Energy Transfer in YAG:Ce,Er and YAG:Ce,Ho Single Crystals

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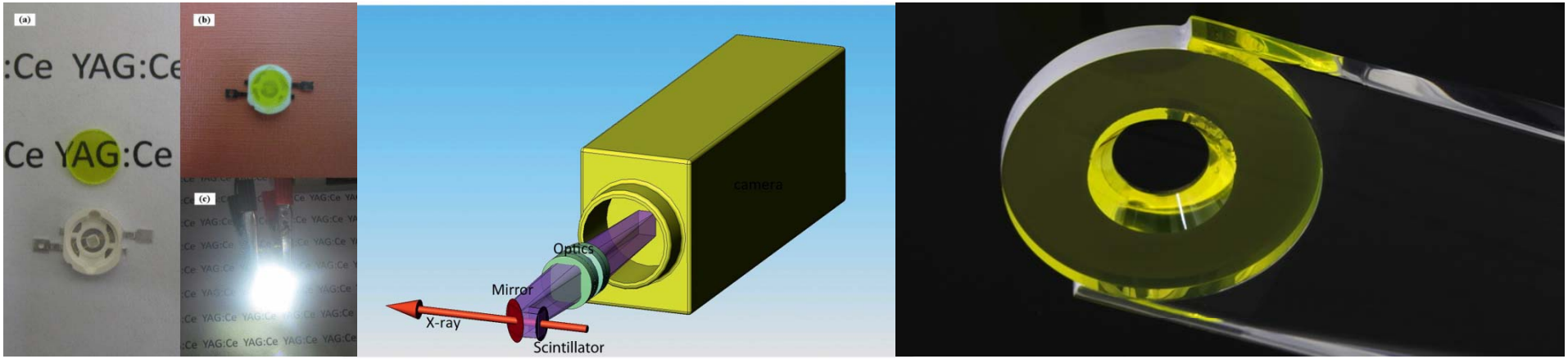
Outline

- Motivation
- YAG:Ce
- Förster-Dexter energy transfer
- Measurement methods
- Samples & results
- Summary

Motivation

- YAG:Ce is widely used nowadays
  - white LEDs, particle beams monitoring, electron microscopy detectors
- New applications require faster response
  - high-energy physics



https://doi.org/10.1016/j.ceramint.2013.12.034
https://doi.org/10.1557/mrs.2017.116
http://www.crytur.cz

YAG:Ce – basic parameters

- Band-gap 6.4 eV, cubic, radiation hard
- Green-yellow emitting
- ~ 60 ns decay time

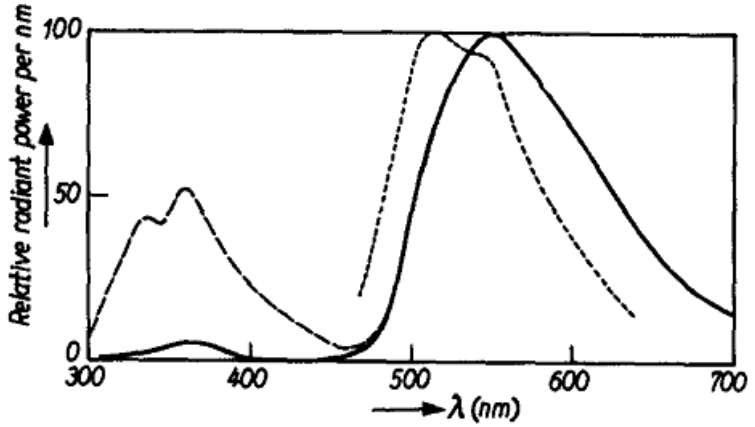


Fig. 1. Spectral energy distribution of $Y_{2.94}Ce_{0.06}Al_5O_{12}$ under cathode ray excitation (full line), uv excitation (broken line) and of $Y_{2.94}Ce_{0.06}Al_2Ga_3O_{12}$ under uv excitation (dotted line). The solid and broken lines coincide in the visible region.

http://dx.doi.org/10.1063/1.1755025
https://doi.org/10.1103/PhysRev.177.1308
https://doi.org/10.1016/0038-1098(73)90326-8

