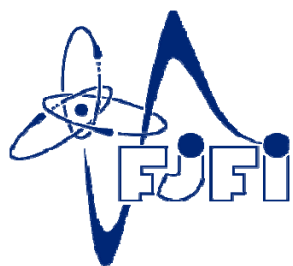


ZnO-based scintillators with band gap modulation

Ing. Lenka Procházková



1 Department of Nuclear Chemistry, FNSPE, CTU in Prague

2 Institute of Physics of the AS CR



13.4. 2018 ASCIMAT workshop

ZnO:Ga as a promising scintillator

Motivation

- Well known scintillator with emission in UV area; treatment in specific conditions – no defect-related emission in visible spectral range
- Optoelectronic properties– wide band gap (3,4 eV), relatively high E_B of excitons (60 meV), low afterglow
- **Extremely short luminescence decay of excitons (sub-ns)**
- Prospective materials in high-energy particles detectors, time of flight detectors for positron emission tomography (TOF PET) and PDTX applications
- Goals
- Band gap modulation by Mg and Cd controlled doping
- Embedding Zn(Cd,Mg)O:Ga into the appropriate matrix
- Improving scintillation properties: enhancement of the emission intensity and light yields; preserving extremely short decays



ZnO:Ga luminescence properties

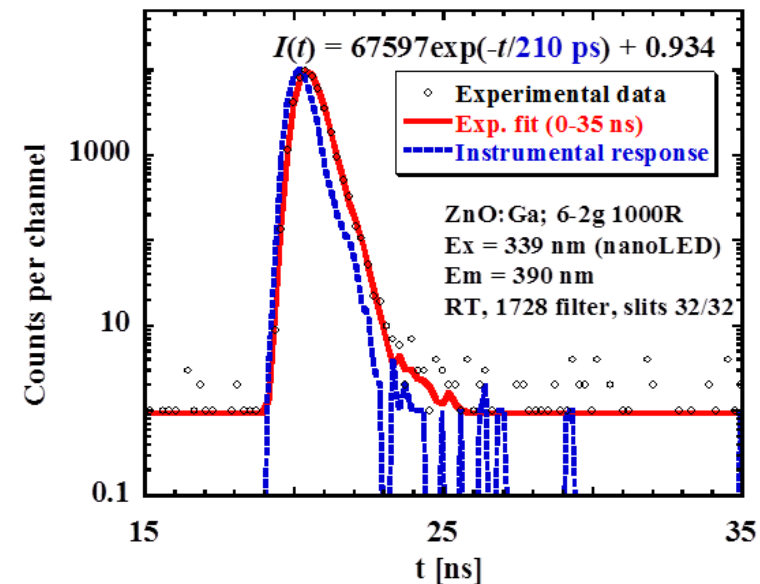
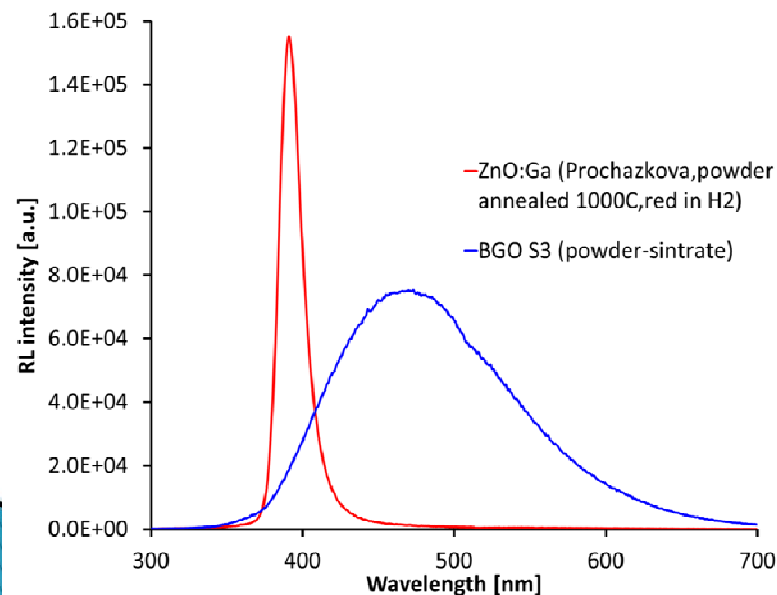
ZnO:Ga annealed at 1000 °C and at 800 °C in reducing atmosphere H₂/Ar – exciton-related emission in UV without defect-related emission in visible area

☺ Optoelectronic properties– wide band gap (3,4 eV), relatively high E_B of excitons (60 meV), low afterglow

