Fast timing with nanocrystalline lead halide perovskite thin films on scintillating wafers

K. Děcká[1,2], J. Král[2], F. Hájek [1,2] P. Průša[2], V. Babin[1], E. Mihóková[1,2] and V. Čuba[2]

Institute of Physics of the Czech Academy of Sciences

CZECH TECHNICAL UNIVERSITY IN PRAGUE

[1]*Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic*
[2] *FNSPE, Czech Technical University in Prague, Prague, Czech Republic*

Fast timing

nanoparticles

quantum confinement

enhanced optical properties vs bulk counterparts

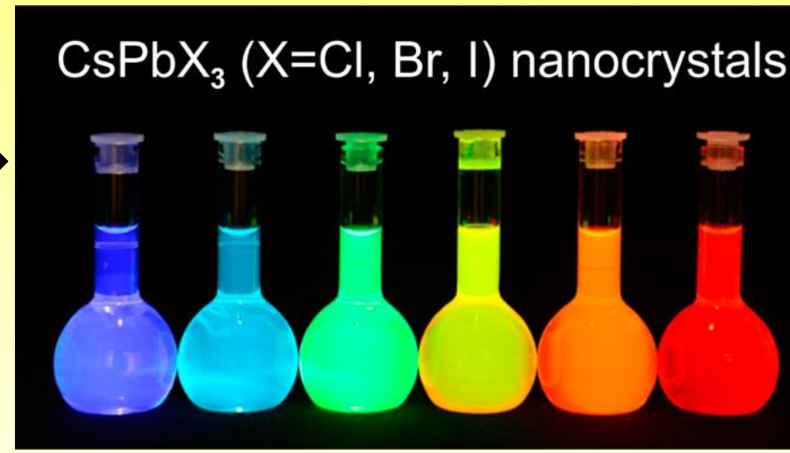
High quantum efficiency

Ultrafast decay

Promising candidates

Cesium lead halide perovskites $CsPbX_3$ (X=Cl, Br, I)

fast Mott-Wannier exciton emission



L. Protesescu et al., Nanolett. **15**, 3692 (2015)

application potential for solar cells, LEDs, displays …

High quantum yields
Decay times 1-29 ns
Tunable emission over all VIS range depending on nanoparticle size and composition (X)

