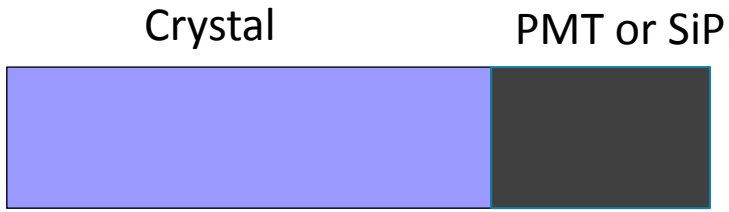
Transient absorption technique as a tool for characterization of scintillator timing properties

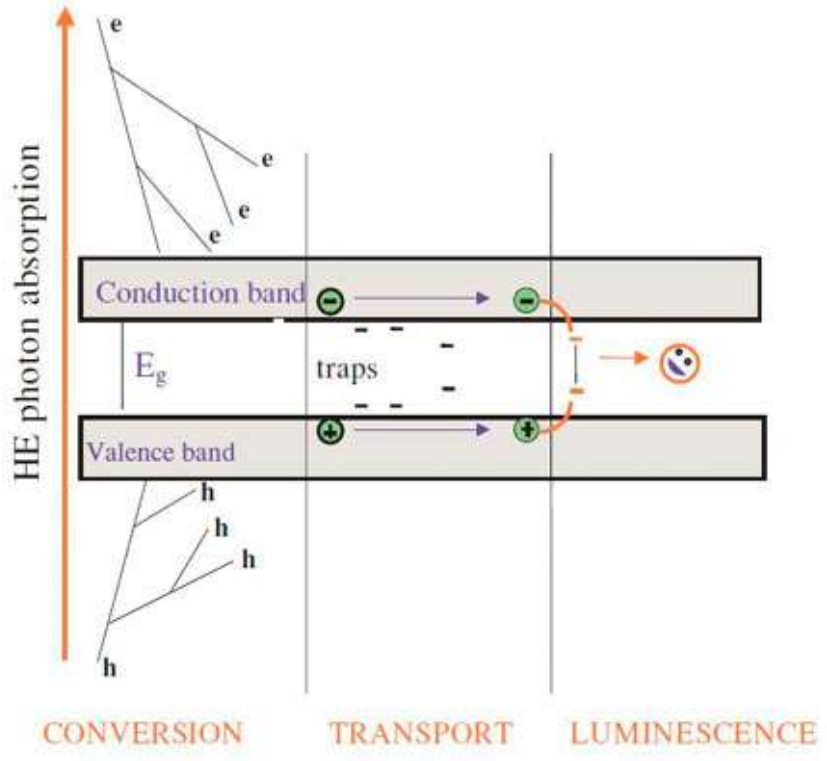
Saulius Nargelas, Augustas Vaitkevičius, Gintautas Tamulaitis
Vilnius University
Marco Lucchini, Etiennette Auffray
CERN
Andrey Fedorov, Vitaly Mechinsky, Mikhail Korjik
Belarus State University

Motivation

The current demand for faster timing of scintillation detectors used both in high luminosity high energy physics experiments and in medical imaging applications inspire deeper studies of the dynamics of excitation relaxation in scintillator materials.



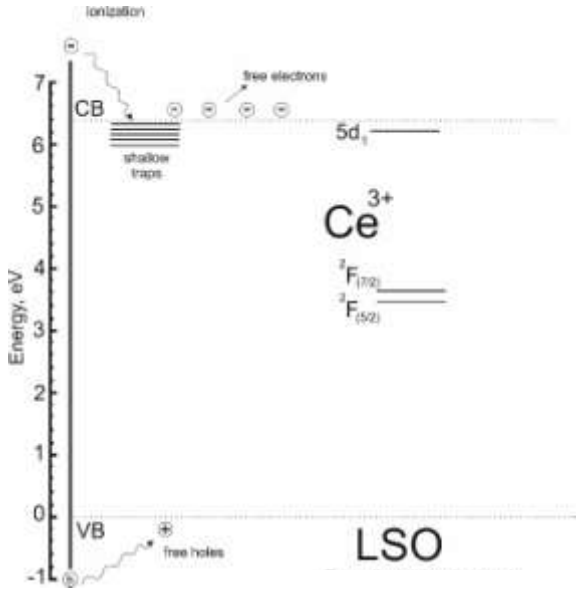
Scintillator based radiation detector.



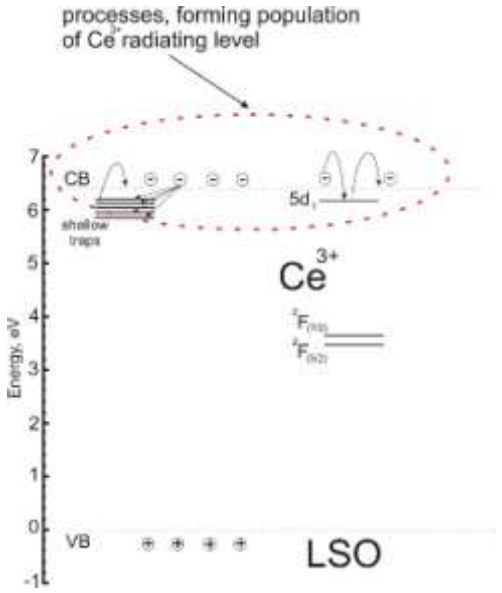
M.Nickl, phys. stat. sol. (b) 245, 1701 (2008)

Transfer of electronic excitation affecting scintillation properties; Ce^{3+} doped material