☺ **Extremely short luminescence decay of excitons (sub-ns)**

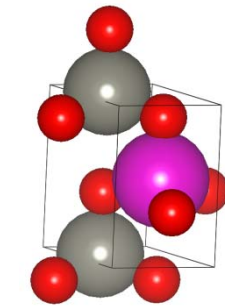
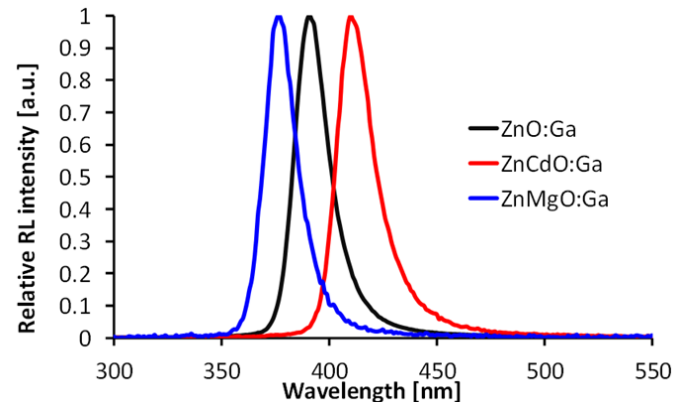
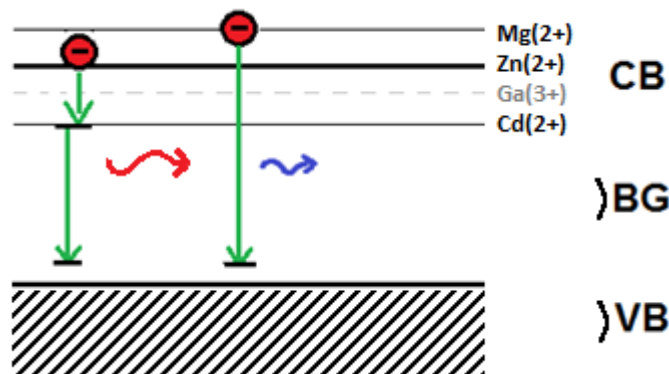
☹ Low light yields

☹ Hexagonal structure –difficult ceramization



Band gap engineering: Solid solutions $\text{Zn}_{1-x}\text{Cd}_x\text{O}$, $\text{Zn}_{1-x}\text{Mg}_x\text{O}$

- Possibility of Cd^{2+} , Mg^{2+} incorporation into the ZnO structure; substitution of Zn^{2+} ions – band gap modulation

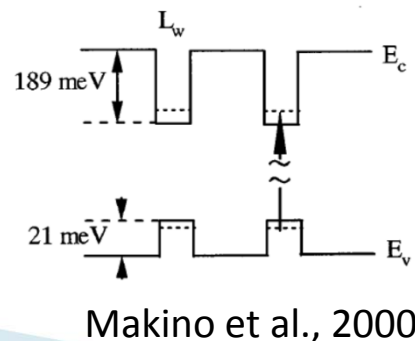


Cd=red shift
Mg=blue shift
of the emission maxima

- Cd/Mg content depends on the preparative technique; **non-conventional synthesis: radiation- or photo-induced precipitation** - up to 20 molar % Cd in the ZnO structure

Applicability:

- ZnO/ZnMgO core-shell quantum wells
⇒ high-energy radiation detectors



Makino et al., 2000

- ZnCdO:Ga scintillator for PDTX

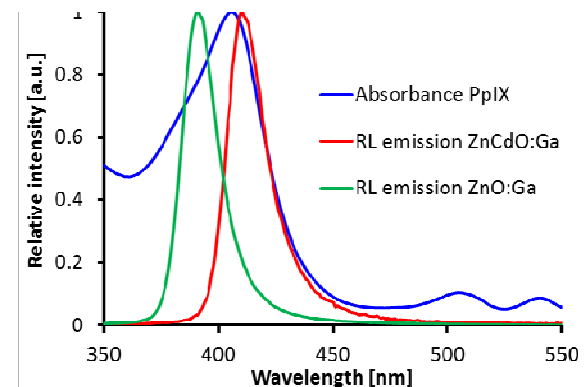
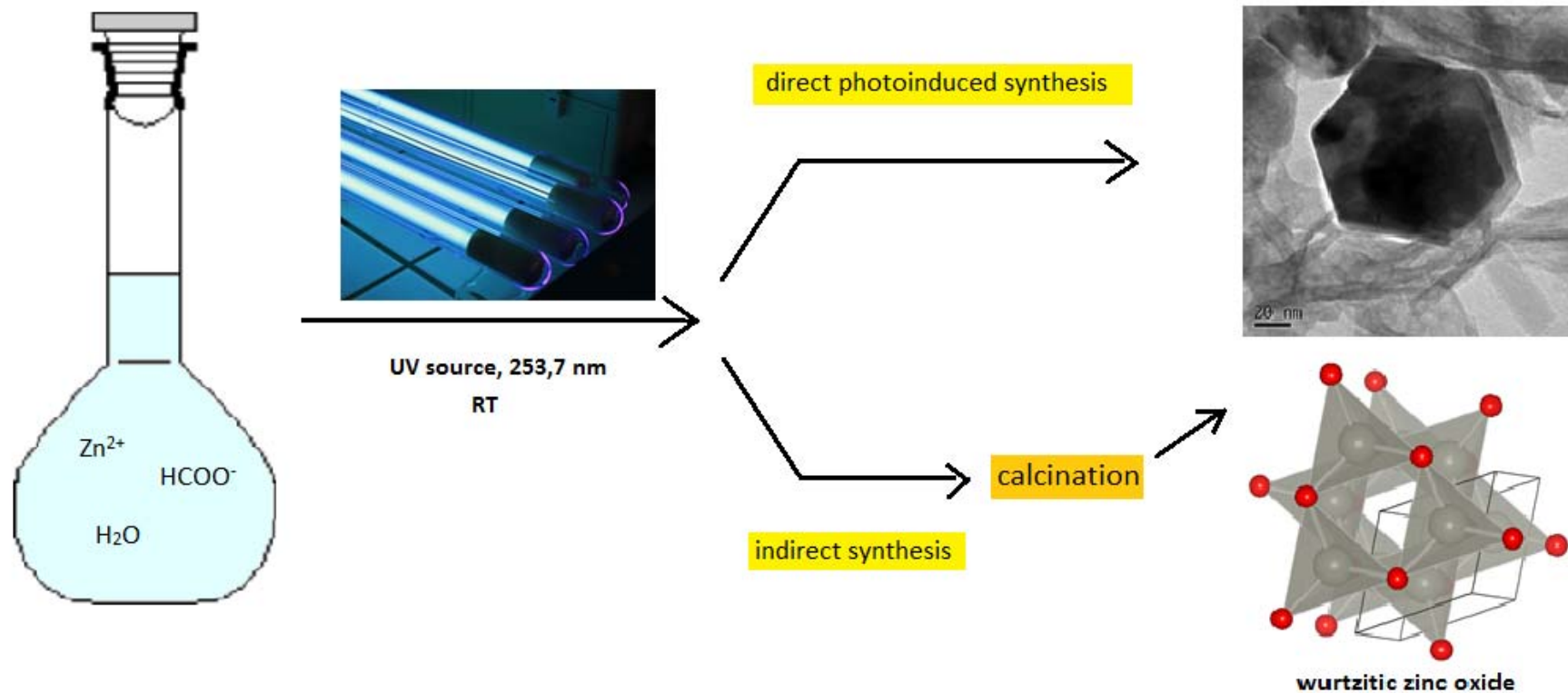


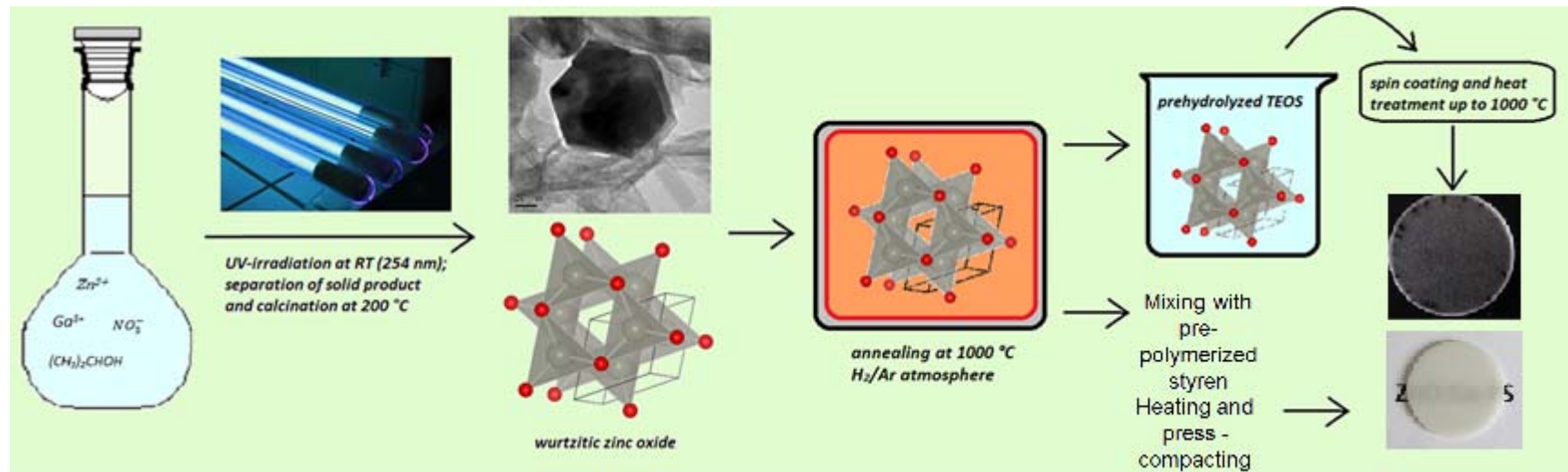
Photo-induced synthesis-overview

Radiation- or photo-induced precipitation:

Principle: reaction of dissolved precursors with products of radio/photolysis of water leading to the precipitation of solid phase (particle size~nm)

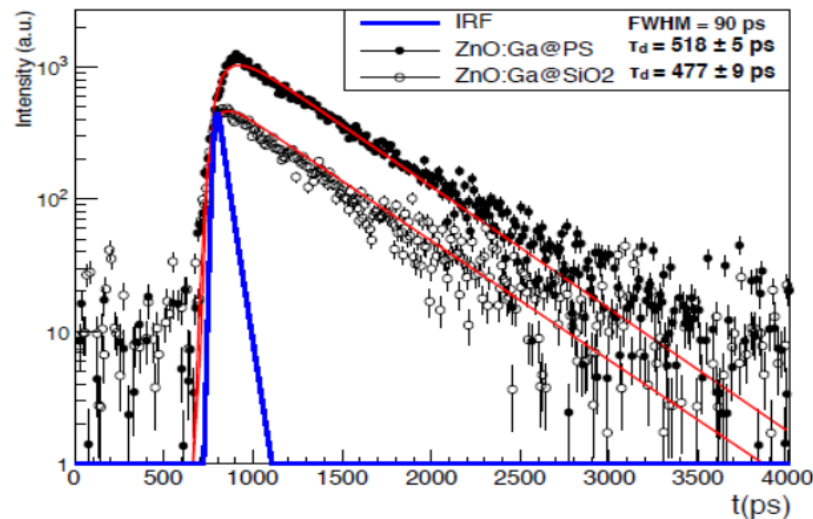


Preparation of ZnO:Ga-based composites

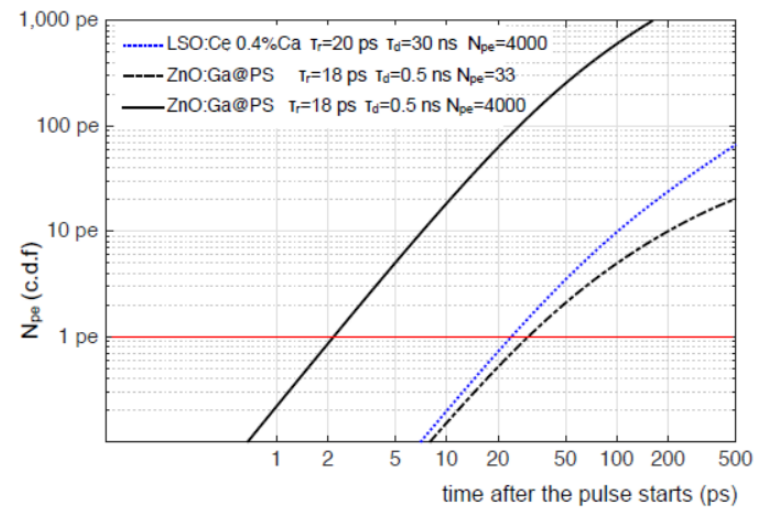


Characterization and prospects

- In cooperation with Institute of Physics AS CR and Etienne Auffray's research team



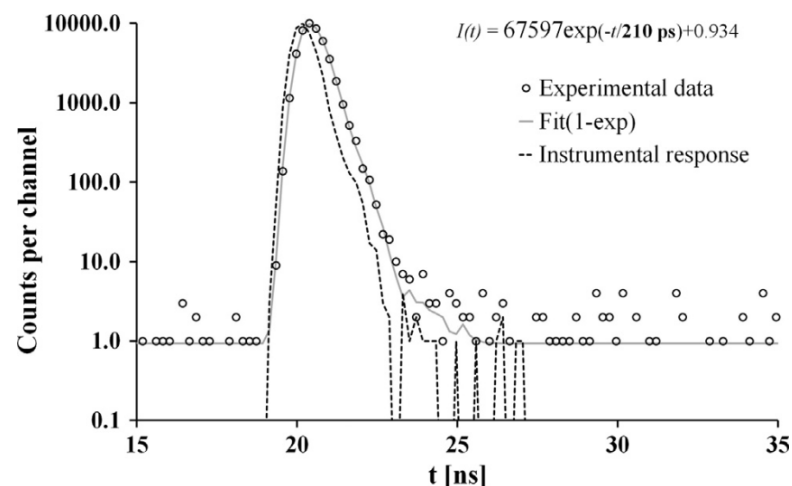
Spectral-time resolved measurement on ZnO:Ga@PS and ZnO:Ga@SiO₂