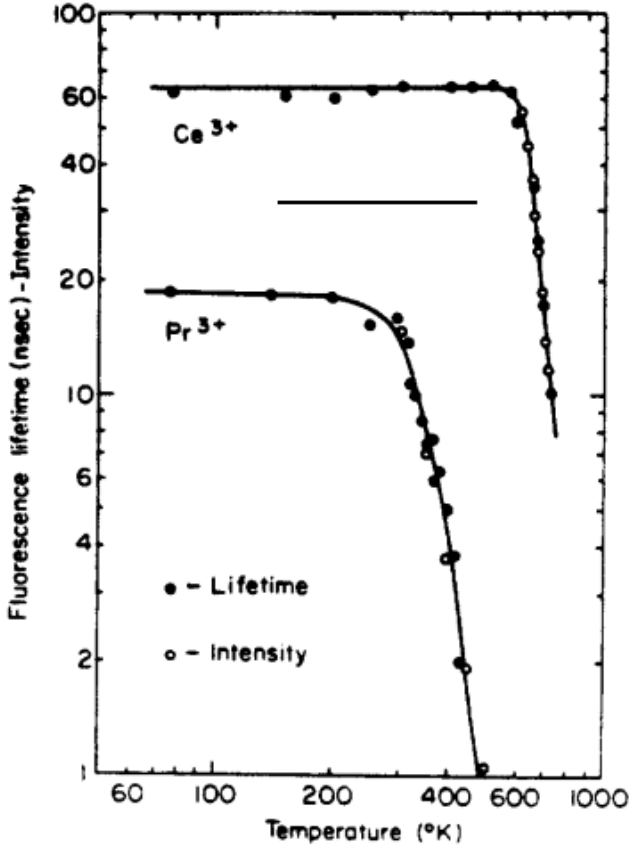
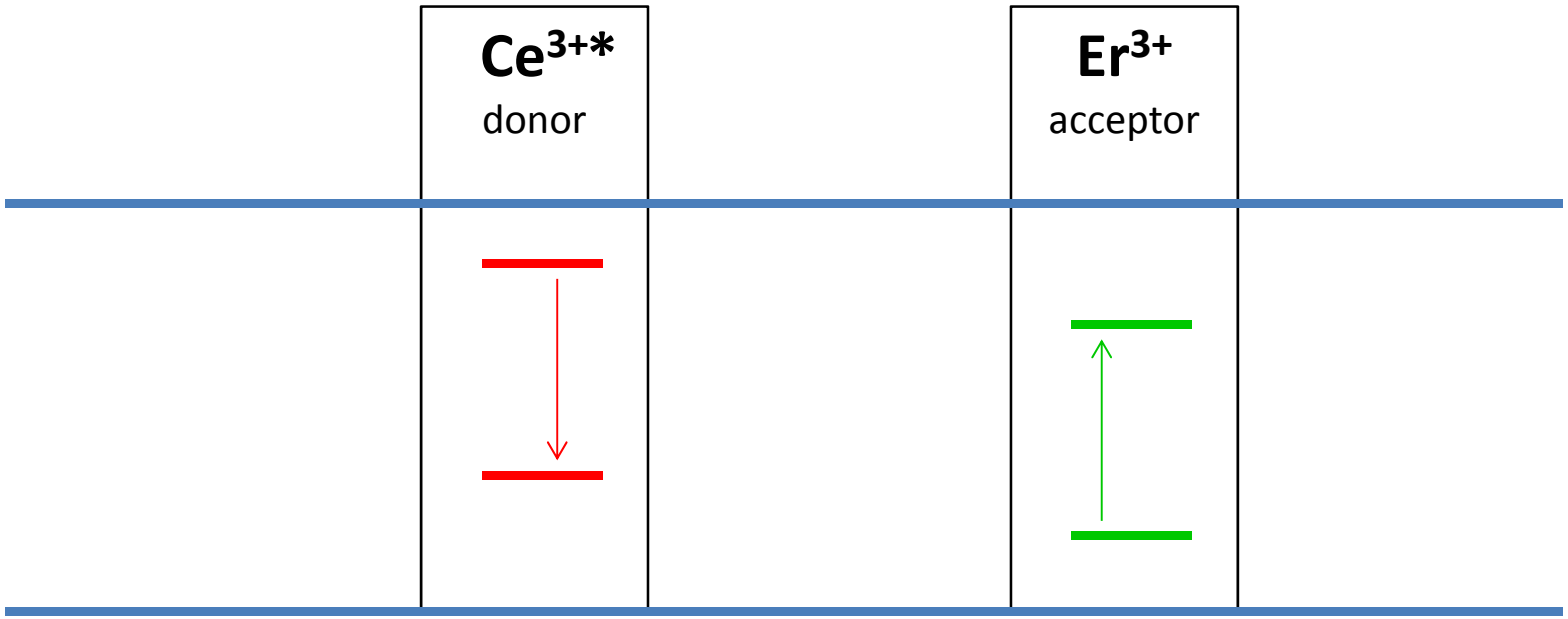


FIG. 2. Temperature dependence of the *5d* fluorescence lifetimes and intensities for Ce^{3+} and Pr^{3+} in $Y_3Al_5O_{12}$.

Multipolar Interaction & Energy Transfer



- Rate of energy transfer is proportional to:
  - spectral overlap
  - 1 / distance^N
- Resulting in $$1/\tau_{Ce^*} = 1/\tau_{RAD} + 1/\tau_{ET}$$

Förster-Dexter Model

- For one fixed pair Ce-Er: $n(t) = n_0 \times \exp(-{}^{t}/_{\tau_{RAD}})$
- For homogenously distributed Ce, Er / Ho:
  - Taking „average“ R would retain monoexponential luminescence decay. This is not the case!
- A lot of work, equations and perspiration

  [Förster, Z. Naturforschung **5**, 321 (1949)]

$$n(t) = n_0 \times exp\left[-\frac{1}{\tau_{RAD}} - \alpha(c)\left(\frac{1}{\tau_{RAD}}\right)^{3/s}\right]$$

$$\alpha = \Gamma\left(1 - {}^{3}/_{s}\right) {}^{c}/_{c_0}$$

s..... degree of multipolar interaction

c_0..... critical concentration

Multipolar Interaction & Energy Transfer

- Overlap of emission (donor) and absorption (acceptor) spectra
- High enough concentration of the acceptor
- Outcome:
  - The decay time of the donor is shortened
  - Increased speed at which the scintillator can work
  - Changes the timing characteristics of both the scintillation and photoluminescence