Free carrier generation



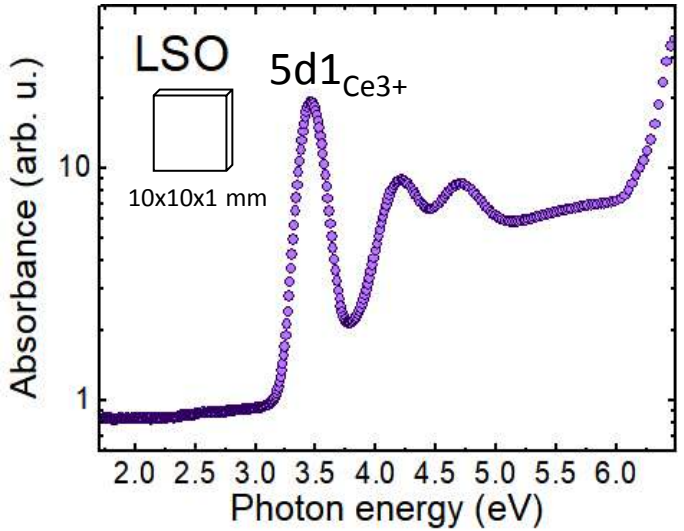
Free carrier capture by shallow traps and Ce^{3+}



Trapping and detrapping of free carriers influences the scintillation properties (light yield, scintillation rise time)

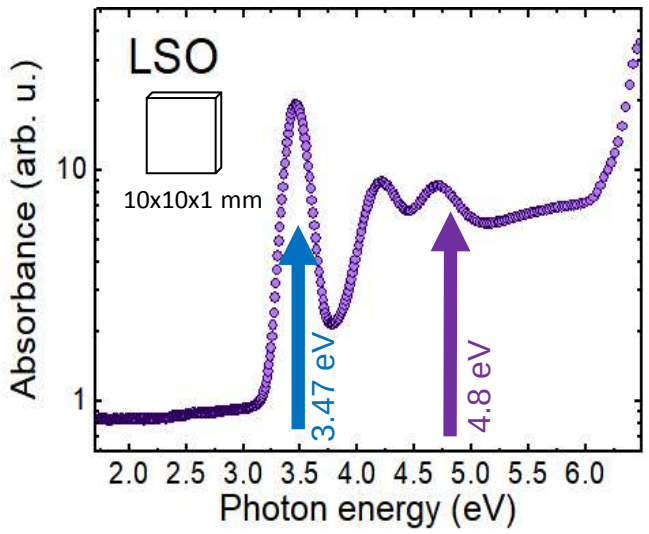
$E_c - E_{5d1(Ce3+)} = 0.41$ eV

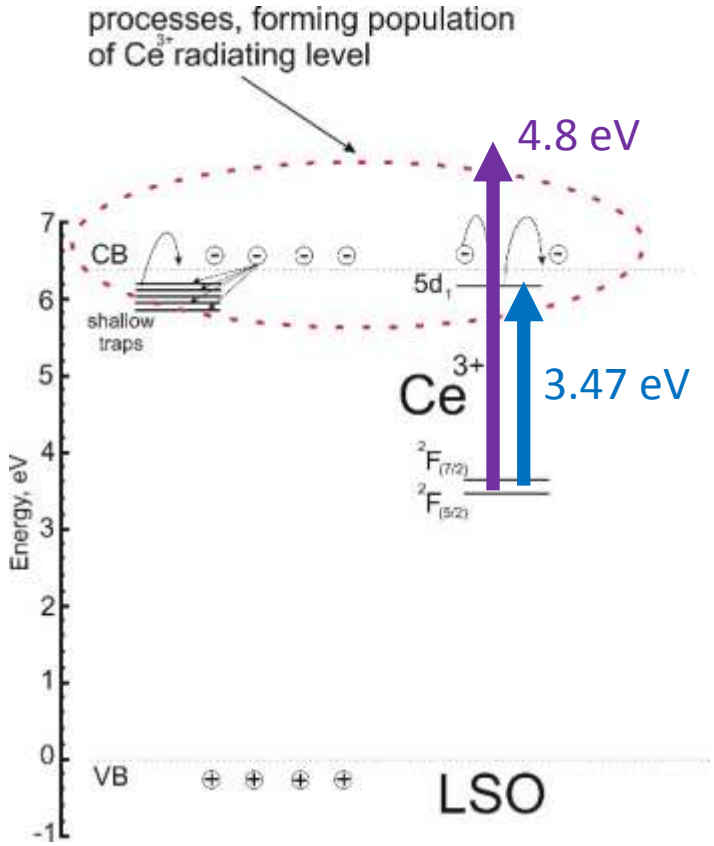
PHYSICAL REVIEW B 71, 165120 (2005)



Absorption spectra of LSO:Ce.

