

Chem Soc Rev

Chemical Society Reviews

www.rsc.org/chemsocrev

The Royal Society of Chemistry is the world's leading chemistry community. Through our high impact journals and publications we connect the world with the chemical sciences and invest the profits back into the chemistry community.

IN THIS ISSUE

ISSN 0306-0012 CODEN CSRVBR 44(6) 1291–1716 (2015)



Cover

See Fan Zhang *et al.*, pp. 1346–1378. Image reproduced by permission of Dongyuan Zhao and Fan Zhang from *Chem. Soc. Rev.*, 2015, 44, 1346.



Inside cover

See Xueyuan Chen *et al.*, pp. 1379–1415. Image reproduced by permission of Xueyuan Chen from *Chem. Soc. Rev.*, 2015, 44, 1379.

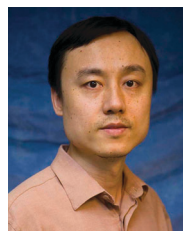
EDITORIAL

1299

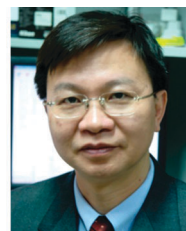
Photon upconversion nanomaterials

Xiaogang Liu,* Chun-Hua Yan* and John A. Capobianco*

Guest editors Xiaogang Liu, Chun-Hua Yan and John A. Capobianco introduce the Photon Upconversion Nanomaterials issue of *Chemical Society Reviews*.



Xiaogang Liu



Chun-Hua Yan



John Capobianco

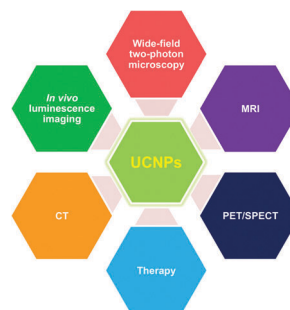
TUTORIAL REVIEWS

1302

Upconverting nanoparticles: a versatile platform for wide-field two-photon microscopy and multi-modal *in vivo* imaging

Yong Il Park, Kang Taek Lee, Yung Doug Suh* and Taeghwan Hyeon*

Upconverting nanoparticles (UCNPs) enable the establishment of a novel UCNP-based platform for wide-field two-photon microscopy and multimodal *in vivo* imaging.



Editorial staff

Interim executive editor

Richard Kelly

Deputy editor

Jeanne Andres

Editorial production manager

Philippa Ross

Development editors

Alessia Millemaggi

Cesar Palmero

Publishing editors

Matthew Bown, Sage Bowser, Hugh Cowley,
Ruth Dilleen, Cally Haynes, Alan Holder,
Samantha Ivell, James Moore, Liisa Niitsoo,
Victoria Richards, Susan Weatherby, Rachel Wood

Publishing assistants

Natalie Ford, Bethany Johnson, Rebecca Wojturska

Publisher

Jamie Humphrey

For queries about submitted papers, please contact
Philippa Ross, Editorial production manager, in the
first instance. E-mail: chemsocrev@rsc.org

For pre-submission queries, please contact

Richard Kelly, Interim executive editor.

E-mail: chemsocrev-rsc@rsc.org

Chemical Society Reviews (print: ISSN 0306-
0012; electronic: ISSN 1460-4744) is published
24 times a year by the Royal Society of Chemistry,
Thomas Graham House, Science Park, Milton Road,
Cambridge, UK CB4 0WF. All orders, with cheques
made payable to the Royal Society of Chemistry,
should be sent to RSC Order Department, Royal
Society of Chemistry, Thomas Graham House,
Science Park, Milton Road, Cambridge, CB4 0WF, UK.
Tel +44 (0)1223 432398; E-mail orders@rsc.org

2015 Annual (print + electronic) subscription
price: £1348; US\$2224. 2015 Annual (electronic)
subscription price: £1280; US\$2112. Customers in
Canada will be subject to a surcharge to cover GST.
Customers in the EU subscribing to the electronic
version only will be charged VAT. If you take an
institutional subscription to any RSC journal you
are entitled to free, site-wide web access to that
journal. You can arrange access via Internet Protocol
(IP) address at www.rsc.org/ip. Customers should
make payments by cheque in sterling payable on a
UK clearing bank or in US dollars payable on a US
clearing bank.

