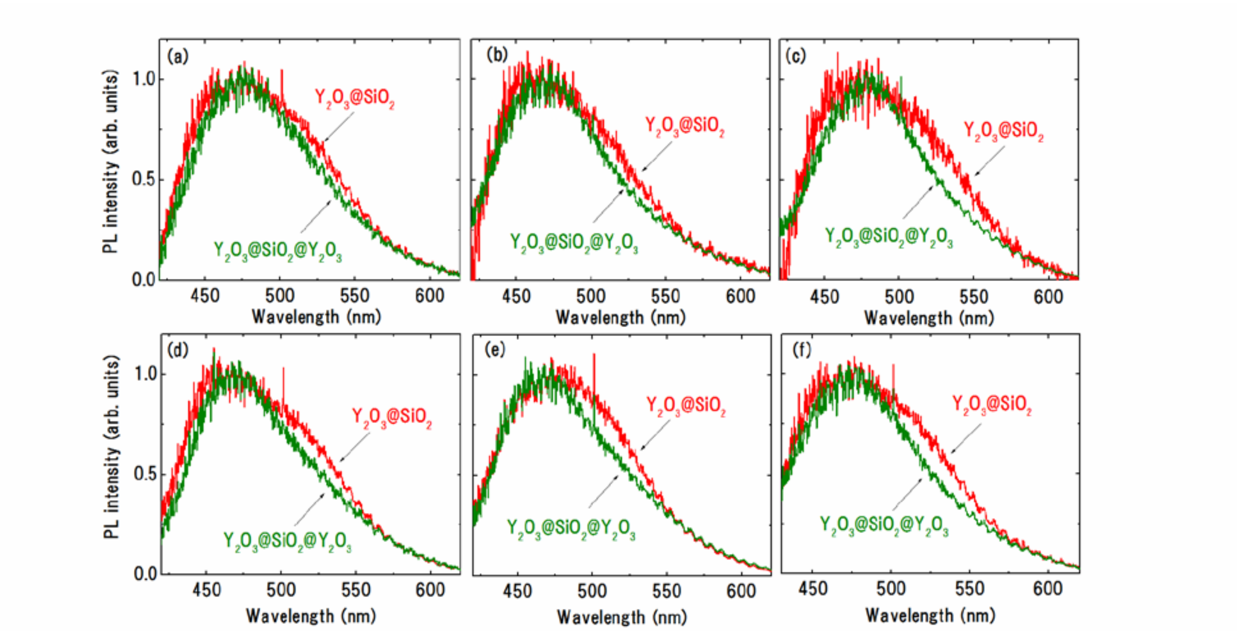

Figure S6(a-f). Normalized PL spectra of a single particle of the $Y_2O_3@SiO_2$ and $Y_2O_3@SiO_2@Y_2O_3$ samples. 6 particles were randomly chosen from the each sample.

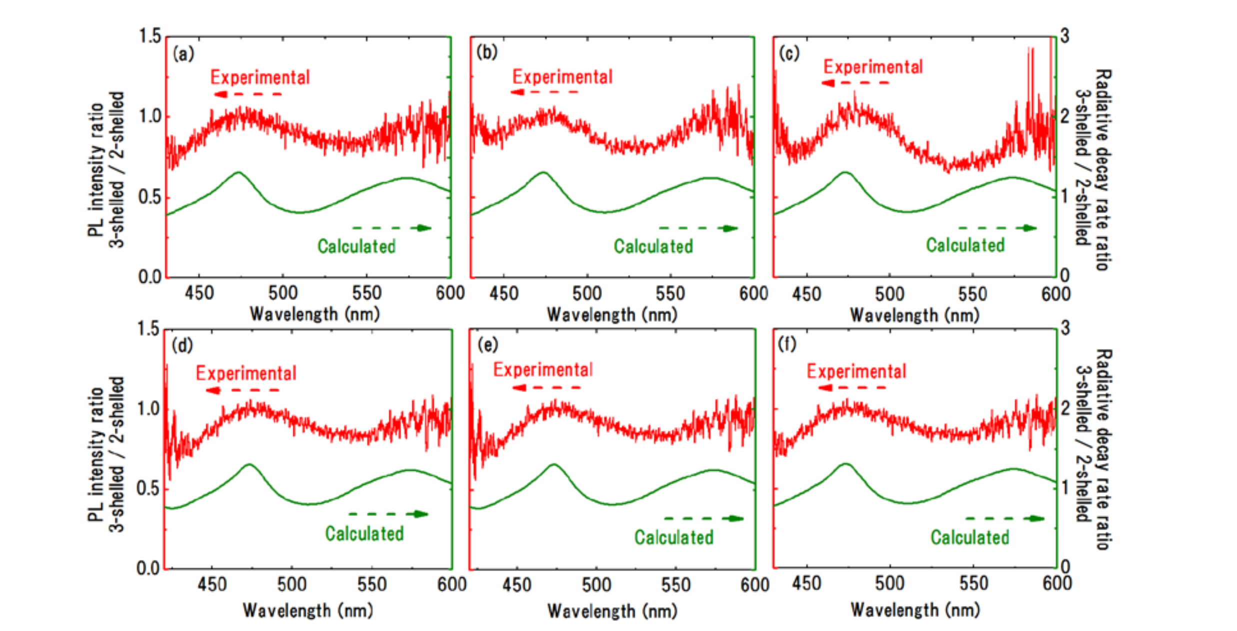

Figure S7(a-f). Ratio of the normalized PL intensity of the Y_2O_3@SiO_2@Y_2O_3 particle to that of the Y_2O_3@SiO_2 one (left axis) and the calculated ratio of the radiative decay rate of a luminescent dipole inside the core of the Y_2O_3@SiO_2@Y_2O_3 particle to that of the Y_2O_3@SiO_2 one (right axis). The PL intensity ratio was calculated using the data shown in Figure S6.