Quantum yield of LSO:Ce



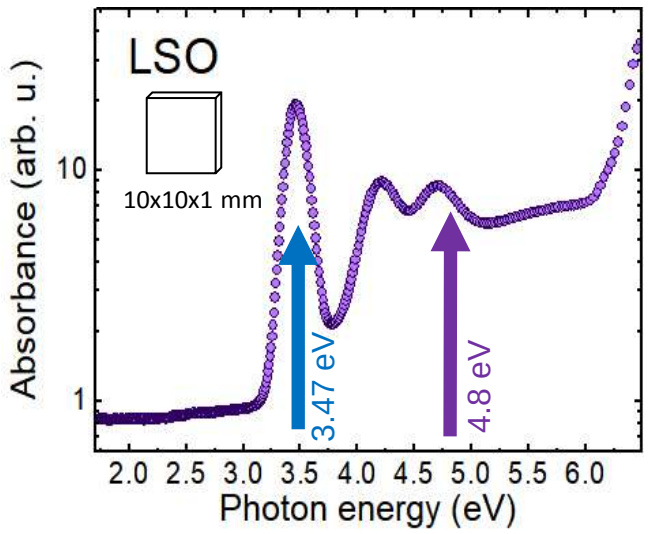


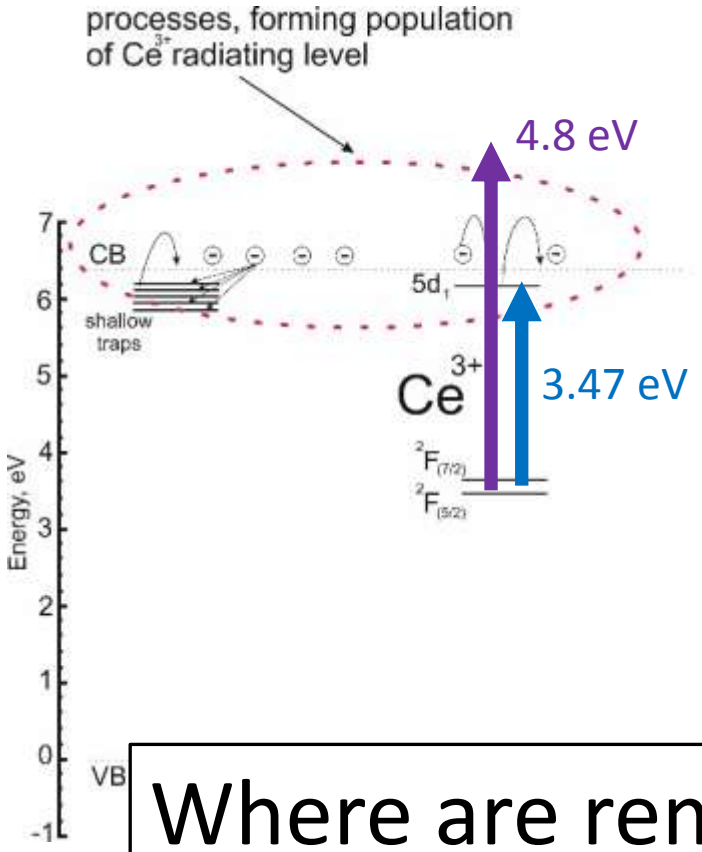
$$\text{Quantum Yield} = \frac{\text{Photons emitted}}{\text{Photons absorbed}}$$

QY@3.47 eV pump ~100%

QY@4.8 eV pump ~35%

Quantum yield of LSO:Ce





$$\text{Quantum Yield} = \frac{\text{Photons emitted}}{\text{Photons absorbed}}$$

QY@3.47 eV pump ~100%

QY@4.8 eV pump ~35%

Where are remaining 2/3 of electrons?

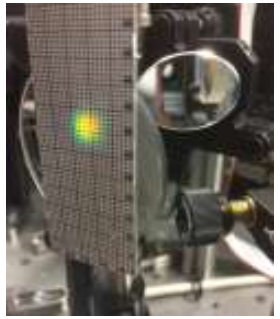
TRANSIENT ABSORPTION TECHNIQUE (1)

Laser "PHAROS"
Yb:KGW
1030 nm / 200 fs
6W @ 30kHz

Opto-mechanical delay line

Retroreflector

White-light continuum
460 – 1700 nm (2.7 - 0.7 eV)



Imaging spectrometer

Sapphire window

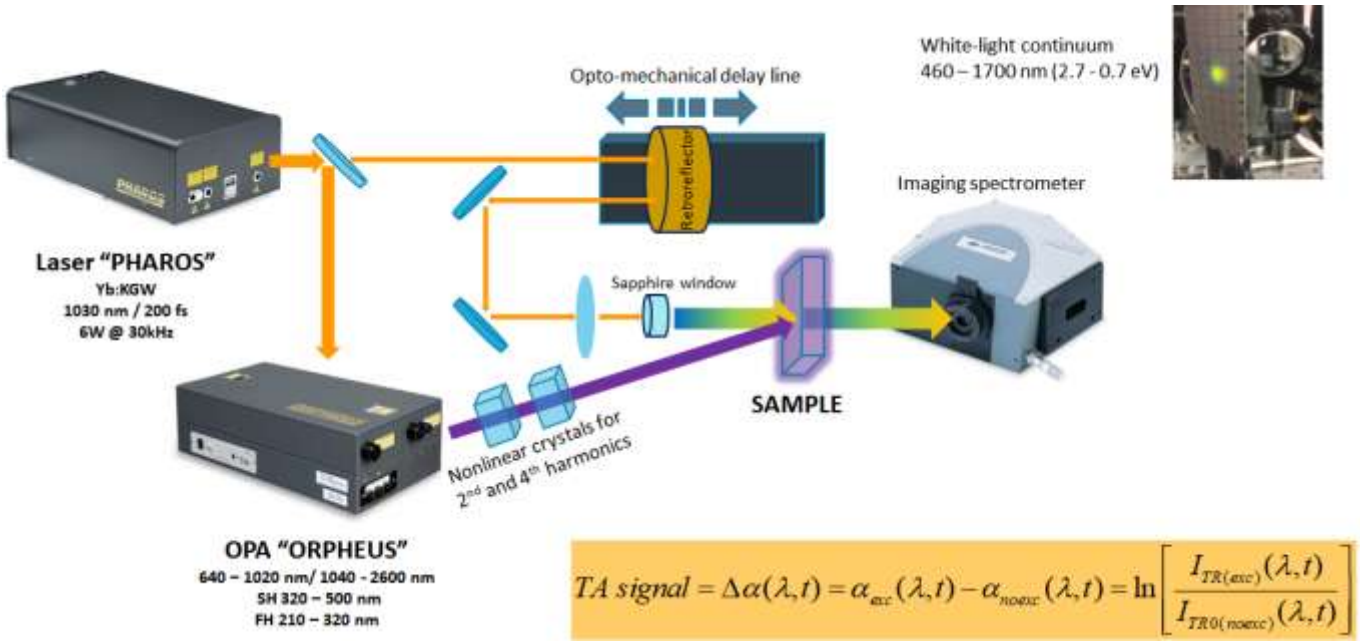
Nonlinear crystals for
2nd and 4th harmonics

