Nanophysics for scintillation registration: Advantages and limits

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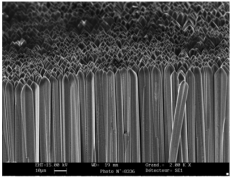
Shapping scintillators

Single Crystal

Many applications

CsI:Tl Needles

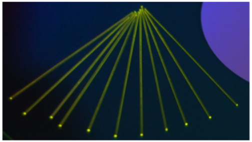


Medical x-ray imaging

Thin films

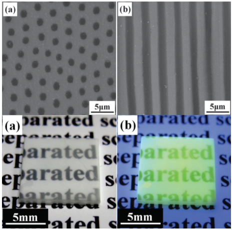
High resolution x-ray imaging

Inorganic Fibers



Calorimetry?

CsI-NaCl eutectic



@Canon, Adv. Mat. 2012

Phosphor powder

x-ray imaging

Shapping scintillators: Nano?

- New physics?
- New materials?
- New functionalities?

This is our job.

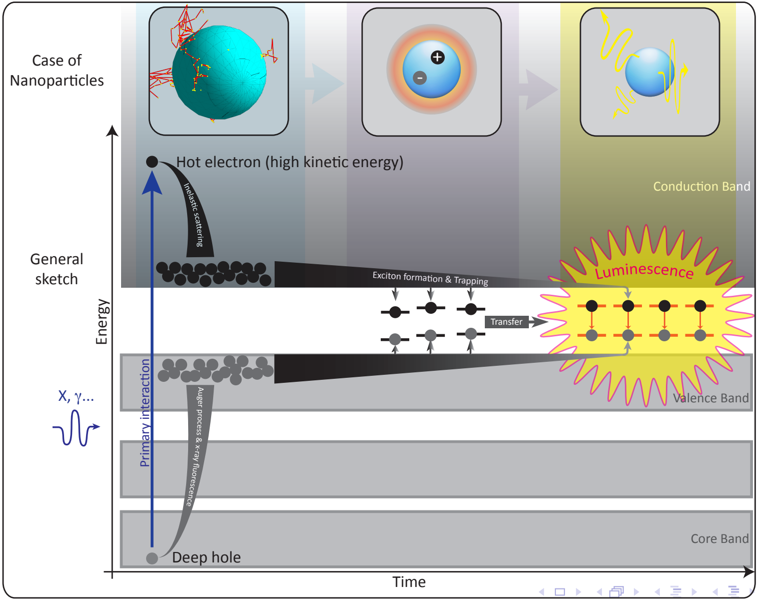
Nanoscintillators: Bibliography

Web of Sciences →∼ 130 papers combining nano* x Scintillat* (except nanosecond) (01/2013)

- 66 correspond to synthesis procedures of compositions of interest for scintillation
- 16 describe some scintillation properties
- 44 deal with some potential applications (most of them are about precursor for transparent ceramics)
- 4 are general/review papers

→ rather open field

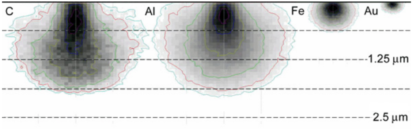
Processes: Specificity of nanosizes?



New Physics: $\beta.S.Q$ (with A.L.Bulin & A.Vasil'ev)

Distribution of energy deposition after primary interaction

15keV electrons in various materials



http://www4.nau.edu/microanalysis/Microprobe-SEM

$\rightarrow$ dimension $\gg$ nanosizes

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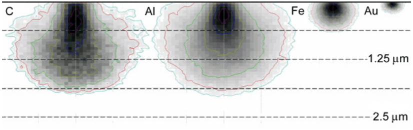
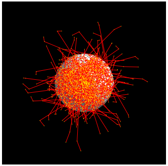


http://www4.nau.edu/microanalysis/Microprobe-SEM

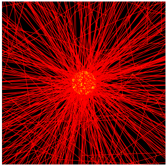
→ dimension ≫ nanosizes

e^- created in a NP of 50nm
case of (Gd_2O_3)

