Rare earth doped upconverting nanoparticles

Rare Earth Doped Upconverting Nanoparticles: Synthesis and Application in Bio-Imaging

Nidhi Malviya [1] , Vinita Rajput Chouhan [1] , Sudeshna Ray [2]

ABSTRACT

Upconversion luminescence, a nonlinear process, which re-emits a photon at a shorter wavelength by the absorption of more than one photon, successively at longer wavelengths via long-lived intermediate energy states, is useful for important applications in various fields like fluorescence bio-imaging and lasers. This NIR-to-NIR up-conversion process provides deeper light penetration into biological specimen and results in high contrast optical imaging due to absence of an auto fluorescence background and decreased light scattering. Excitation at long wavelengths also minimizes damage to biological materials. Herein, we report the different mechanisms responsible for the Upconversion process of rare-earth (Er^{3+} *,* Ho^{3+} *,* Tm^{3+} *) doped nanoparticle and methods that are used to synthesize and decorate up converting nanoparticle.*

I INTRODUCTION

Upconversion is an optical process that involves the conversion of lower-energy photons into higher-energy photons. It has been extensively studied since mid-1960s and widely applied in optical devices. Over the past decade, high-quality rare earth-doped Upconversion Nanoparticles have been successfully synthesized with the rapid development of nanotechnology and are becoming more prominent in biological sciences. The main difference between Upconversion Nanoparticles and other nonmaterial’s is that they can emit visible light under near infrared irradiation. Upconversion nanoparticle (UCNPs), particularly lanthanide-doped nanocrystals, which emit high energy photons under excitation by the near-infrared (NIR) light, have found potential applications in many fields, including biomedicine and is found improved tissue penetration and higher photochemical stability as compared with traditional down-conversion fluorescence imaging. The unique Upconversion process of UCNPs may be utilized to activate photosensitive therapeutic agents for applications in cancer treatment. Upconversion luminescence imaging in vivo is expected to be the next generation photoluminescence imaging technique since it provides high sensitivity and spatial resolution. Due to their multicolour emission, high brightness and long lifetime, lanthanide ions based luminescent nonmaterial have tremendous promise as indicators and photon sources for numerous application such as boilable, light-emitting devices, sensor technology, and low-threshold lasers. So it is very important to successfully prepare the rare-earth doped inorganic nanocrystals with good dispensability in organic solvents.

The Up conversion phenomenon has been transition metals, actinides, but mainly in the rare earth elements, which contain the lanthanide (Ln) series, Yttrium, and scandium. Ln^{3+} ions heave special $4f^{n} 5d^{0-1}$ inner shell configurations that are well – shielded by outer shell and have unique energy level structures. These Ln^{3+} ions can exhibit sharp luminescence emission via intra-4f or 4f-5d transitions. Their luminescence properties, as narrow bandwidth, long-time emission, and anti-stokes emission, have been widely applied in lasers, solar cell, analytical sensors, optical imaging, and photodynamic therapy.

Most fluorescent materials, including dye molecules, quantum dots, and dye-doped silica/gold nanomaterials, emit light by the down conversion process (emitting lower-energy photons under higher-energy irradiation). Although the uses of a conventional organic dye molecule or quantum dot (QD) based biomarker have achieved significant progress in real-time detection and bio imaging, they still have drawbacks. These fluorescent materials are generally excited by ultraviolet (UV) or visible light, which may induce auto fluorescence and photo damage to biological samples, resulting in low signal-to-noise ratio and limited sensitivity. These limitations prompted the development of a new type of high-quality and well-shaped nonmaterial's known as up conversion nonmaterial's (UCNs [1-7].

Lanthanide-doped Upconversion (UC) nanophosphors are promising optical contrast agents for biomedical applications due to their photo stability, sharp emission peaks, and long emission lifetime [8, 9]. Upon near infrared (NIR) excitation, UC nanoparticle exhibit intense visible emission via multiphoton processes involving the lanthanide ions within them [10-12]. For *in vitro* or *in vivo* imaging, the use of NIR excitation minimizes absorbance, scattering, and fluorescence from cells and tissues, allowing imaging against a dark background [13]. In contrast, commercially available labels, such as organic dyes and quantum dots, typically must be imaged against a background of Stokes-shifted tissue autofluorescence induced by UV, blue, or green excitation[14]. In addition, because of the existence of real intermediate energy levels in lanthanide ions, this Upconversion process can be much more efficient than in conventional multiphoton-absorption-induced fluorescence of organic dyes or quantum dots, where the intermediate levels are virtual.