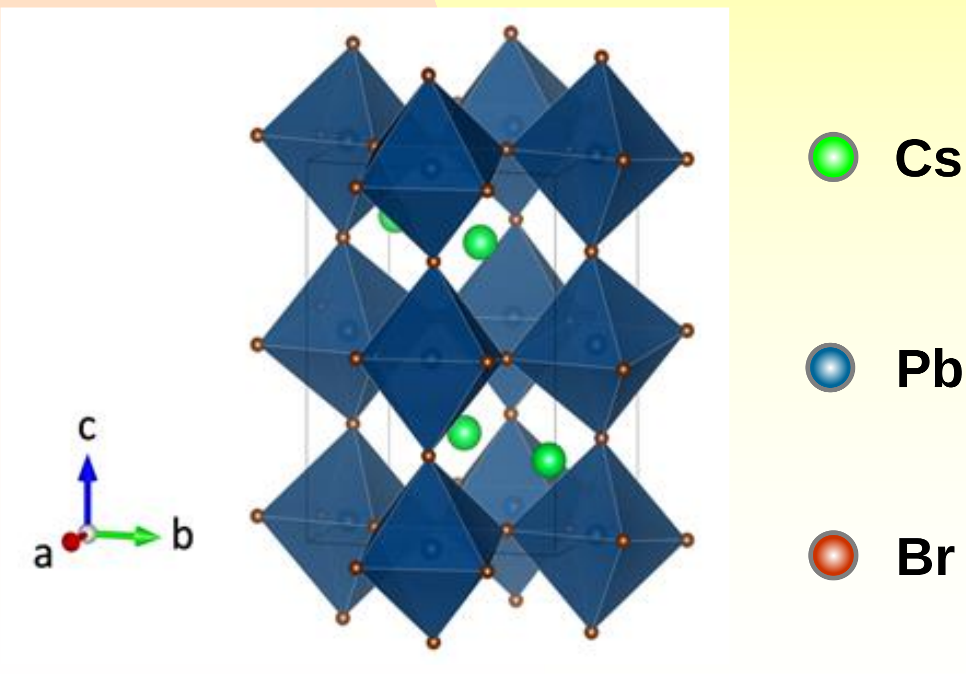
$CsPbBr_3$ nanocrystals

poor chemical stability in air

solution : encapsulation in inert matrices or organic polymers

Presentation K. Děcká

$CsPbBr_3$
3D perovskite

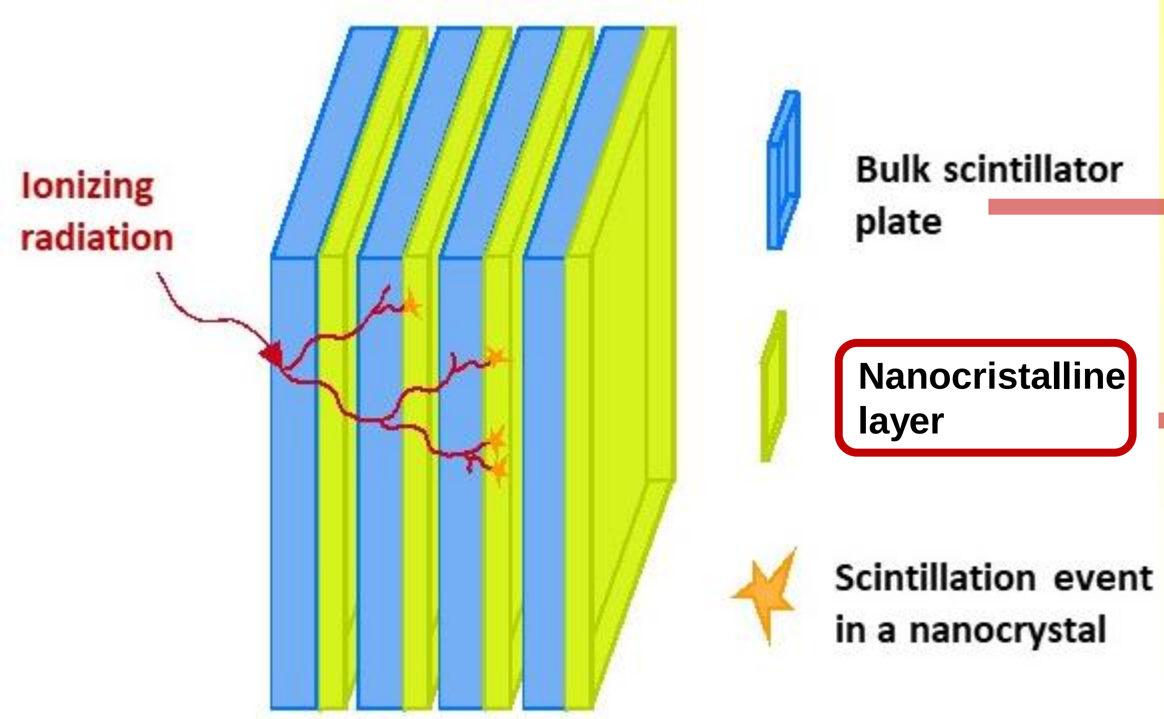


corner sharing $PbBr_6^{4-}$ octahedra

$CsPbBr_3$ nanocrystals for scintillator applications

The most serious issue: poor stopping power

Solution: heterostructure



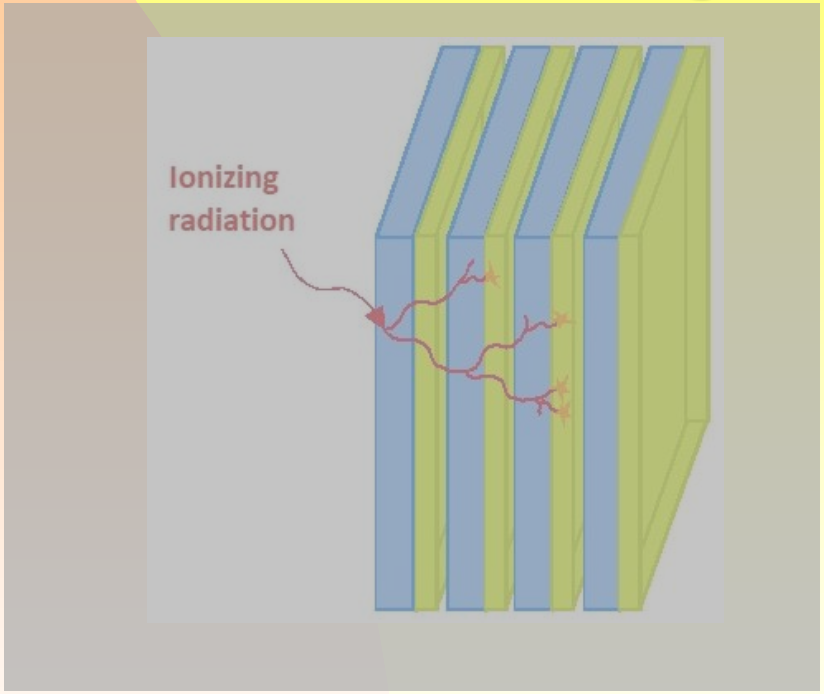
High stopping power
+ good energy resolution

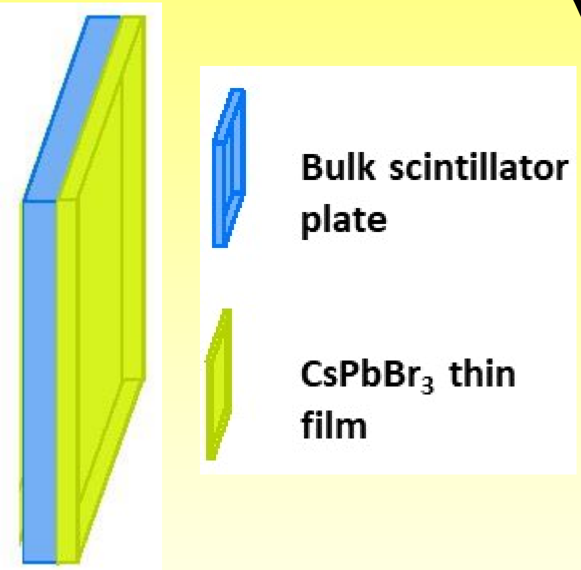
Time tagger