1keV



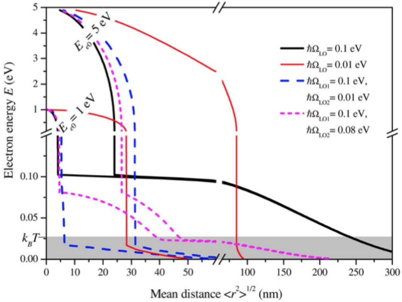
10keV



New Physics: $\beta.S.Q$, with A.N Vasil'ev & A.Belsky

Interaction with Phonons

Thermalization length $\gg$ particle size



Kirkin et al. IEEE-TNS 2012

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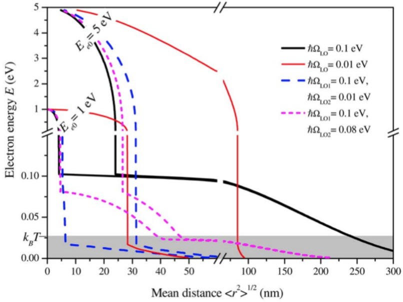
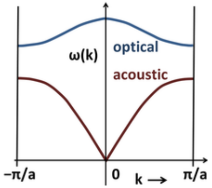


Kirkin et al. IEEE-TNS 2012

Confinement on phonon energy?



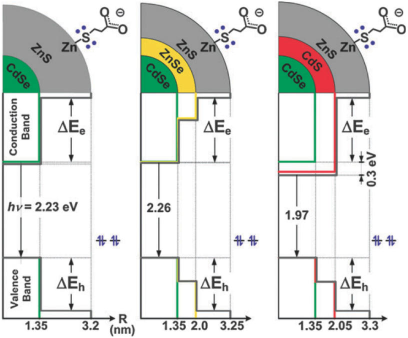
- Optical branch $\rightarrow$ flat
- nano $\rightarrow \lambda_{max} \geqslant 2L_{nano} \rightarrow$ k $\sim$ 0 "vanish"
- no effects on optical modes
- cut off of acoustical mode

probably no effect of nano sizes regarding this aspect

New Physics: $\beta.S.Q$

Potential barrier for low energy electrons

Nanotechnologies use to play with potential barriers and Gap



Bonghwan Chon, PhysChem.ChemPhys, 2009

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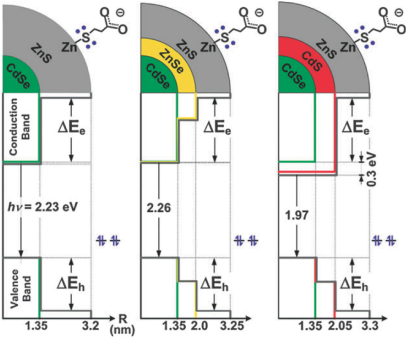
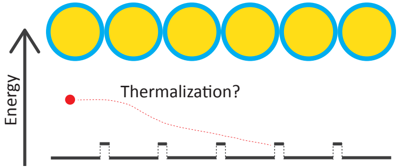


Bonghwan Chon, PhysChem.ChemPhys, 2009

Assembly of core-shell system might create structured potentials



Effect on spacial distribution of charges during relaxation → non-proportionnality?

New Physics: $\beta.S.Q$

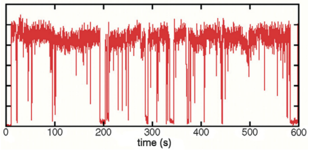
Excitons

- As for low energy electrons and holes, excitons have a mobility
  $\rightarrow$ effect on the rise time in case of transfer to activator?
  $\rightarrow$ potential barrier at the particle edge?

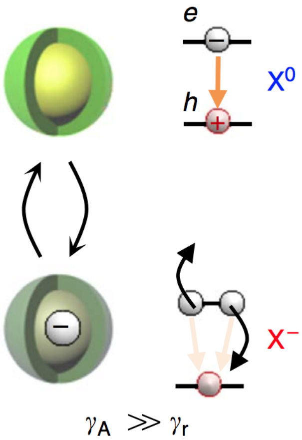
New Physics: $\beta.S.Q$

Excitons

- As for low energy electrons and holes, excitons have a mobility $\rightarrow$ effect on the rise time in case of transfer to activator? $\rightarrow$ potential barrier at the particle edge?
- Charging effect $\rightarrow$ Auger process instead of radiative recombination (blinking of QD)



Smider et. Al., Materials Today, 2001



Galland et. al., Nature Comm., 2012

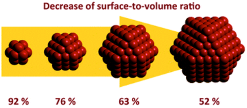
New Physics: $\beta.S.Q$

Traps

Traps might be different in nanoparticles

Stress

Large Surface/Volume ratio



P.Sonström et. al., Phys.Chem.Chem.Phys, 2011

Pt, 2nm $\rightarrow$ 50% of the atoms at the surface

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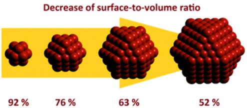
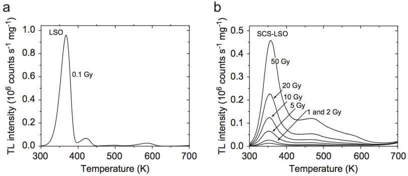
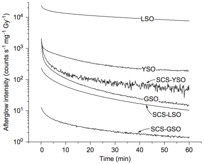