The Royal Society of Chemistry takes reasonable
care in the preparation of this publication but does
not accept liability for the consequences of any
errors or omissions. Inclusion of an item in this
publication does not imply endorsement by
The Royal Society of Chemistry of the content of
the original documents to which that item refers.

Advertisement sales: Tel +44 (0) 1223 432246;

Fax +44 (0) 1223 426017;

E-mail advertising@rsc.org

For marketing opportunities relating to this journal,
contact marketing@rsc.org



Chem Soc Rev

Chemical Society Reviews

www.rsc.org/chemsocrev

Chemical Society Reviews publishes accessible, succinct and reader-friendly articles on topics of current interest in the chemical sciences. The promotion of international and multidisciplinary awareness and cooperation is particularly encouraged. *Chemical Society Reviews* publishes two article types: tutorial reviews, which present an accessible introduction to the topic, and review articles, which provide a deeper evaluation of the current literature.

Editorial board

Chair

Philip Gale, University of
Southampton

Douglas Stephan, University of
Toronto

Zhong-Qun Tian, Xiamen University
Huw Davies, Emory University

Shunichi Fukuzumi, Osaka University
Zijian Guo, Nanjing University

Rachel O'Reilly, University of
Warwick

Helma Wennemers, ETH Zurich

Associate editors

David Amabilino, The University of
Nottingham

Members

Dwayne Heard, University of Leeds

Advisory board

Dave Adams, University of Liverpool
Takuzo Aida, University of Tokyo
Helen Blackwell, University of Wisconsin
- Madison

Anne-Marie Caminade, University of
Toulouse

Joseph Caruso, University of Cincinnati
Peng Chen, Peking University

Jeroen Cornelissen, University of Twente
Lee Cronin, University of Glasgow

Wim Dehaen, Catholic University of
Leuven

Luiz Carlos Dias, State University of
Campinas, UNICAMP

Antonio Echavarren, Institute of
Chemical Research of Catalonia

Elena Fernández, Universitat Rovira i
Virgili

Song Gao, Peking University

Steven Goldup, Queen Mary, University
of London

Jinlong Gong, Tianjin University

Duncan Graham, University of
Strathclyde

Dirk Guld, Friedrich Alexander University
of Erlangen-Nuremberg

Itaru Hamachi, Kyoto University

Feihe Huang, Zhejiang University

Jérôme Lacour, University of Geneva
Stephen Loeb, University of Windsor
Rafael Luque, Cordoba University

Uday Maitra, Indian Institute of Science
Ian Manners, University of Bristol

Manfred Martin, Aachen University
Nazario Martin, Complutense University
of Madrid

Feliu Maseras, Institute of Chemical
Research of Catalonia

Fiona Meldrum, University of Leeds
Johannes Messinger, Umeå University

Ulrich Müller, BASF Aktiengesellschaft

Takashi Ooi, Nagoya University
Chris Orvig, University of British
Columbia

Mario Pagliaro, National Research
Council (CNR)

Hongkun Park, Harvard University
Jon Preece, University of Birmingham

Peter Roesky, Karlsruhe Institute of
Technology

Vincent Rotello, University of
Massachusetts

Paolo Samori, University of Strasbourg
Clément Sanchez, Pierre and Marie
Curie University

Laurel Schafer, University of British
Columbia

Michael Scott, University of Florida
Injae Shin, Yonsei University

Rint Sijbesma, Eindhoven University of
Technology

David Spring, University of Cambridge
Franklin Tao, University of Kansas

James Tucker, University of Birmingham
Rein Ulijn, University of Strathclyde

Peng Wang, Changchun Institute of
Applied Chemistry

Bert Weckhuysen, Utrecht University
Aaron Wheeler, University of Toronto

Stephen Withers, University of British
Columbia

Shigehiro Yamaguchi, Nagoya University
Haw Yang, Princeton University

Xueming Yang, Dalian Institute of
Chemical Physics

Eiji Yashima, Nagoya University
Juyoung Yoon, Ewha Womans
University

Shuli You, Shanghai Institute of
Organic Chemistry

Jin-Quan Yu, The Scripps Research
Institute

Claudio Zannoni, University of Bologna
Hua Zhang, Nanyang Technological
University

Information for authors

Full details on how to submit material for publication in
Chem Soc Rev are given in the Instructions for Authors
(available from <http://www.rsc.org/authors>).
Submissions should be made via the journal's homepage:
<http://www.rsc.org/chemsocrev>.