Materials & Methods

Er^{3+} codoping:

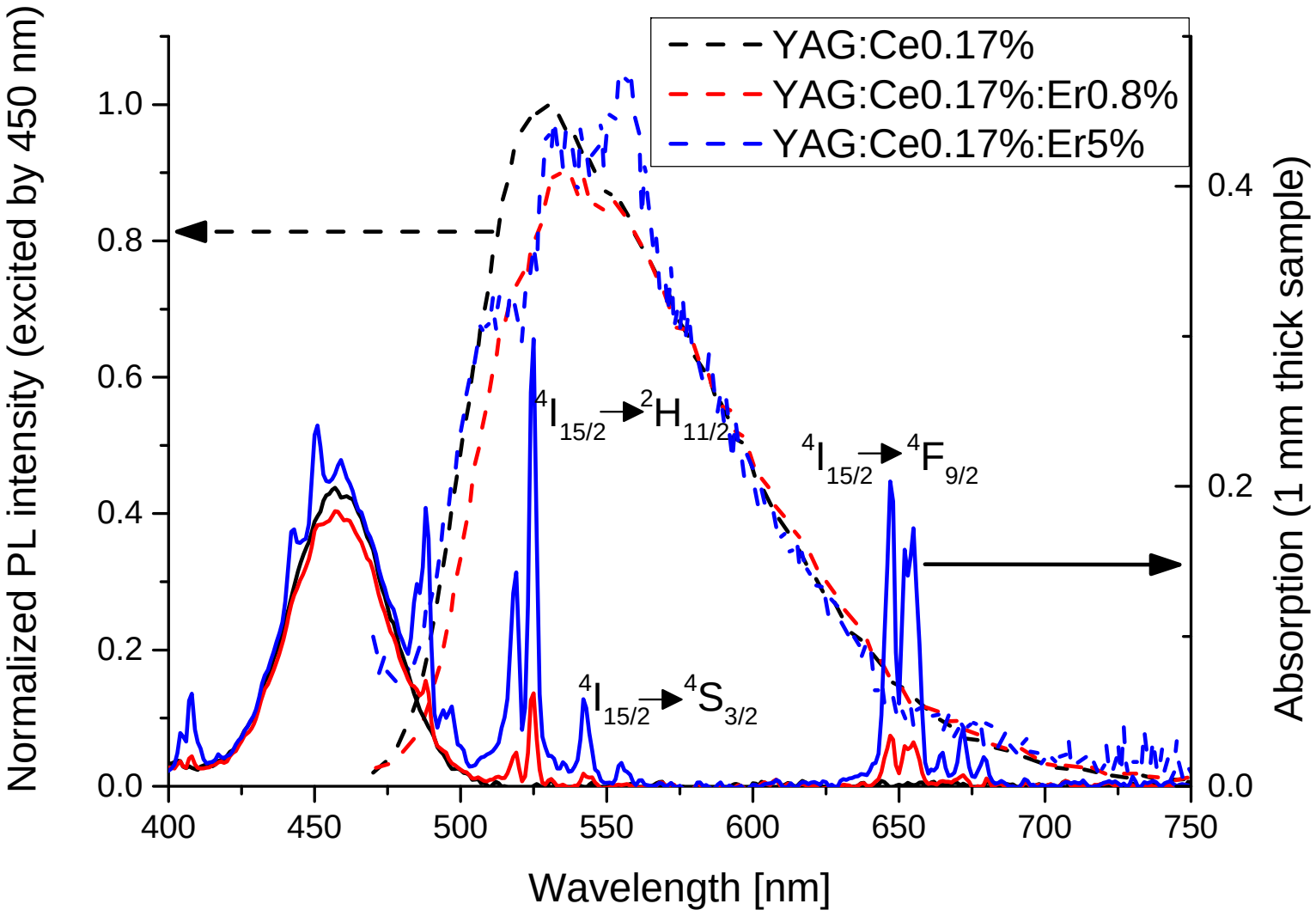
- 0.17 at.%
- 0.34 at.%
- 0.80 at.%
- 1.00 at.%
- 1.5 at.%
- 2.0 at.%
- 5.0 at.%

Ho^{3+} codoping:

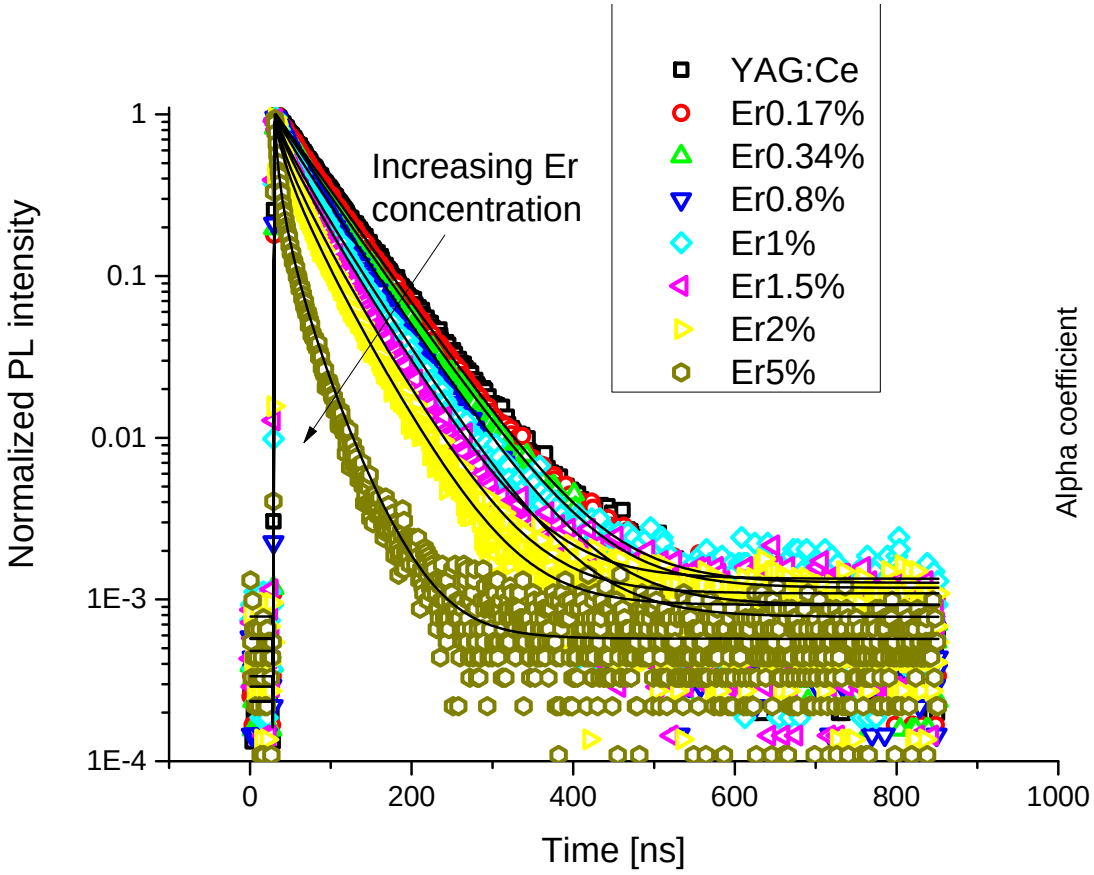
- 0.4 at.%
- 0.8 at.%
- 1.00 at.%
- 1.5 at.%
- 2.0 at.%
- 5.0 at.%

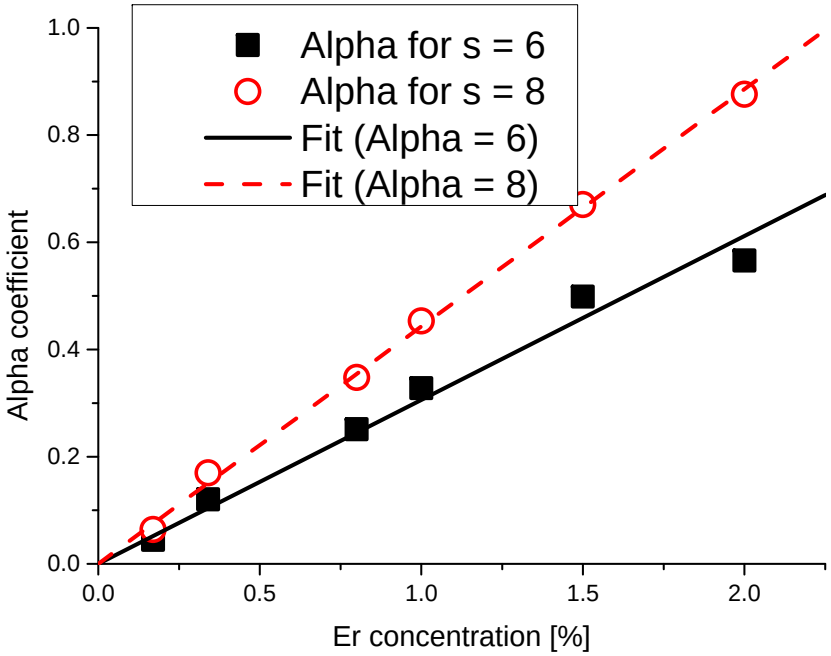
- PL emission + excitation spectra
- Optical absorption
- PL decay
- RL spectra