SAMPLE

OPA "ORPHEUS"
640 – 1020 nm/ 1040 - 2600 nm
SH 320 – 500 nm
FH 210 – 320 nm
(from 0.5 to 5.9 eV)

$$TA\ signal = \Delta\alpha(\lambda,t) = \alpha_{exc}(\lambda,t) - \alpha_{noexc}(\lambda,t) = \ln\left[\frac{I_{TR(exc)}(\lambda,t)}{I_{TR0(noexc)}(\lambda,t)}\right]$$

TRANSIENT ABSORPTION TECHNIQUE (2)

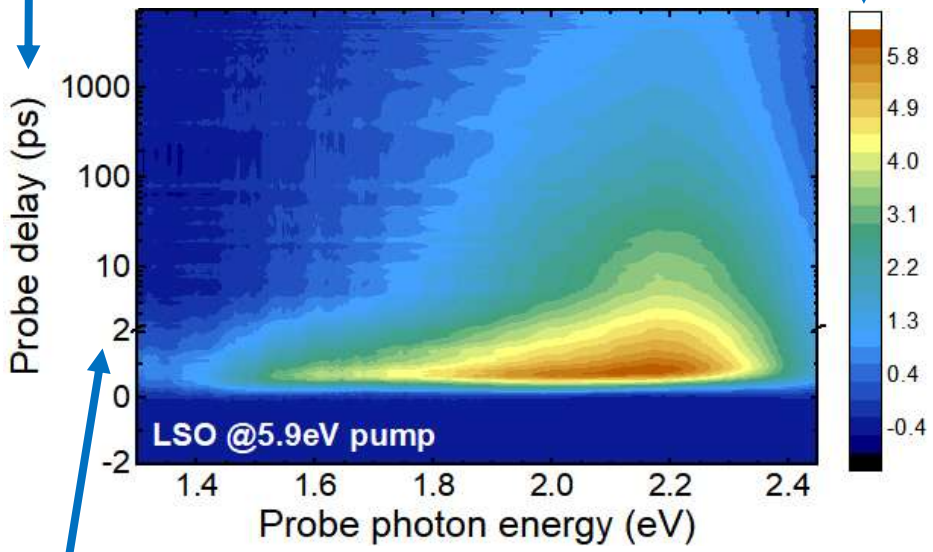


$$TA\ signal = \Delta\alpha(\lambda,t) = \alpha_{exc}(\lambda,t) - \alpha_{noexc}(\lambda,t) = \ln\left[\frac{I_{TR(exc)}(\lambda,t)}{I_{TR0(noexc)}(\lambda,t)}\right]$$

- Time resolution is limited by the laser pulse duration (in our experiments ~300fs)
- Allows selective excitation of crystal units
- Provides information about dynamics of all photo-excited carriers