The Editorial Board typically commission articles that
encourage international, interdisciplinary progress in
chemical research. The Board welcomes proposals for
new tutorial reviews or review articles. Please contact the
Editorial Office for further details (chemsocrev-rsc@rsc.org). Colour figures are reproduced free of charge.
Additional details are available from the Editorial Office or
<http://www.rsc.org/authors>.

Authors may reproduce/republish portions of their
published contribution without seeking permission
from the RSC, provided that any such republication is
accompanied by an acknowledgement in the form:
(Original Citation)–Reproduced by permission of
The Royal Society of Chemistry.

This journal is ©The Royal Society of Chemistry 2015.
Apart from fair dealing for the purposes of research or
private study for non-commercial purposes, or criticism
or review, as permitted under the Copyright, Designs
and Patents Act 1988 and the Copyright and Related
Rights Regulation 2003, this publication may only be
reproduced, stored or transmitted, in any form or by
any means, with the prior permission in writing of the
Publishers or in the case of reprographic reproduction
in accordance with the terms of licences issued by the
Copyright Licensing Agency in the UK. US copyright law
is applicable to users in the USA.

⊗ The paper used in this publication meets the
requirements of ANSI/NISO Z39.48–1992
(Permanence of Paper).

Registered Charity No. 207890.

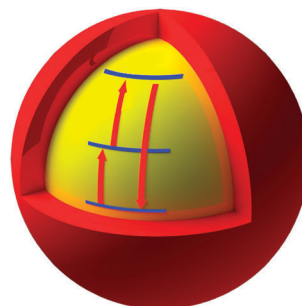
TUTORIAL REVIEWS

1318

Photon upconversion in core-shell nanoparticles

Xian Chen, Denfeng Peng, Qiang Ju and Feng Wang*

This tutorial review highlights recent advances in the development of upconversion core-shell nanoparticles to cater for biological and energy applications.

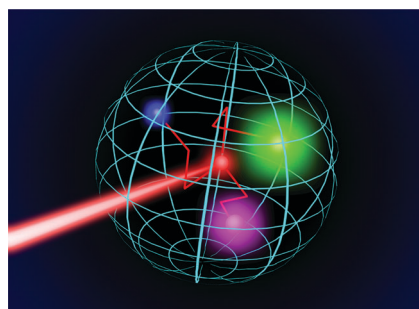


1331

Excitation energy migration dynamics in upconversion nanomaterials

Langping Tu, Xiaomin Liu, Fei Wu and Hong Zhang*

Excitation energy migration in a rare earth ions doped upconversion nanoparticle.



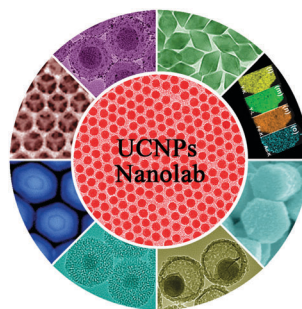
REVIEW ARTICLES

1346

Lab on upconversion nanoparticles: optical properties and applications engineering via designed nanostructure

Xiaomin Li, Fan Zhang* and Dongyuan Zhao

This review aims to summarize recent progress in optical properties and applications engineering of upconversion nanoparticles via the designed nanostructure.

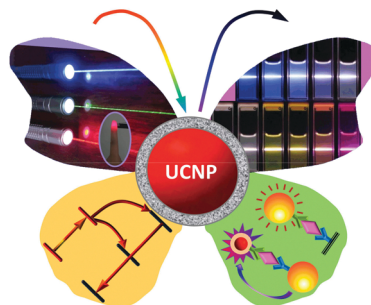


1379

Lanthanide-doped upconversion nano-bioprobes: electronic structures, optical properties, and biodetection

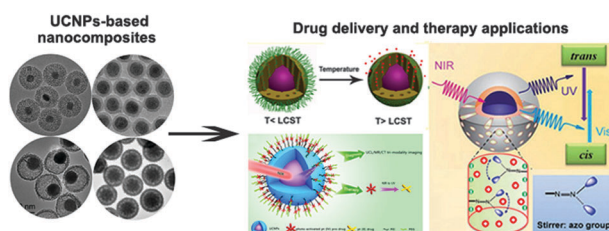
Wei Zheng, Ping Huang, Datao Tu, En Ma, Haomiao Zhu and Xueyuan Chen*

The latest advances in lanthanide-doped upconversion nanoparticles were comprehensively reviewed, which covers from their fundamental photophysics to biodetection.