R. M. Turtos et al., Npj 2D Materials and Applications **3** (1), 37 (2019)

Goal

To fabricate $CsPbBr_3$ thin films on scintillating wafers

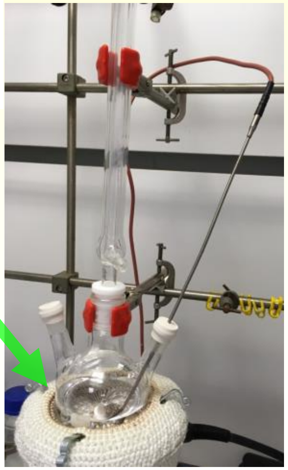




To test whether such nanocomposite can be a candidate for fast timing detector

Hot injection (HI) synthesis of $CsPbBr_3$

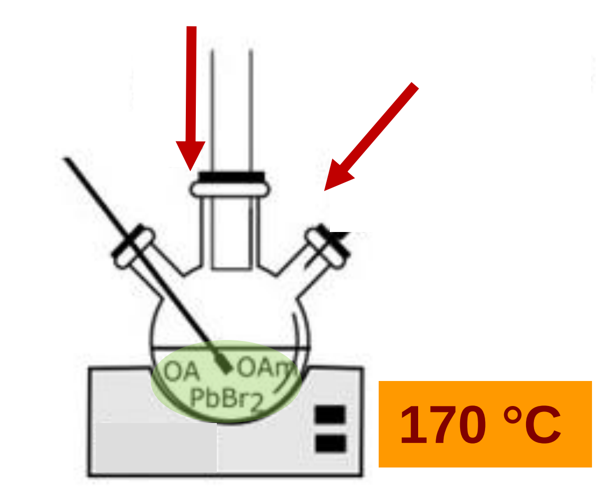
L. Protesescu et al., Nanolett. **15**, 3692 (2015)



Schlenk line installed at the FNSPE CTU

Hot injection (HI) synthesis of $CsPbBr_3$

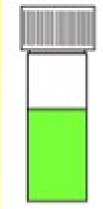
L. Protesescu et al., Nanolett. **15**, 3692 (2015)