P.Sonström et. al., Phys.Chem.Chem.Phys, 2011

Pt, 2nm $\rightarrow$ 50% of the atoms at the surface

Exemple with LSO (25-100nm) as precursor for ceramics





Yukihara, J.of.Lum, 2010

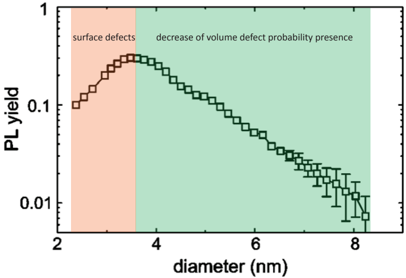
Effect on afterglow, Bright Burn / might be good for Photostimulation applications

New Physics: $\beta.S.Q$

Traps: example with Silicon

- Indirect band gap → the yield is driven by the defect concentration
- at small sizes, the probability to find a bulk defect is smaller
- at very small sizes, surface defects → requires surface passivation

Evolution of the Light Yield with the size

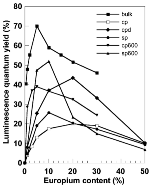


Ledoux, Applied Phys. Let., 2002

New Physics: $\beta.S.Q$

Surface = bad for luminescence

- Well-known in semi-conductor QD
  → confinement of charges
- in doped insulator, a lot of activators are next to the surface
  → surface treatment are required



Huignard et. al., J.Phys.Chem. B, 2003

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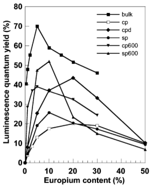
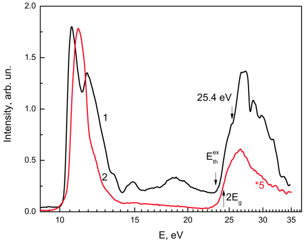


Huignard et. al., J.Phys.Chem. B, 2003

STE emission of 20nm and 140nm CaF_2 particles
→ effect of thermalization length



Vistovskyy et. al., J. of Applied Phys., 2012

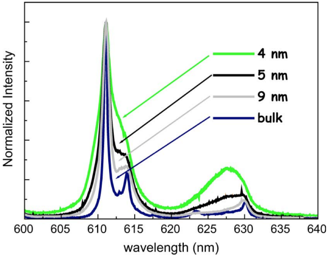
→ no improvement and even some losses are expected in very efficient materials
→ but potential improvements for materials having non-radiative recombinations

New Physics: $\beta.S.Q$

Effects on Luminescence

Disorder → Broadening

Case of nano-$Gd_2O_3 : Eu^{3+}$



Dujardin et. al., IEEE TNS, 2010

New Physics: $\beta.S.Q$

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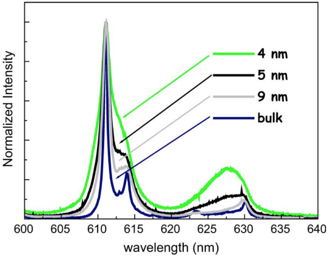
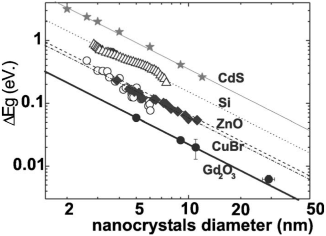


Dujardin et. al., IEEE TNS, 2010

Ionic materials ∼ No confinement effect on gap

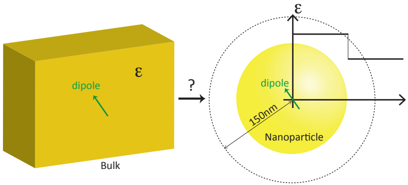


Mercier et. al., J.Chem. Phys., 2007

New Physics: $\beta.S.Q$

Effects on Luminescence: Dielectric confinement

The radiative decay time depends on the index of refraction which is a macroscopic parameter



New Physics: $\beta.S.Q$

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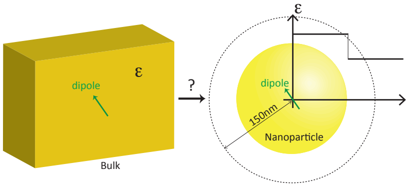
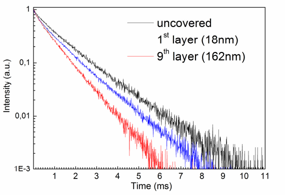


several models: Fully macroscopic, empty and virtual cavity



LeBihan et. al., PRB, 2008

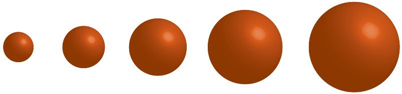
→ nano-LuAG:Ce $\tau =$ 117ns vs 58ns in bulk
(Barta et.al. J.Mat.Chem,2012)

In addition, competition between radiative and non-radiative probabilities: $\eta = \frac{W_{rad}(n)}{W_{rad}(n)+W_{nonrad}}$

Difficulties

Experimental difficulties

The physicist wants



- size gradient over a wide range
- sharp size and shape distribution
- identical surface states
- single phase domain
- ...