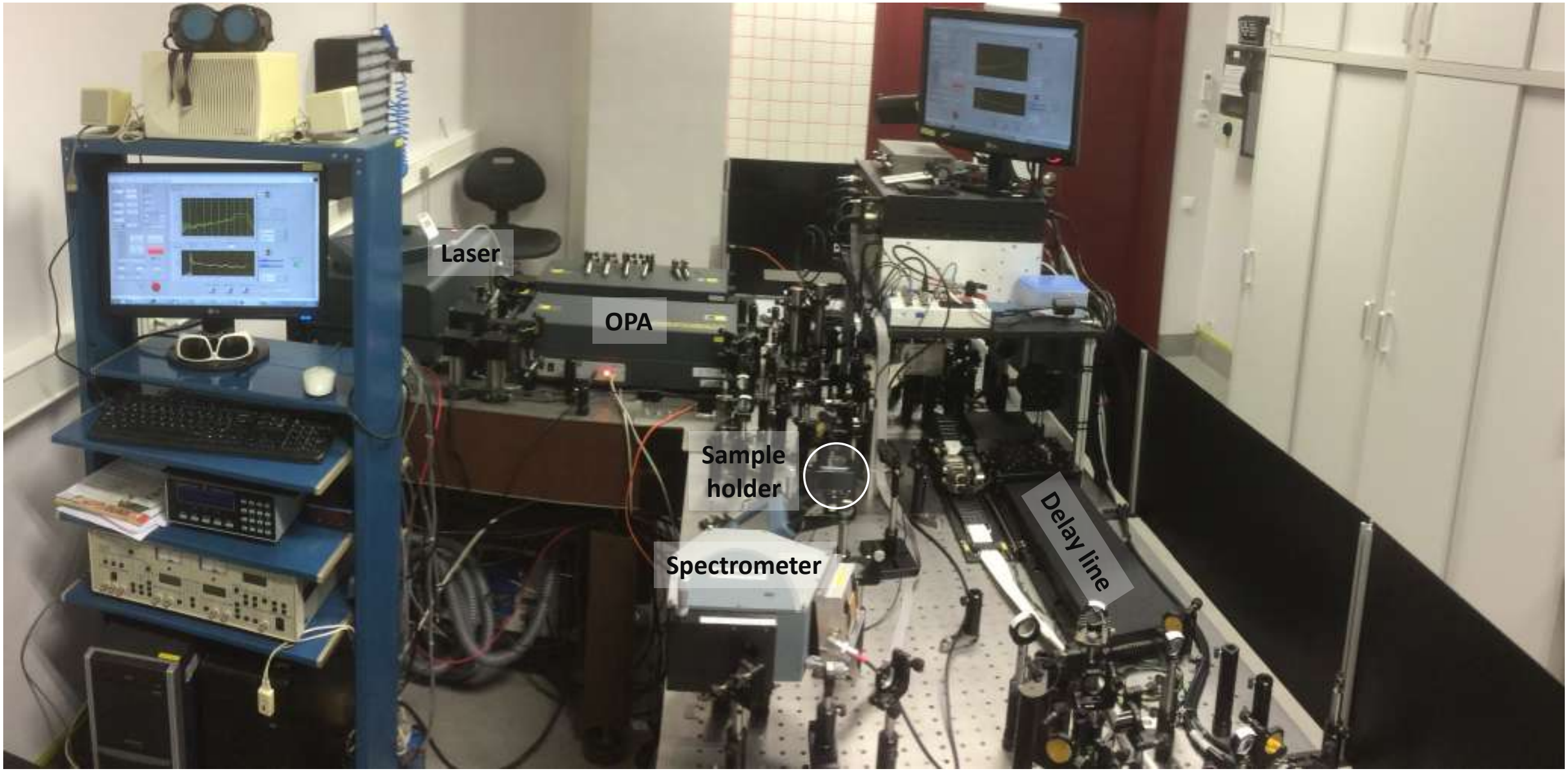
Delay between pump and probe pulses

TA signal amplitude (mOD)

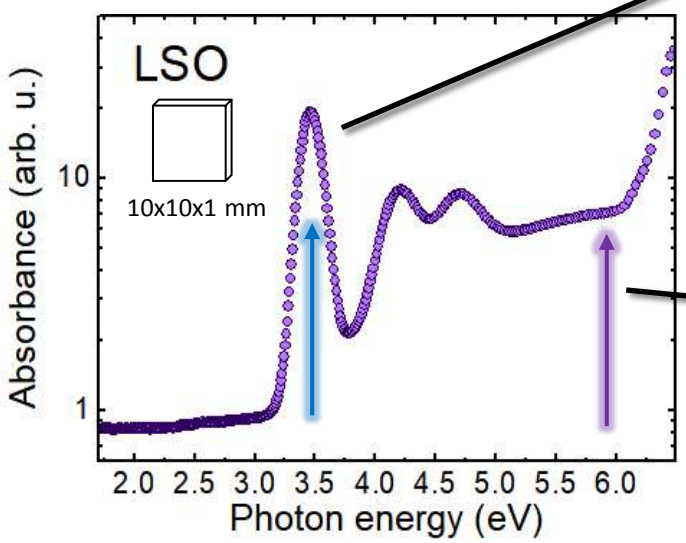


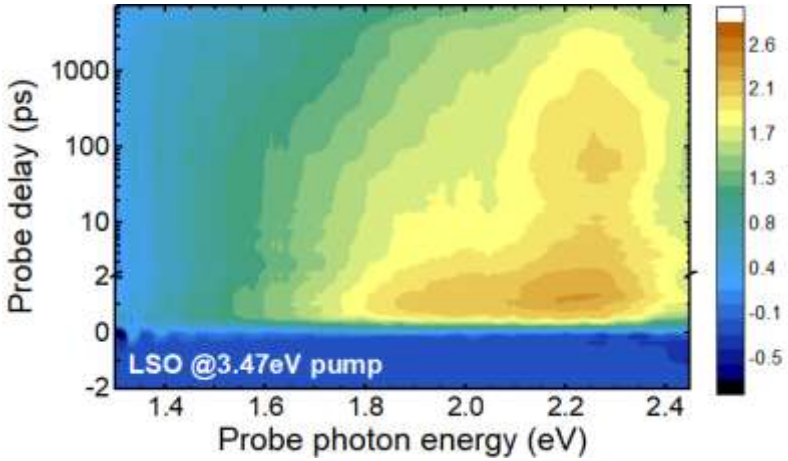
Probe delay axis is divided into linear and log parts to evenly show fast and slow changes of TA signal.

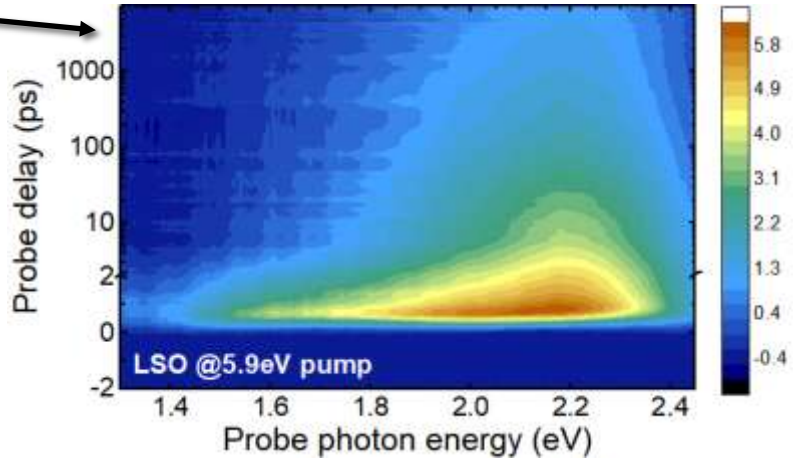
TRANSIENT ABSORPTION TECHNIQUE – EXPERIMENTAL SETUP