Er^{3+} Codoping – Spectral Overlap



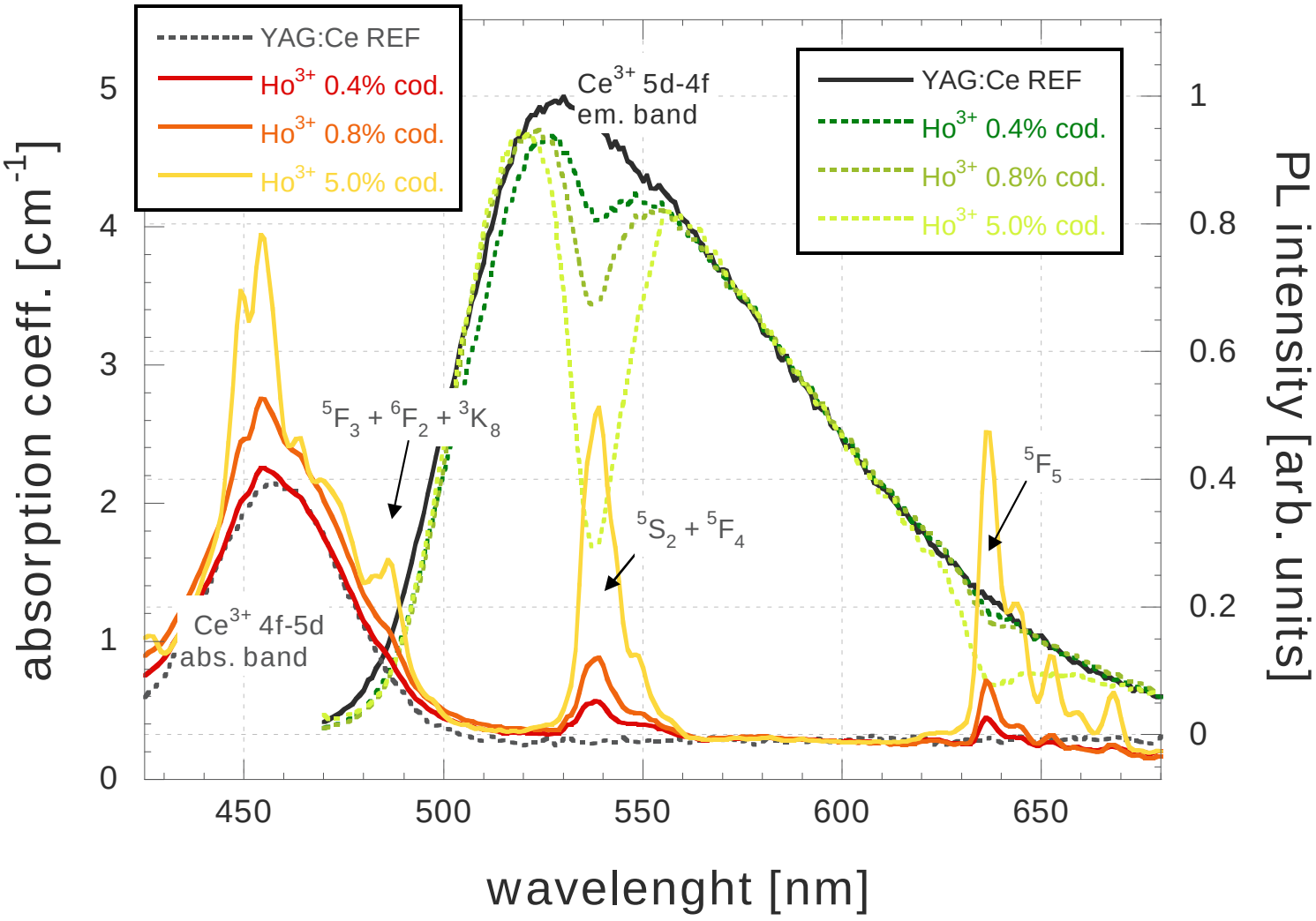
Er^{3+} Codoping – Decay Analysis



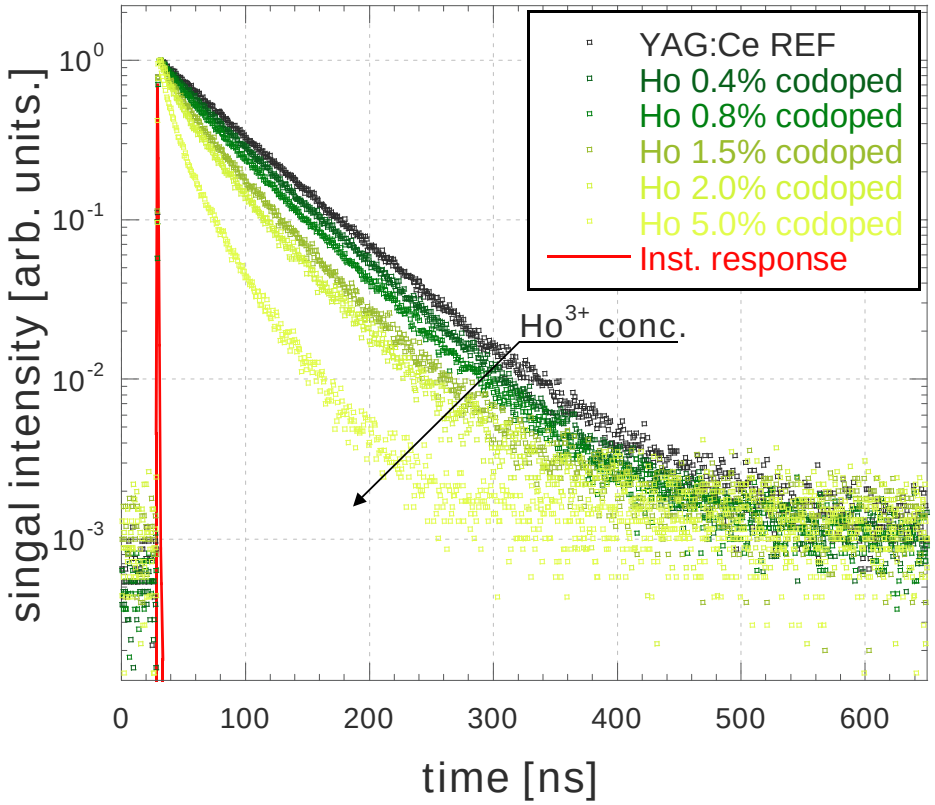