OA– oleic acid
OAm – oleylamine

concentrated $CsPbBr_3$ solution

$CsPbBr_3$ capped with OA, OAm



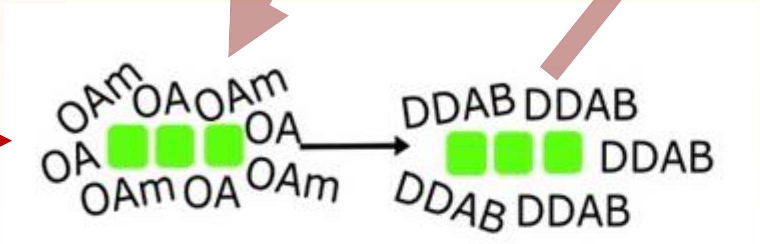
$CsPbBr_3$ capped with DDAB

characterization

Ligand exchange procedure

M. Imran et al., ACS Energy Lett. **4**, 819 (2019)

at RT in air

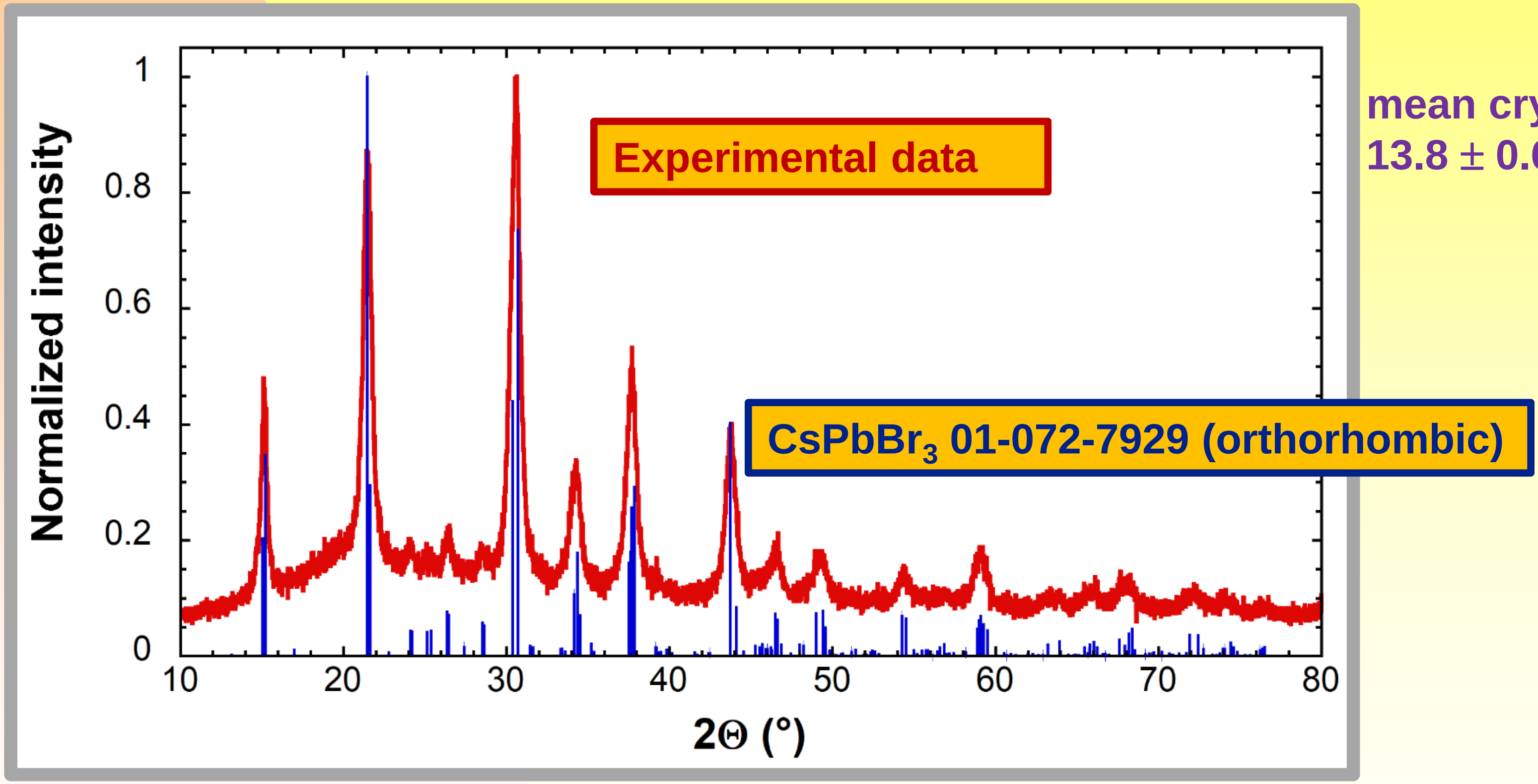


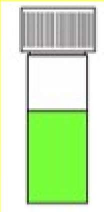
Thicker films
More intense RL

DDAB – didodecyldimethylammonium bromide

X-ray powder diffraction

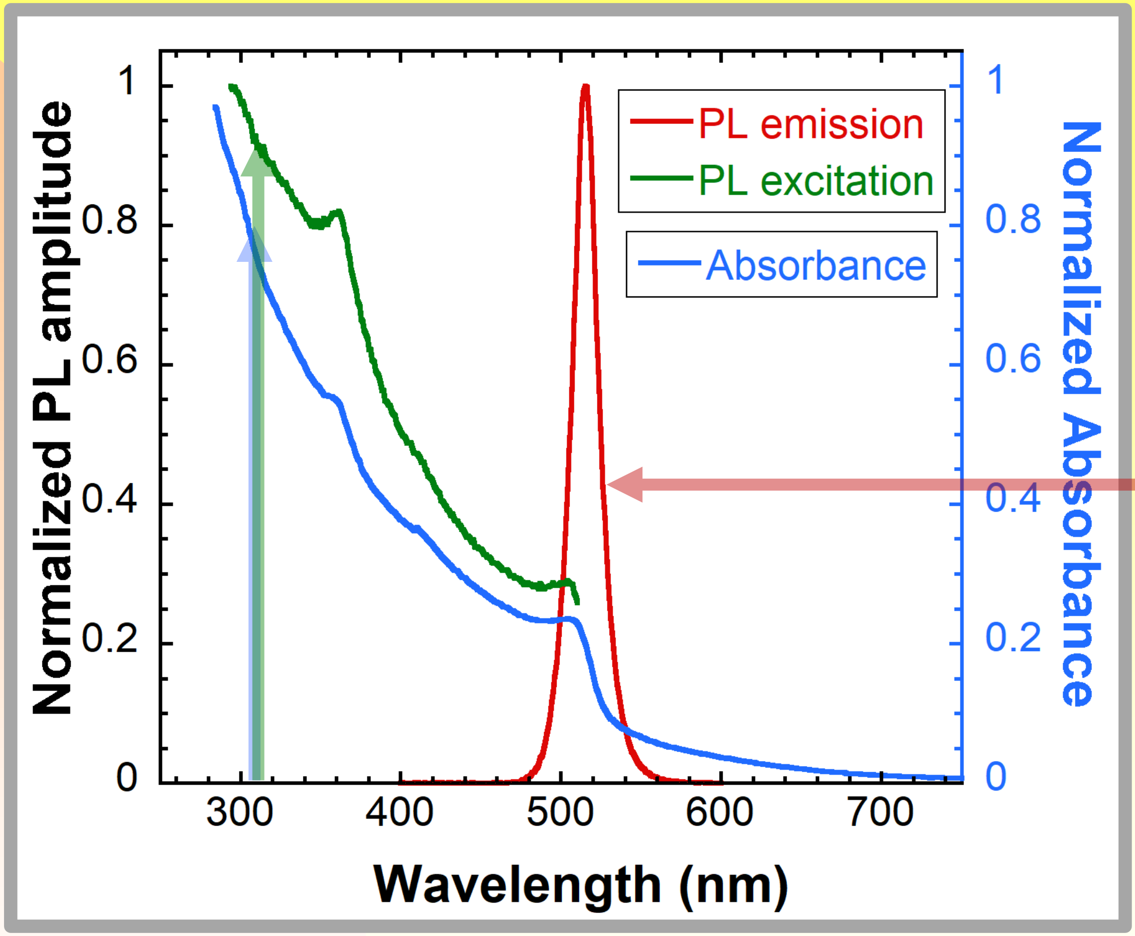
XRPD pattern of the synthesized material used for the spin coating