Results – transient absorption carpets



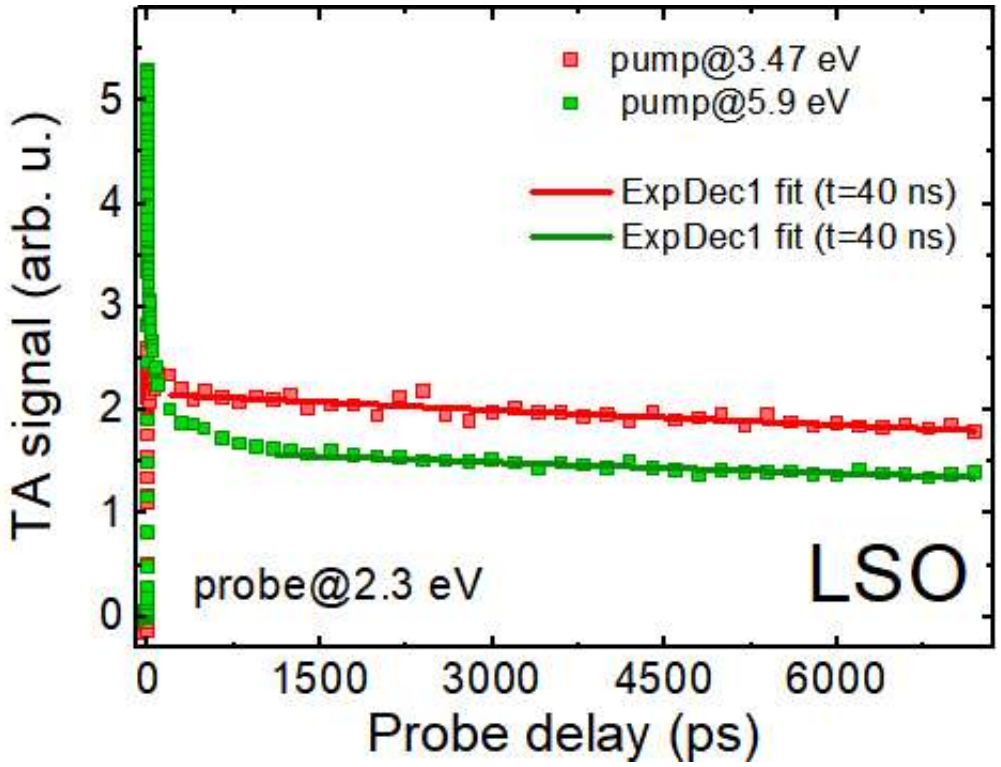


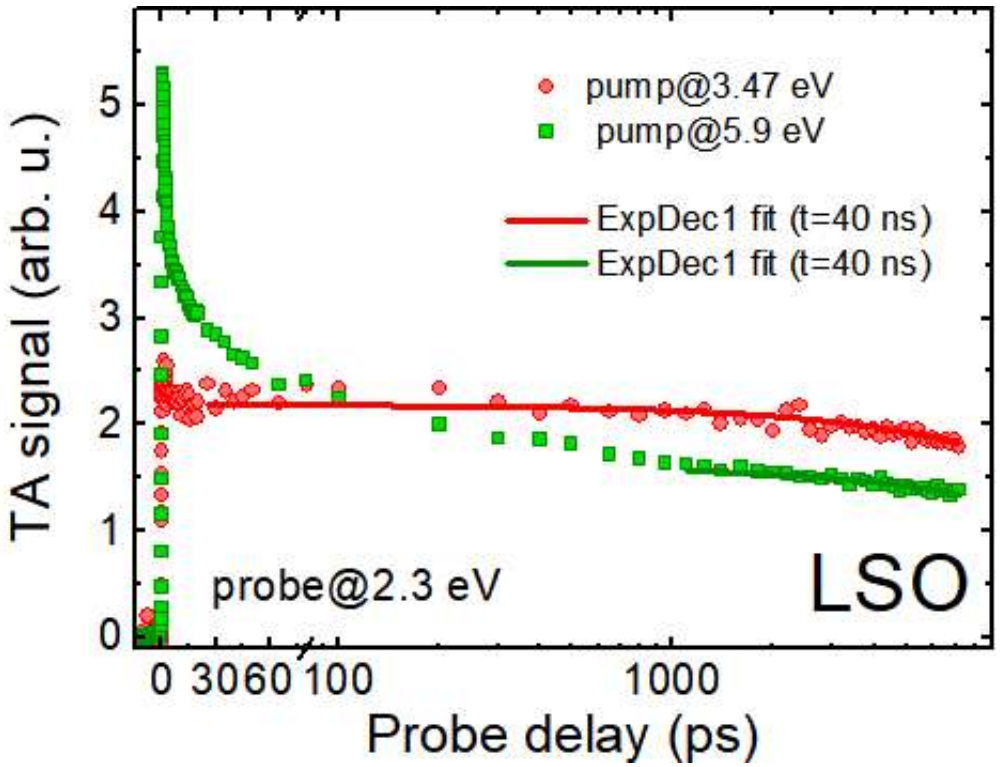


The transient absorption spectrum centered at ~2.2 eV at both excitation conditions indicates that TA signal is caused by absorption of electrons populating the first excited state of Ce^{3+}.

Fast decay component appears at excitation in the vicinity of the conduction band bottom.