REVIEW ARTICLES

1416

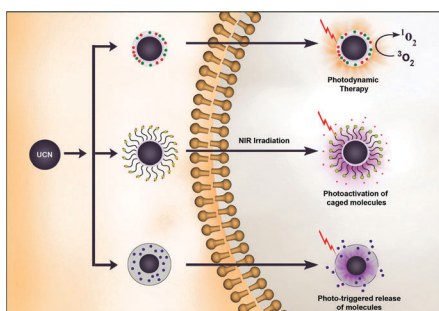


Current advances in lanthanide ion (Ln^{3+})-based upconversion nanomaterials for drug delivery

Dongmei Yang, Ping'an Ma, Zhiyou Hou, Ziyong Cheng, Chunxia Li* and Jun Lin*

This review mainly focuses on the recent advances in various chemical syntheses of Ln^{3+} -based upconversion nanomaterials, with special emphasis on their application in stimuli-response controlled drug release and subsequent therapy.

1449

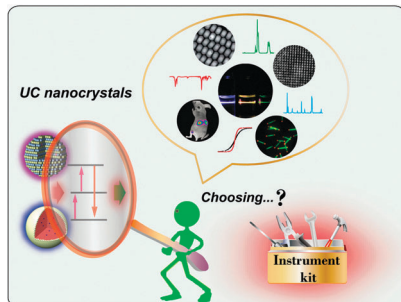


Upconversion nanoparticles as versatile light nanotransducers for photoactivation applications

Niagara Muhammad Idris, Muthu Kumara Gnanasammandhan Jayakumar, Akshaya Bansal and Yong Zhang*

Upconversion nanoparticles enable use of near infrared light for spatially and temporally controlled activation of therapeutic compounds in deeper tissues.

1479

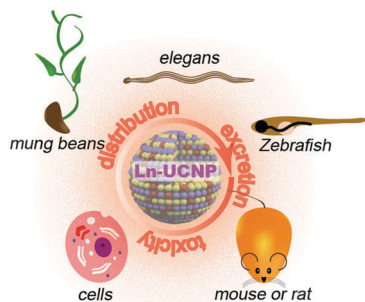


Probing the nature of upconversion nanocrystals: instrumentation matters

Xiaowang Liu, Renren Deng, Yuhai Zhang, Yu Wang, Hongjin Chang, Ling Huang* and Xiaogang Liu*

Understanding upconversion nanocrystals: this review intends to summarize instrumental matters related to the characterization of upconversion nanocrystals from surface structures to intrinsic properties to ultimate challenges in nanocrystal analysis at single-particle levels.

1509



The biosafety of lanthanide upconversion nanomaterials

Yun Sun, Wei Feng, Pengyuan Yang, Chunhui Huang and Fuyou Li*

The association between the chemo-physical properties of UCNPs and their biodistribution, excretion, and toxic effects is presented in this review.

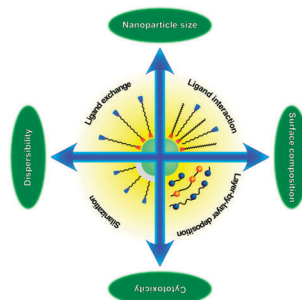
REVIEW ARTICLES

1526

Surface modification and characterization of photon-upconverting nanoparticles for bioanalytical applications

Andreas Sedlmeier and Hans H. Gorris*

A well-defined surface architecture is essential to generate water-dispersible UCNPs that are long-term stable and enable a wealth of bioanalytical applications.