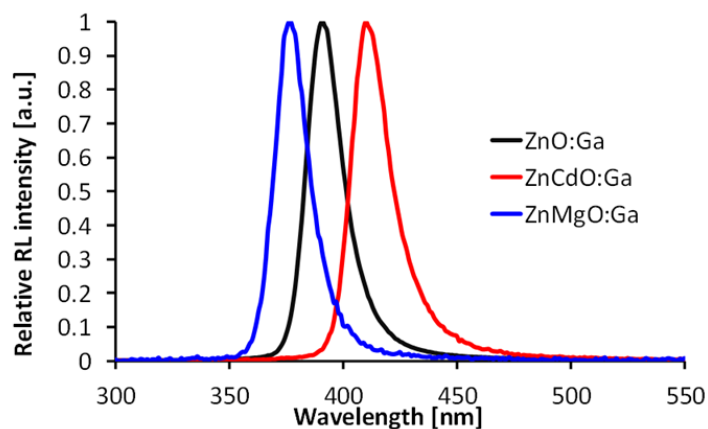
ZnO:Ga nanocrystal's potential to improve coincidence time resolution to sub-20 ps values

Major results

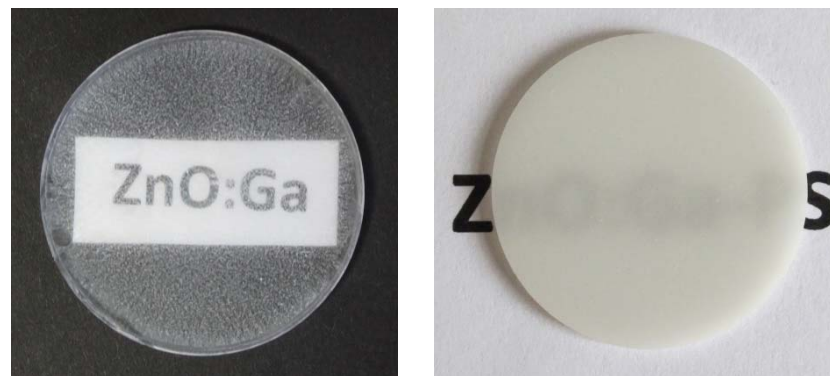
- 1) High-intensity ultrafast scintillator
ZnO:Ga



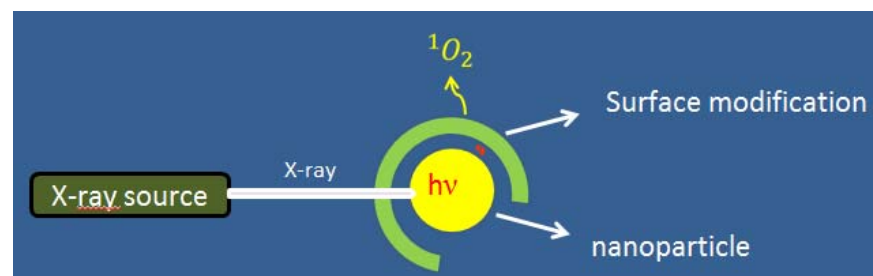
- 2) Band gap modulation by controlled doping with Mg^{2+} and Cd^{2+}