Bio-imaging is a term that covers the complex chain of acquiring, processing and visualizing structural or functional images of living objects or systems, including extraction and processing of image-related information.

II MOTIVATION OF MY WORK

Lanthanide-doped upconversion-luminescent nanoparticles (UCNPs), which can be excited by near-infrared (NIR) laser irradiation to emit multiplex light, have been proven to be very useful for *in vitro* and *in vivo* molecular imaging studies. In comparison with the conventionally used down-conversion fluorescence imaging strategies, the NIR light excited luminescence of UCNPs displays high photostability, low cytotoxicity, little background auto-fluorescence, which allows for deep tissue penetration, making them attractive as contrast agents for biomedical imaging applications. In this review, we will mainly focus on the latest development of a new type of lanthanide-doped UCNP material and its main applications for *in vitro* and *in vivo* molecular imaging and we will also discuss the challenges and future perspectives.

New materials with high Biocompatibility and more intense emission spectra are needed to be developed so for deep tissue imaging.

III CONCLUSION

The past decade a large number of scientists have investigated the potential application of UCNPs in bioimaging. Lim et al. firstly reported the use of

UCNPs as in vivo Caenorhabditis elegans imaging agent. Along with the fast developement of UCNPs for biological applications. UCNPs have also been applied contrasts agents in positron emission tomography (PET), magnetic resonance imaging (MRI), & X-ray computer tomography (CT) for in vitro and in vivo multimodal imaging. Futhermore, UCNPs could also be combined with anti-cancer drugs, photosensitizers or gold nanostructures for potential therapeutic application. Up to now, a variety of Upconversion nanophosphors have been developed for bioimaging, and most of them are based on rare earth doped $NaYF_4$. Other kinds of RE doped nanoparticles, such as $NaGdF_4$, $NaLaF_4$, Y_2O_3, GdF_3, CeO_2, $LiNaF_4$, $Ca_3(PO_4)_2$, ZrO_2 and GdOF etc. have al so been considered as excellent UCNPs in recent years due to their strong Upconversion luminescence intensity and good photostability.

REFERENCES

1. F. Auzel, Chem. Rev. 2004, 104, 139;
2. F. Wang, X Liu, Chem. Soc. Rev. 2009, 38, 976;
3. D. K. Chatterjee, M. K. Gnanasammandhan, Y. Zhang, Small 2010, 6, 278
4. M. Haase, H. Schafer, Angew. Chem. Int. Ed. 2011, 50, 5808.
5. D. K. Chatterjee, A. J. Rufaihah, Y. Zhang, Biomaterials 2008, 29, 937
6. J. Zhou, Y. Sun, X. Du, L. Xiong, H. Hu, F. Li, Biomaterials 2010, 31, 3287;
7. L. Xiong, T. Yang, Y. Yang, C. Xu, F. Li, Biomaterials 2010, 31, 7078.
8. Wu SW, Han G, Milliron DJ, Aloni 8 S, Altoe V, Talapin DV, et al. Proceedings of the National Academy of Sciences of the United States

of America. 2009; 106: 10917-21. doi: DOI 10. 1073/pnas. 0904792106.

9. Mai H-X, Zhang Y-W, Si R, Yan Z-G, Sun L-d, You L-P, et al. J Am Chem Soc. 2006; 128: 6426. doi: 10. 1021/ja060212h.

10. Boyer J-C, Cuccia LA, Capobianco JA. Nano Letters. 2007; 7: 847-52. doi: 10. 1021/nl070235

11. Heer S, Kömpe K, Güdel HU, Haase M.. Advanced Materials. 2004; 16: 2102-5. doi: 10. 1002/adma. 200400772.

12. Chen GY, Ohulchanskyy TY, Kumar R, Agren H, Prasad PN. ACS Nano. 2010; 4: 3163-8. doi: Doi 10. 1021/Nn100457j.

13. Nyk M, Kumar R, Ohulchanskyy TY, Bergey EJ, Prasad PN. Nano Letters. 2008; 8: 3834-8. doi: 10. 1021/nl802223f.

14. Wang M, Mi CC, Wang WX, Liu CH, Wu YF, Xu ZR, et al.. ACS Nano. 2009; 3: 1580-6. doi: Doi 10. 1021/Nn900491j.