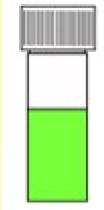




mean crystallite size
13.8 ± 0.6 nm

Absorption and photoluminescence





Single excitonic peak at **515 nm**

Lack of the **peak (dip)** at 310 nm in **absorbance** and **PLE spectra** (characteristic of Cs_4PbBr_6 impurity) confirms the purity of $CsPbBr_3$ phase

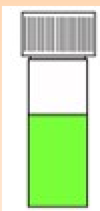
Small Stokes shift – problem of reabsorption

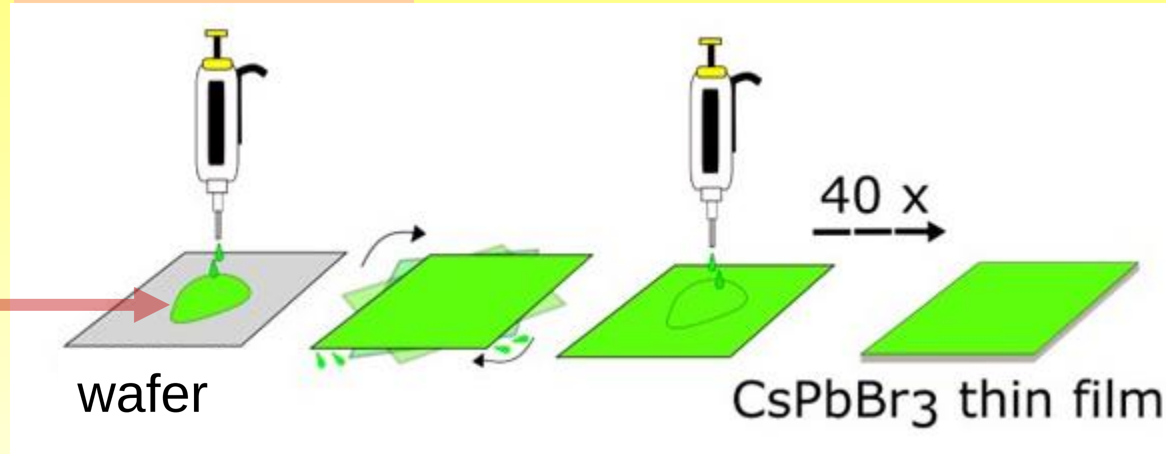
$CsPbBr_3$ thin film fabrication