- 3) Embedding in matrices: SiO_2 , PS

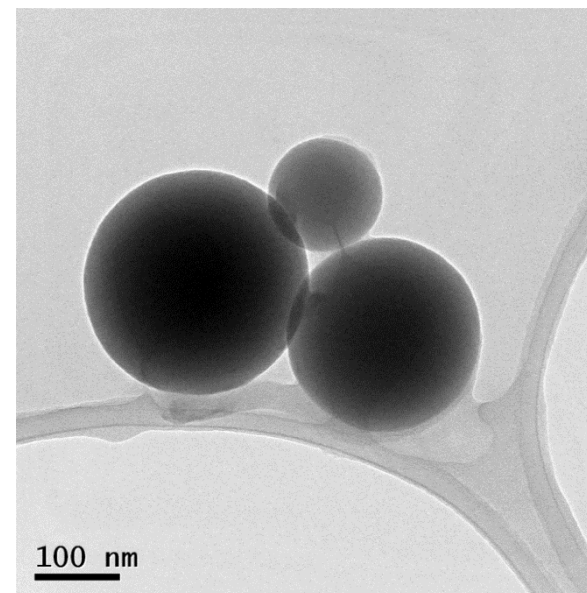
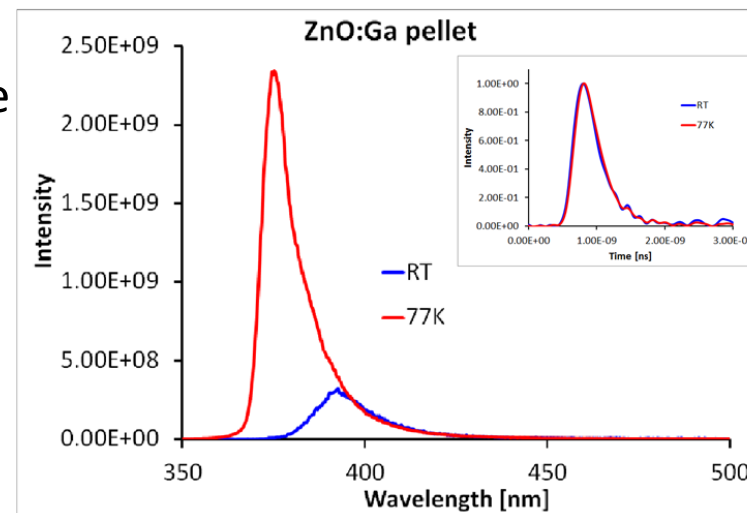
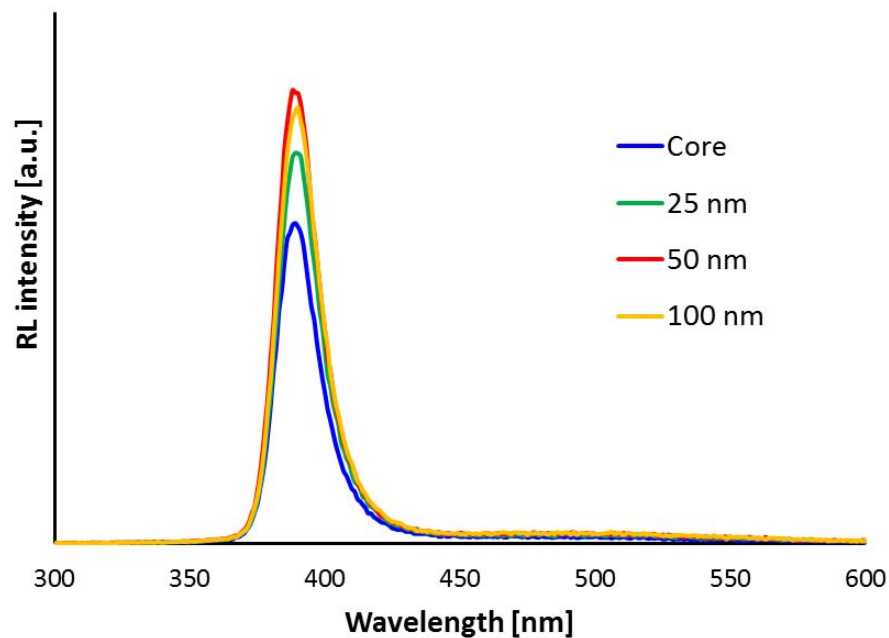


- 4) Study and characterization of ZnCdO:Ga solid solutions