Results – transient absorption kinetics

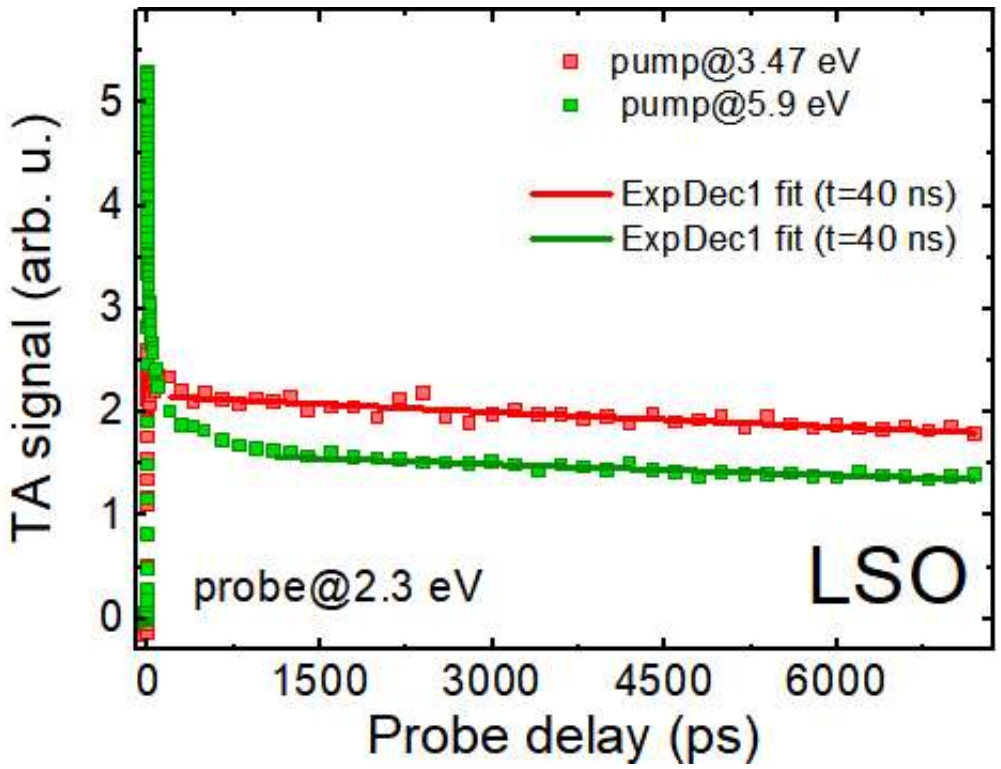


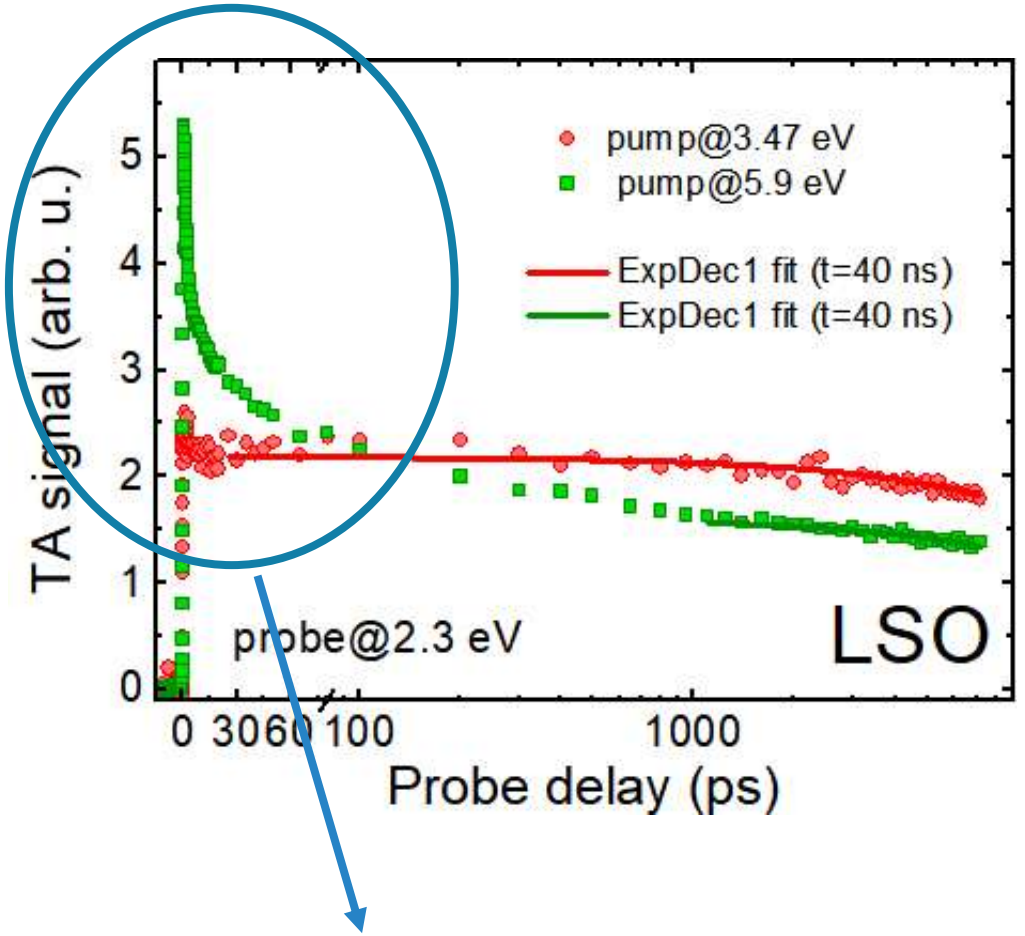


- The decay time of slow TA component is the same for both excitation conditions and follows typical luminescence decay time of LSO:Ce (~40ns).

- The fast TA decay is attributed to fast trapping of free electrons, which results in reduction of quantum yield.