Difficulties

Experimental difficulties

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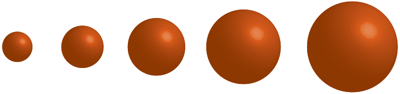
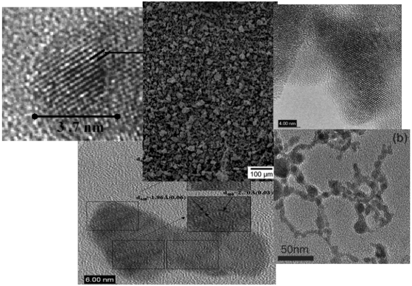


- size gradient over a wide range
- sharp size and shape distribution
- identical surface states
- single phase domain
- ...

The chemist provides

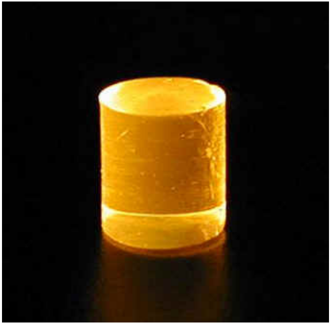


→ difficult for comparison

Applications

nanoparticles are small
→ they can be mixed into matrix while preserving transparency

ZnS:Mn NP dispersed in PMMA



http://chm.tu-dresden.de

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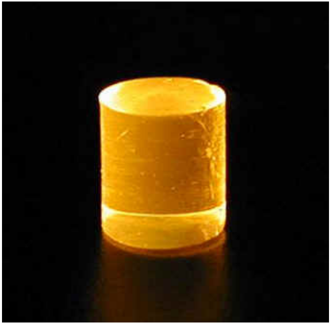
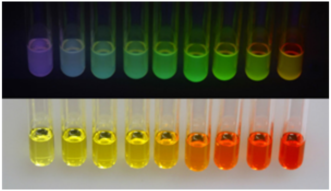


http://chm.tu-dresden.de

Colloïdale solution

@ILM



http://www.webexhibits.org

→ hybrides & liquid scintillators

Applications-Hybrides

Doping with nano particles
Claimed advantages: low cost as compared to single crystals

CdSe/ZnS Qdots in glasses

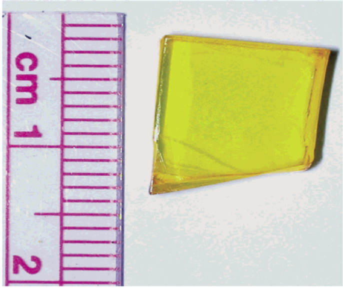
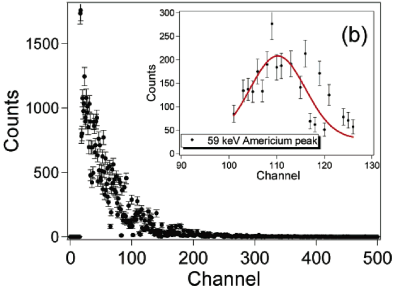


Figure 1. Picture of a 1/16 in. thick nanoporous glass slab impregnated with CdSe/ZnS quantum dots emitting at 510 nm.

Photopeak?



Letant et. al. NanoLetters, 2006

Nevertheless, some scintillation can be observed

Applications-Hybrides

In the same spirit, but with $LaF_3 : Ce^{3+}$ but in organics

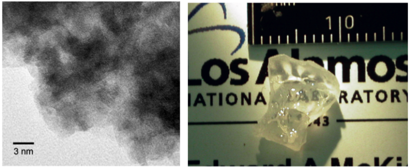
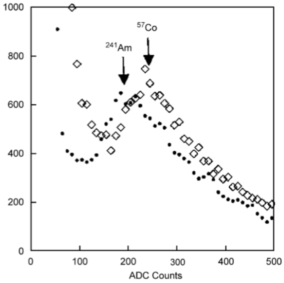


Figure 1. Transmission electron microscopy image of the Ce:LaF_3 particles (left) and a 1cm thick oleic-based nancomposite of Ce:LaF_3 with nearly 30% volume loading of the phosphor.