- 5) Preliminary testing for PDTX application



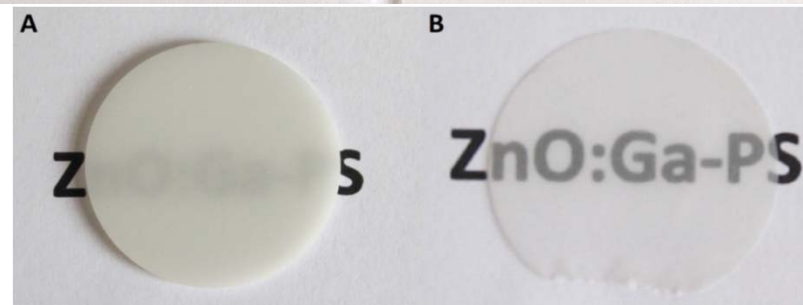
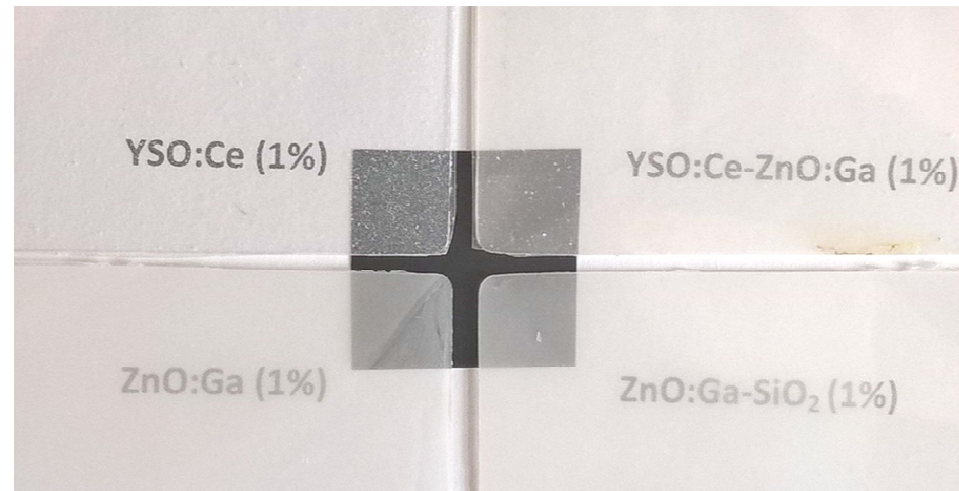
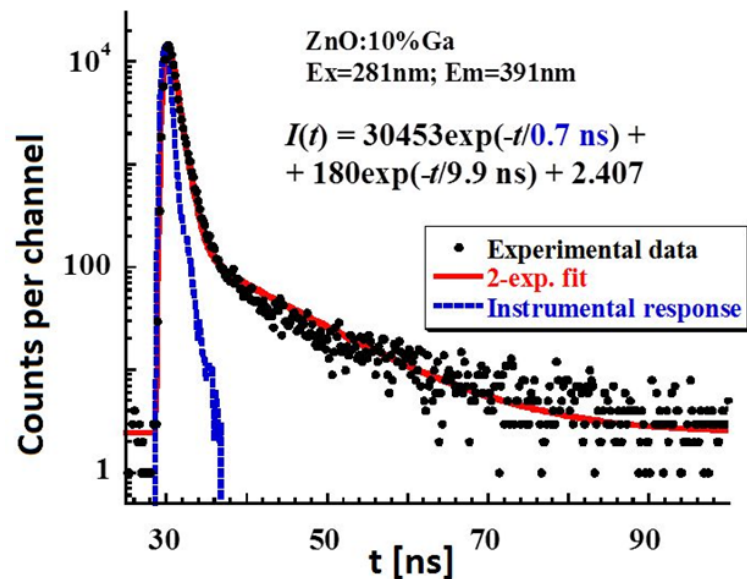
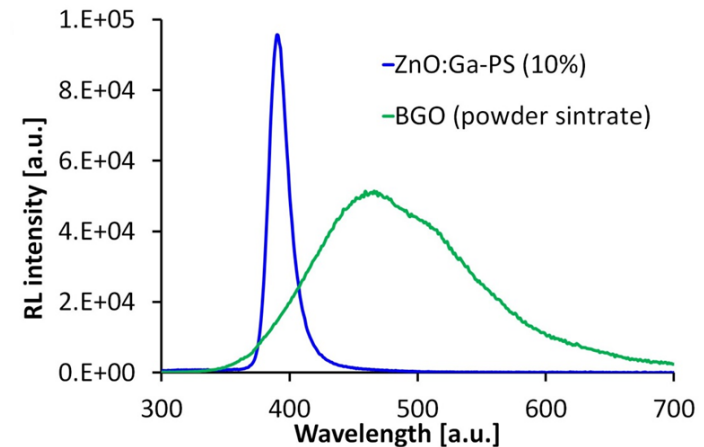
Surface modification of ZnO:Ga grains