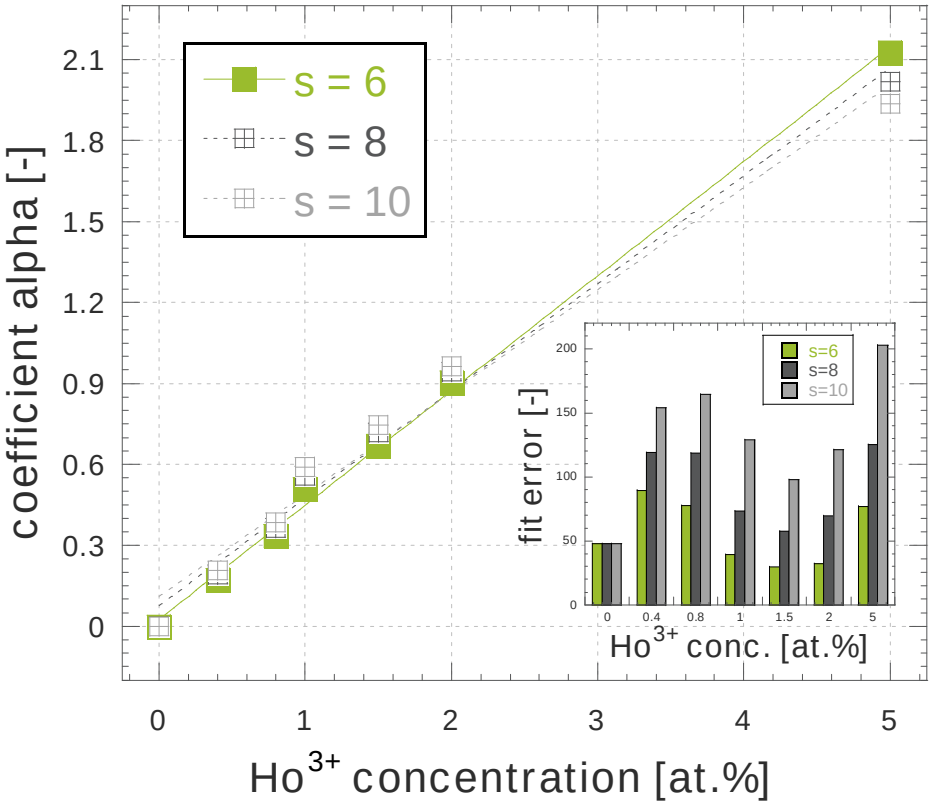
$$n(t) = n_0 \times exp\left[-\frac{1}{\tau_{RAD}} - \alpha\left(\frac{1}{\tau_{RAD}}\right)^{3/s}\right]$$