Spin coating on wafer: glass, GGAG:Ce

$Gd_{2.985}Ce_{0.015}Ga_{2.7}Al_{2.3}O_{12}$

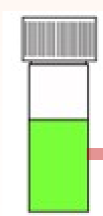
Static method

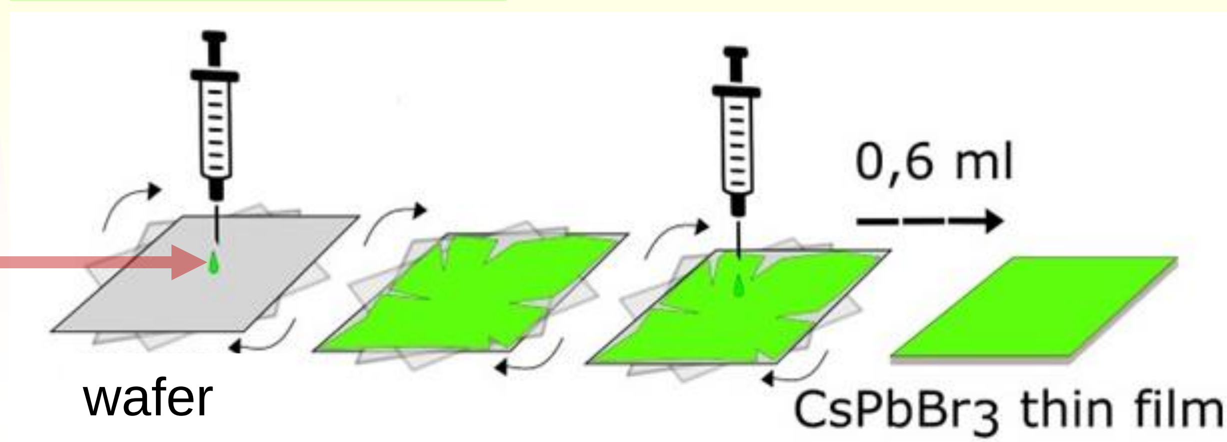




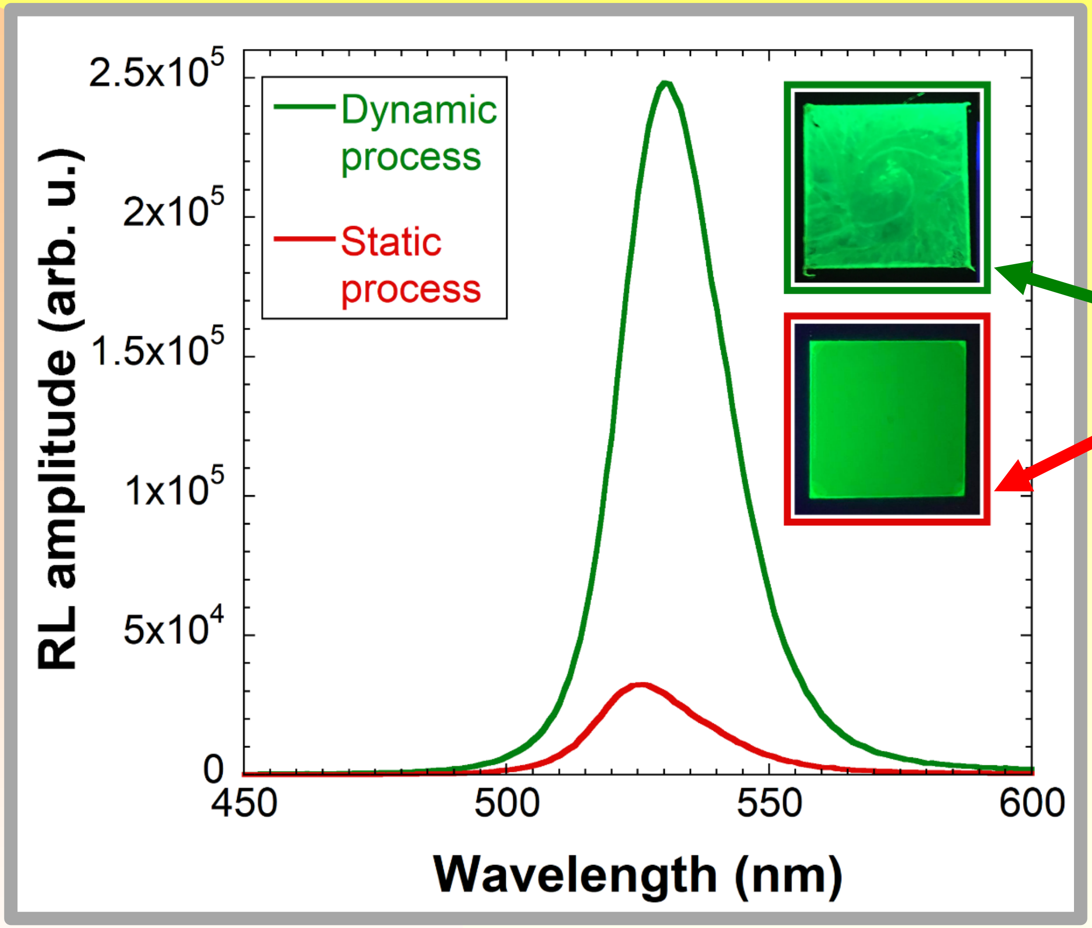
Concentrated solution of $CsPbBr_3$ capped with DDAB

Dynamic method





Radioluminescence of thin films on glass



Photograps under UV illumination

Dynamic process – more intense RL

– less material used (0.6 mL vs 1.6 mL for 40 layers of the static process)