- Motivation – quenching the luminescence at RT – on surface defects???
- Aim – heal surface defects by inorganic layer of SiO_2 resulting in RL intensity enhancement



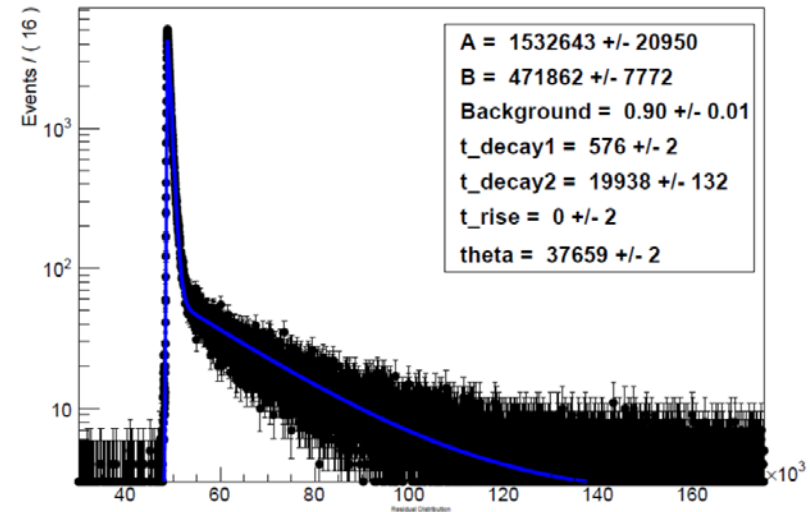
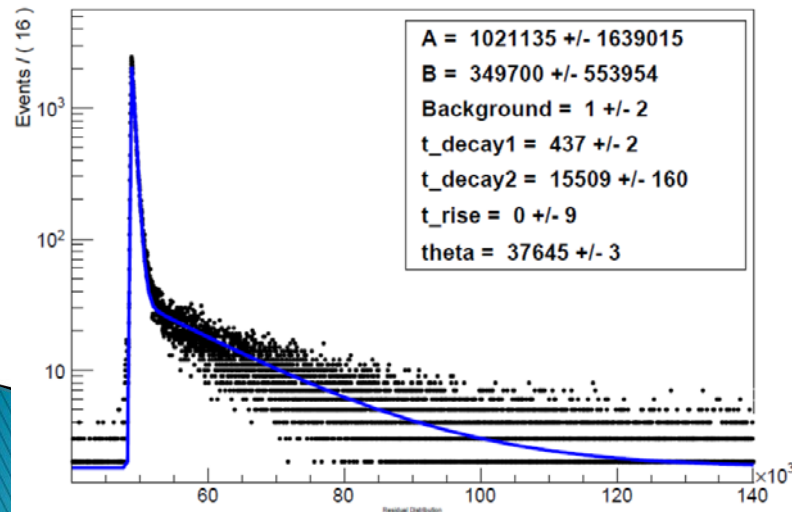
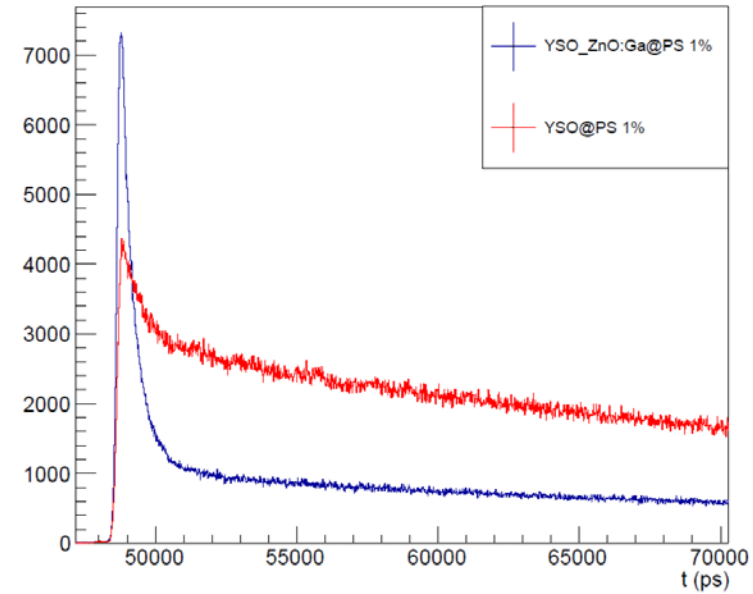
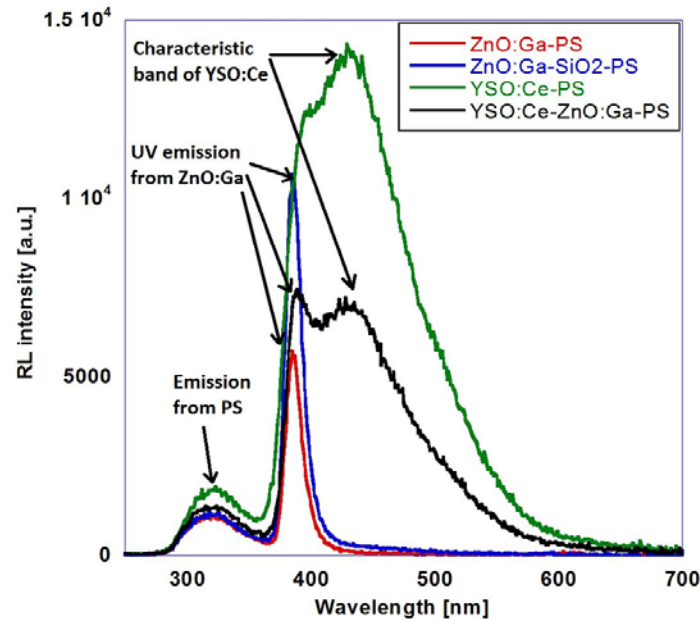
Scintillating composite of ZnO:Ga-PS

- Polystyrene (PS) is appropriate matrix – effective scintillator itself
- Various powder filling tested (1, 10, 20%)
- RL spectrum – only fast excitonic emission from ZnO:Ga
- PL decay – also slow component present



Scintillating composite of ZnO:Ga-PS

- 1 % of ZnO:Ga, ZnO:Ga-SiO₂ core shell, YSO:Ce and YSO:Ce/ZnO:Ga in PS



Conclusions

- Modulation of ZnO:Ga BG via photo-induced synthesis of solid solutions – various Cd and Mg contents shift exciton-related emission maxima in the range of 376 nm to 425 nm
- Composite materials ZnO:Ga@PS, ZnO:Ga@SiO₂ were tested
- Extremely short decays – 200-500 ps, practically zero rising time
- Despite of some disadvantages, photosynthesised Zn(Cd,Mg)O:Ga-based scintillators show strong promise for applications in future generation of detectors and photo/radiotherapy

Acknowledgement

- ▶ COST Action TD1401 WG2: Fast advanced Scintillator Timing (FAST)
- ▶ Crystal Clear Collaboration (CCC)
- ▶ GAČR GA13-09876S: Inorganic nanoscintillators: novel synthesis and size-dependent characteristics (Czech Science Foundation)

... and all colleagues from the group of radiation chemistry (FNSPE CTU),
Institute of Physics AS CR, CERN group, Institute of Physics University of Tartu...

Thank you for your attention!