Results – transient absorption kinetics



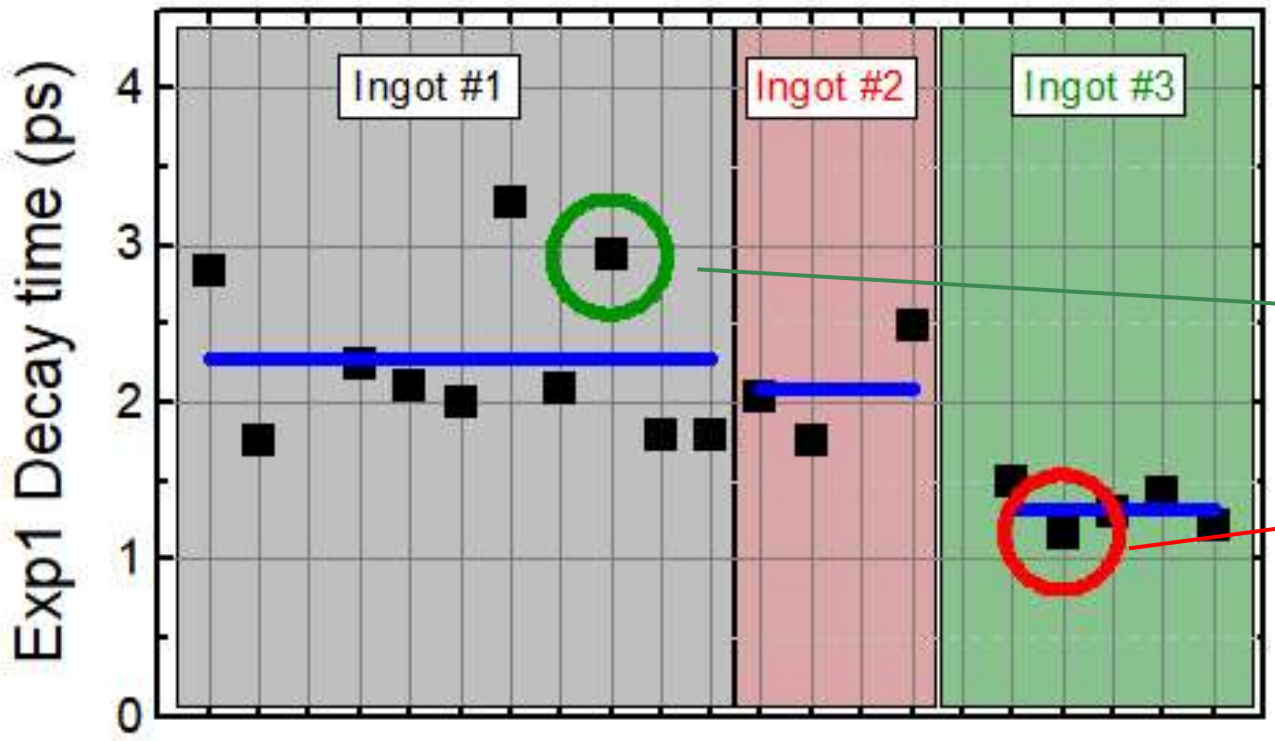


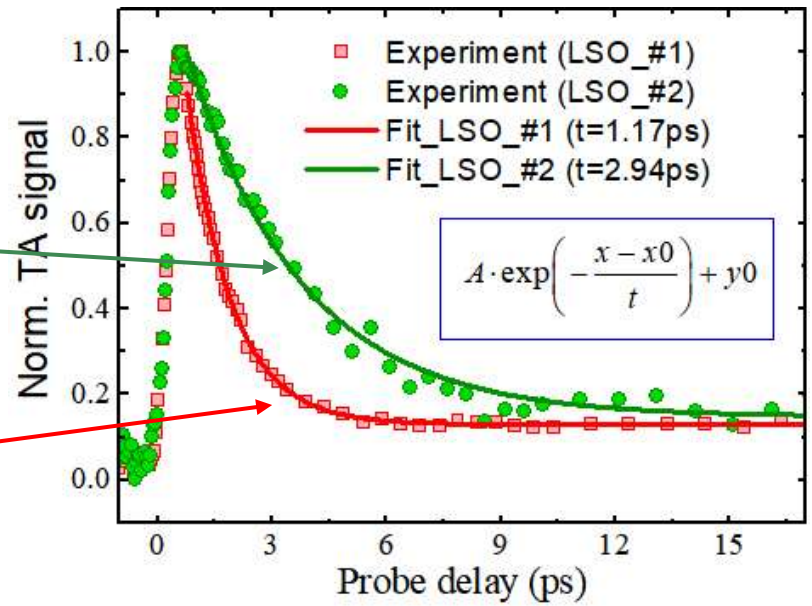
- The decay time of slow TA component is the same for both excitation conditions and follows typical luminescence decay time of LSO:Ce (~40ns).
- The fast TA decay is attributed to fast trapping of free electrons, which results in reduction of quantum yield.

Could this feature be used to characterize different LSO:Ce samples?

Results - comparison of different LSO ingots

18 different samples from three LSO:Ce ingots





Conclusions

- After photoexcitation to 5d1 level of Ce^{3+}, transient absorption signal decays with typical luminescence decay time (~40 ns).
- All the photoexcited electrons recombines radiativelly (QY=100%) after excitation to 5d1 level of Ce^{3+}.
- The ratio between radiative and nonradiative recombination is **1:3** when electrons is excited to the third excited Ce^{3+} level, which is in the conduction band of LSO:Ce.
- Transient absorption technique could be exploited to characterize the timing properties of LSO:Ce samples.

THANK YOU FOR ATTENTION

Acknowledgment
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