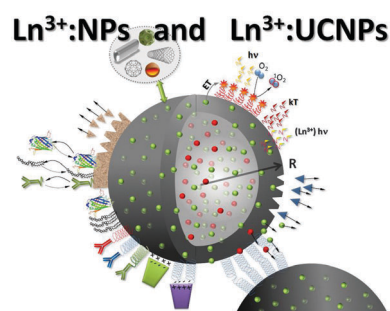


1561

Upconverting nanoparticles: assessing the toxicity

Anna Gnach, Tomasz Lipinski, Artur Bednarkiewicz*, Jacek Rybka and John A. Capobianco

Based on a survey of existing studies, low nanotoxicity of lanthanide doped upconverting nanoparticles holds promise for their safety and suitability for biomedical detection and imaging.

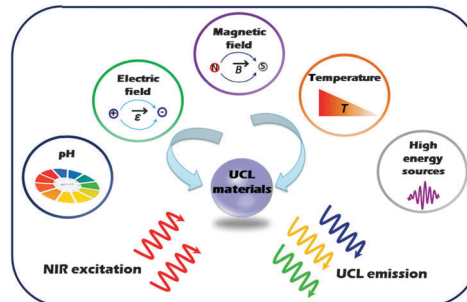


1585

Stimuli responsive upconversion luminescence nanomaterials and films for various applications

Ming-Kiu Tsang, Gongxun Bai and Jianhua Hao*

This review highlights recent advances in upconversion luminescence materials in response to various stimuli for a broad spectrum of applications.

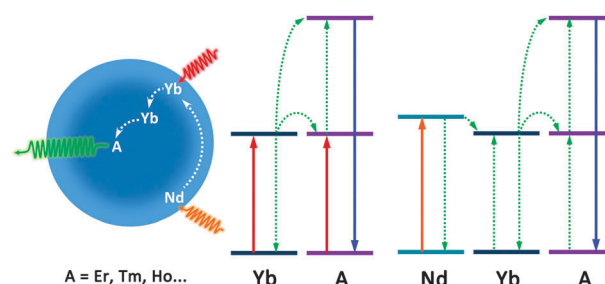


1608

Energy transfer in lanthanide upconversion studies for extended optical applications

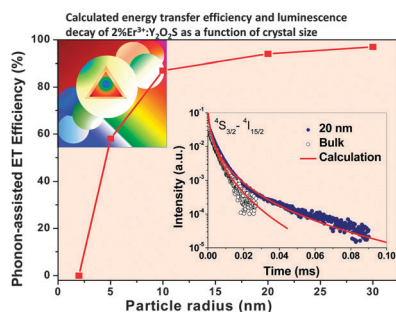
Hao Dong, Ling-Dong Sun* and Chun-Hua Yan*

In this review, the various energy transfer pathways involved in lanthanide-related upconversion emissions are comprehensively discussed.



REVIEW ARTICLES

1635

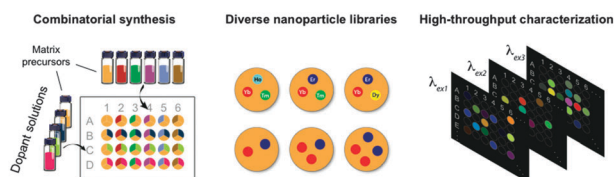


Advances in the theoretical understanding of photon upconversion in rare-earth activated nanophosphors

Guokui Liu

A comprehensive review of the theoretical background is provided for understanding photon upconversion with particular attention to assessing photoluminescence dynamics in rare-earth activated nanophosphors.

1653

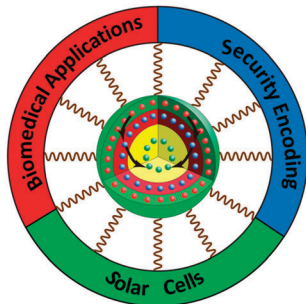


Combinatorial approaches for developing upconverting nanomaterials: high-throughput screening, modeling, and applications

Emory M. Chan

This review surveys the use of combinatorial and high-throughput techniques for the rapid discovery, optimization, and application of upconverting nanomaterials.

1680



Light upconverting core-shell nanostructures: nanophotonic control for emerging applications

Guanying Chen,* Hans Ågren, Tymish Y. Ohulchanskyy and Paras N. Prasad*

Nanophotonic control of light upconversion in the hierarchical core-shell nanostructures, their biomedical, solar energy and security encoding applications were reviewed.