Ho^{3+} Codoping – Spectral Overlap



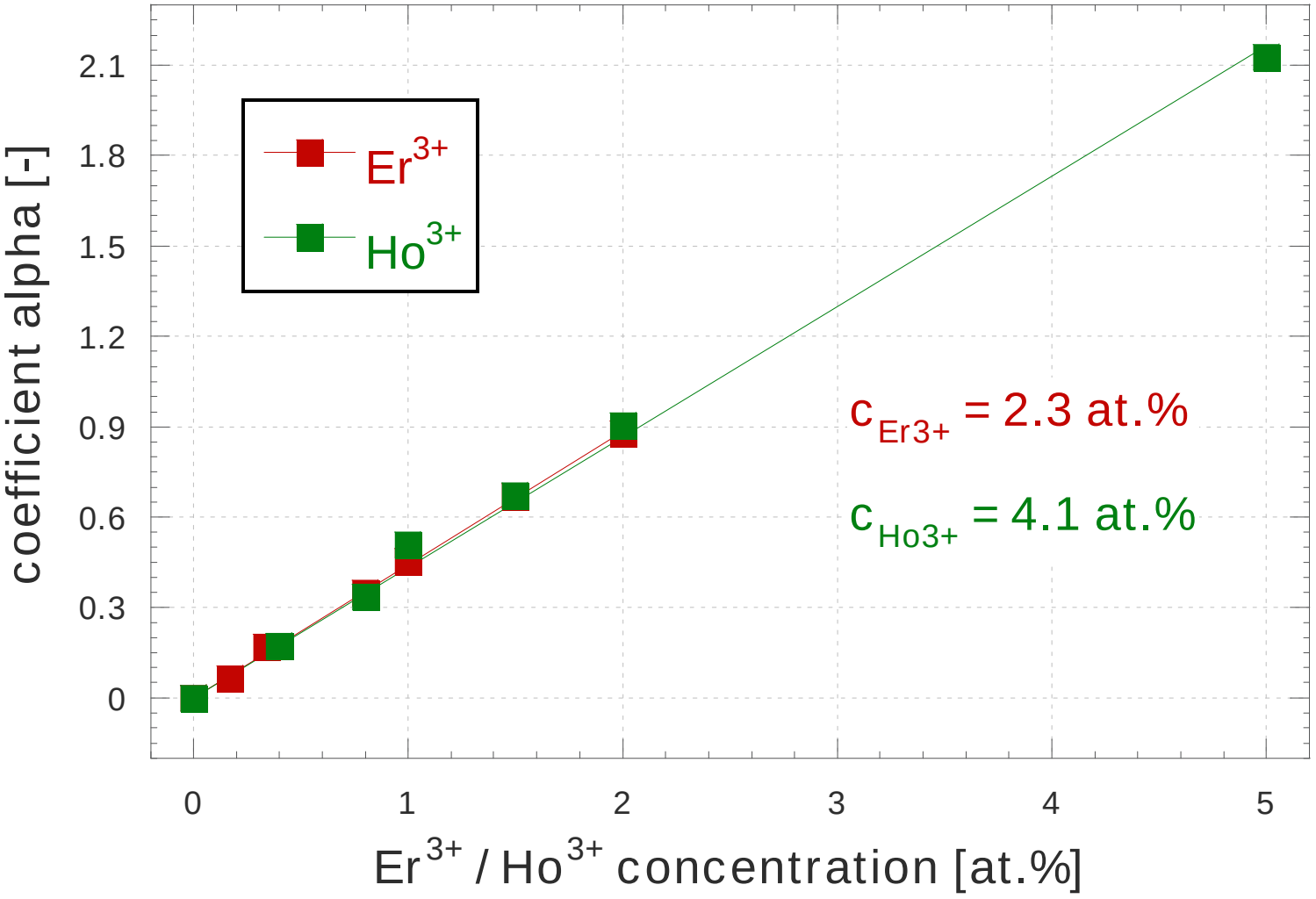
Ho^{3+} Codoping – Decay Analysis



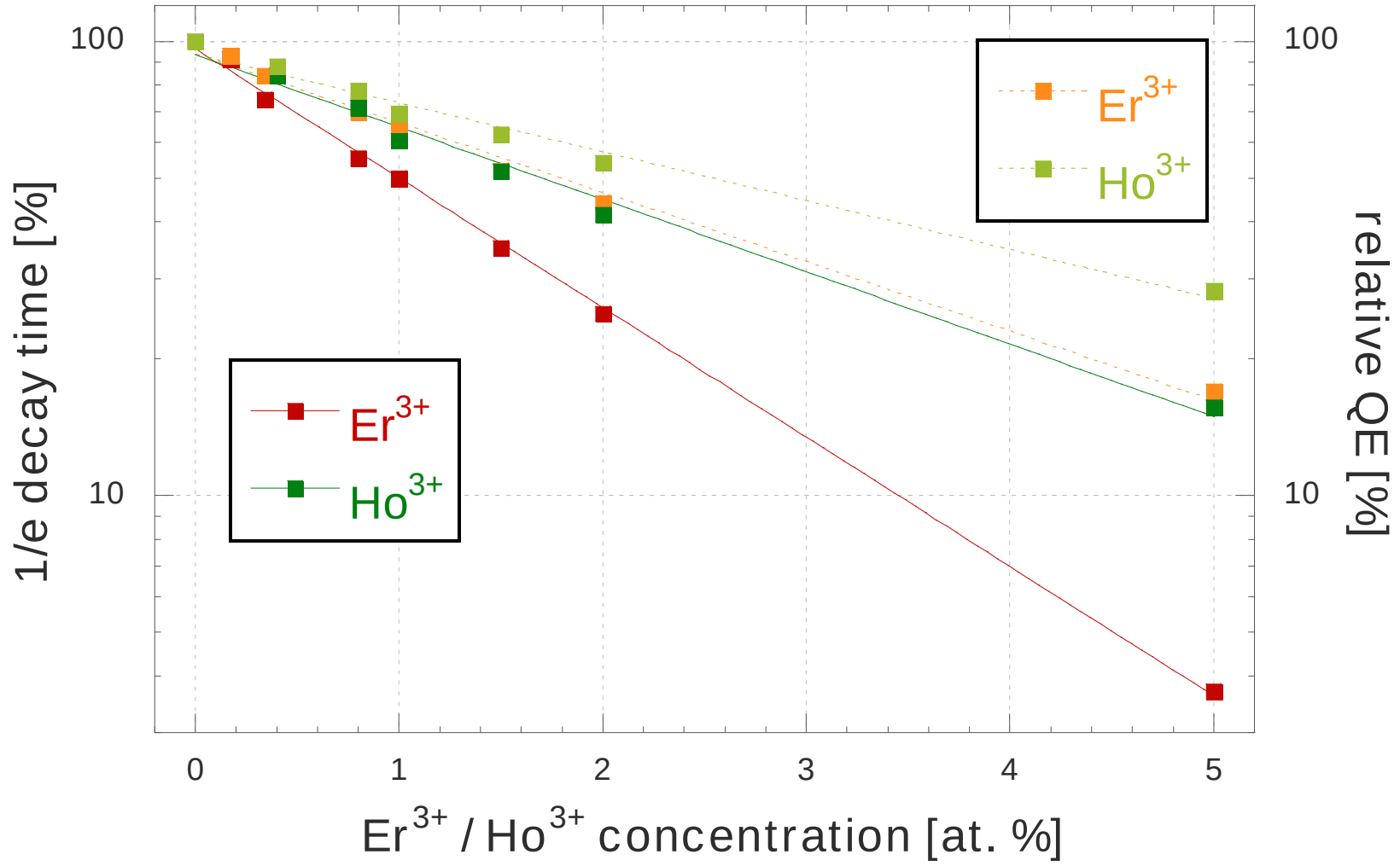


- best fit for s = 6 -> dipole-dipole interaction

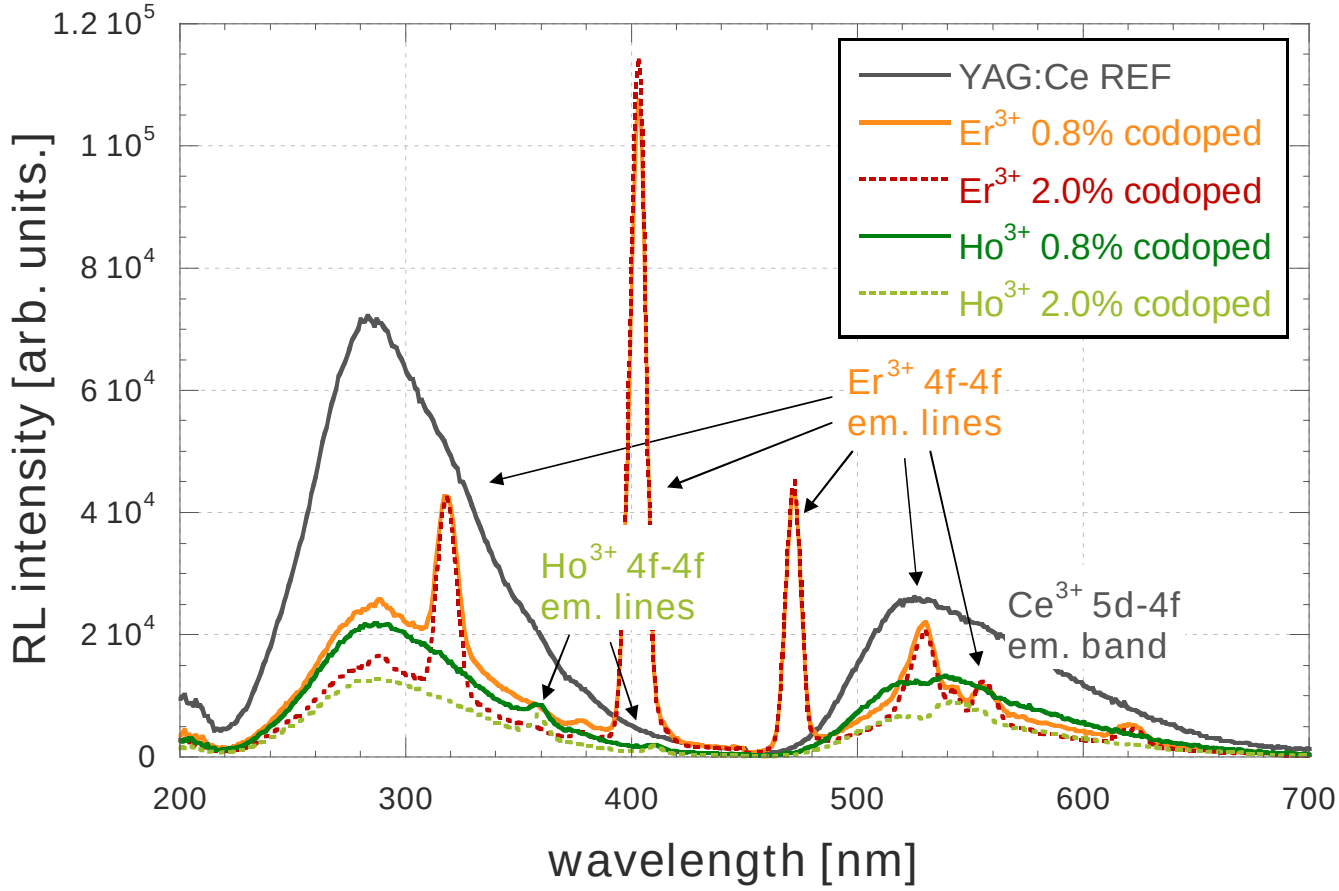
Ho^{3+} vs. Er^{3+} – Critical Concentration



Ho^{3+} vs. Er^{3+} – Acceleration x Light Output



Ho^{3+} vs. Er^{3+} – Emission Spectrum



- additional emission lines of Er – slow decay components

Summary

- The Förster-Dexter mechanism describes the energy transfer from Ce^{3+*} to Er^{3+} or Ho^{3+} in YAG
- The degree of interaction determined to dipole-quadrupole for Er^{3+} and dipole-dipole for Ho^{3+}
- The Ce^{3+*} decay can be tailored (60→30 ns)
- The critical concentration determined to 2.3 at.% of Er^{3+} and 4,1 at.% of Ho^{3+}