McKigney et. al., NIMA, 2007

issue → high loading while preserving the transparency & properties

personal opinion :
not sure that it can compete with crystals regarding performances.

Application-Hybride

US Congres report

Congressional Research Service

Detection of Nuclear Weapons and Materials: Science, Technologies, Observations

Jonathan Medalia
Specialist in Nuclear Weapons Policy

June 4, 2010

...However, unexpected nanoscale physics could impair energy resolution...

Application-Hybride

Doping organics with optically "active" nano particles specific functionality: neutron detection/ increase of density

Radiation Measurements 48 (2013) 7–11

Contents lists available at SciVerse ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

$GdBr_3$:Ce in glass matrix as nuclear spectroscopy detector

Z.T. Kang, R. Rosson*, B. Barta, C. Han, J.H. Nadler, M. Dorn, B. Wagner, B. Kahn

Georgia Tech Research Institute, Georgia Institute of Technology, 925 Dalney St NW, Atlanta, GA 30332, USA

Fig. 1. Cerium-activated gadolinium bromide glass-matrix cylinder, 2.5-cm dia. × 3.0-cm height, under 365 nm UV illumination.

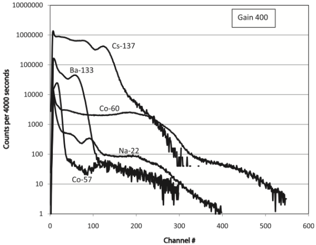


Fig. 3. Five gamma-ray spectra with 2.5-cm dia., 3.0-cm height, alumina-silica glass-matrix detector at gain 400.

Application-New Materials

Doping organics with optically "passive" nano particles

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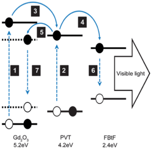
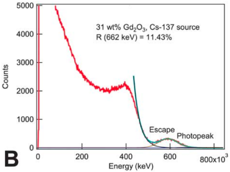
Cite this: *J. Mater. Chem. C*, 2013, **1**, 1970

Synthesis of bulk-size transparent gadolinium oxide–polymer nanocomposites for gamma ray spectroscopy

Wen Cai,†[ad] Qi Chen,†[a] Nerine Cherepy,[b] Alex Dooraghi,[c] David Kishpaugh,[a] Arion Chatziioannou,[c] Stephen Payne,[b] Weidong Xiang[d] and Qibing Pei*[a]





Application-New Materials

Improving Organic Scintillators

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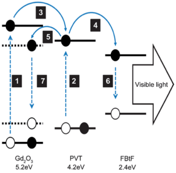

Application-New Materials

Improving Organic Scintillators

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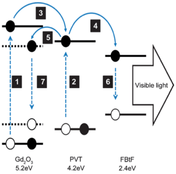
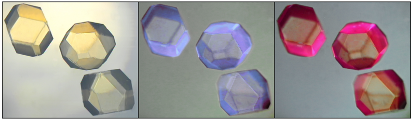


Out of traditional scintillators: MOF Metal Organic Framework

www.advmat.de
ADVANCED MATERIALS

Scintillating Metal-Organic Frameworks: A New Class of Radiation Detection Materials

By F. P. Doty,* C. A. Bauer, A. J. Skulan, P. G. Grant, and M. D. Allendorf*



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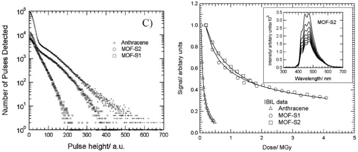


Application-Liquid Scintillation

Various applications: metrology, neutrino

Toluene + PPO molecule

- molecule ↔ active nanoparticles?
- Advantage: large Stokes shift
- Drawbacks: stabilization of high concentration & knowledge about energy transfers?

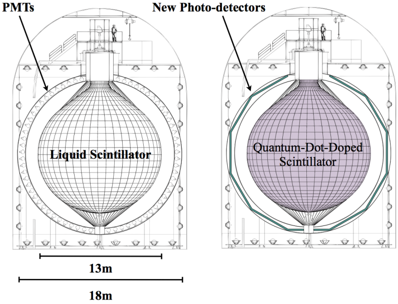
Application-Liquid Scintillation

Various applications: metrology, neutrino

Toluene + PPO molecule

- molecule $\leftrightarrow$ active nanoparticles?
- Advantage: large Stokes shift
- Drawbacks: stabilization of high concentration & knowledge about energy transfers?

One example



Winslow et. al., JINST, 2012

In this case the Stokes shift is not so large, cost???

Conclusion

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- yes: around the interactions with their surrounding (hybrid)

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worth investigating