Light Science & Applications

Size-dependent lanthanide energy transfer amplifies upconversion luminescence quantum yields

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Optical upconversion from lanthanide-doped nanoparticles is promising for a variety of applications ranging from bioimaging, optogenetics, nanothermometry, super-resolution nanoscopy and volumetric displays to solar cells. Despite remarkable progress made in enhancing upconversion to fuel these applications, achieving luminescence of upconversion nanoparticles (UCNPs) that is comparable to or higher than the bulk counterparts has been challenging due to nanoscale-induced quenching effects. Here we present a size-dependent lanthanide energy transfer effect in a conceptual design of hexagonal sodium yttrium fluoride core–shell–shell $NaYF_4$@$NaYF_4$:Yb/Tm@$NaYF_4$ UCNPs with depleted surface quenching. We show that precise control over the domain size (from 1.2 to 13 nm) increases the lanthanide energy transfer efficiency (from 30.2 to 50.4%) and amplifies the upconversion quantum yield to a high value of $13.0 \pm 1.3\%$ in sub-50 nm UCNPs (excitation: 980 nm, 100 W cm^{-2}), which is around fourfold higher than the micrometre-scale hexagonal NaYF4:Yb/Tm bulk counterparts. Spectroscopic studies and theoretical microscopic modelling reveal that long-range lanthanide energy transfer (>9.5 nm) takes place and underlies the observed size-dependent phenomena. Demonstration of size-dependent lanthanide energy transfer and upconversion quantum yields at the nanoscale transforms our long-existing conceptual understanding of lanthanide energy transfer (size independence), thereby having important implications for applications of lanthanide nanophotonics and biophotonics.

Short Bio:

Guanying Chen received his B.S. degree in applied physics and Ph.D. degree in optics from Harbin Institute of Technology in 2004,and 2009, respectively. He is currently a full professor at Harbin Institute of Technology, China. His interests include lanthanide luminescence, lanthanide biophotonics, and solar cells.