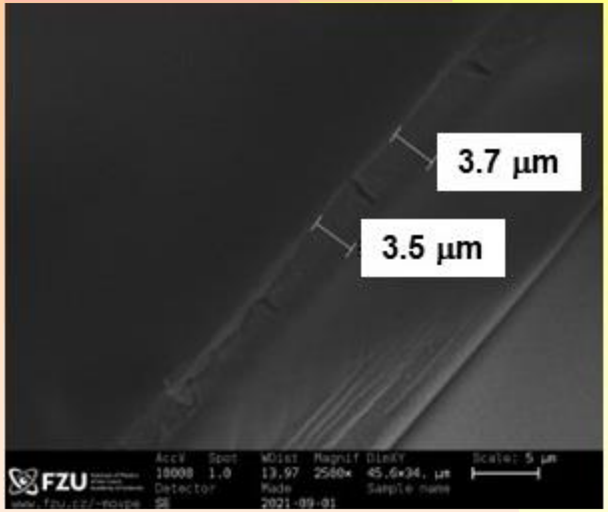
Static process – much higher homogeneity

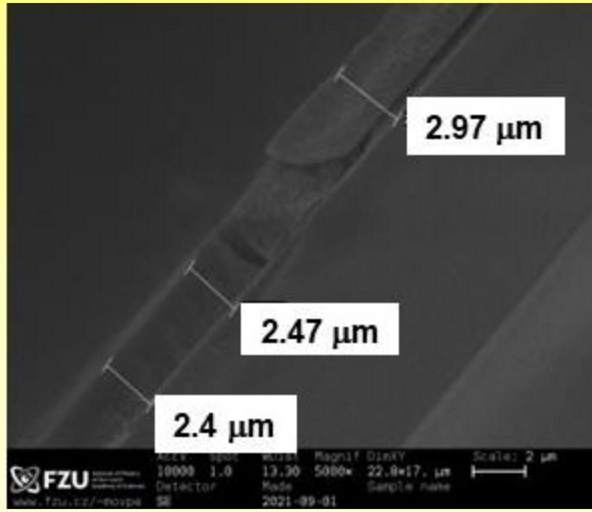
Is homogeneity important for intended application ?

Thin films on GGAG:Ce - mean thickness

SEM images of the thin film edge

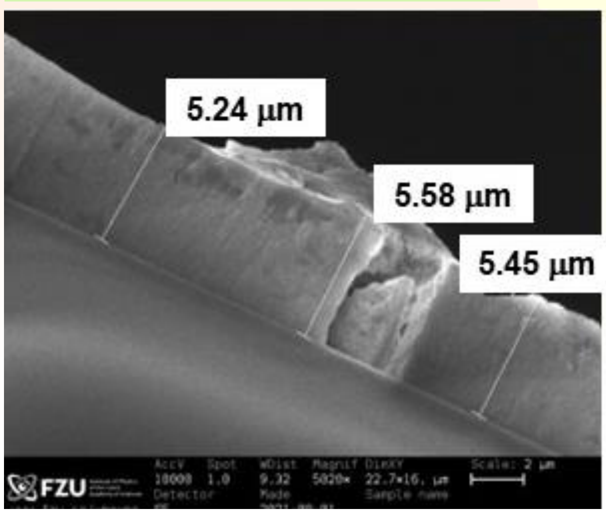
Static process **50 layers** Mean thickness: ~ 3 μm

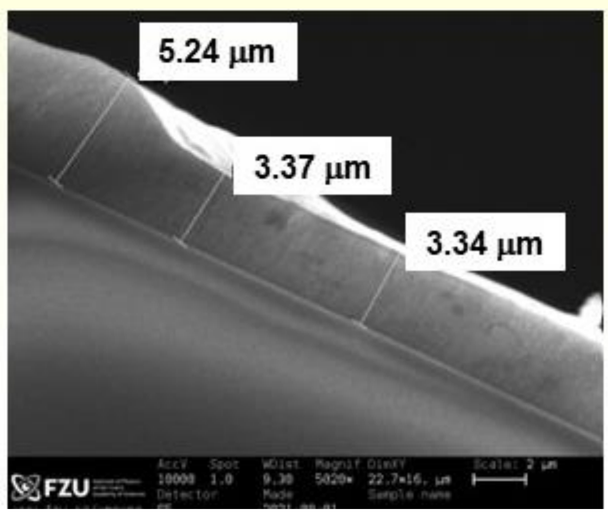


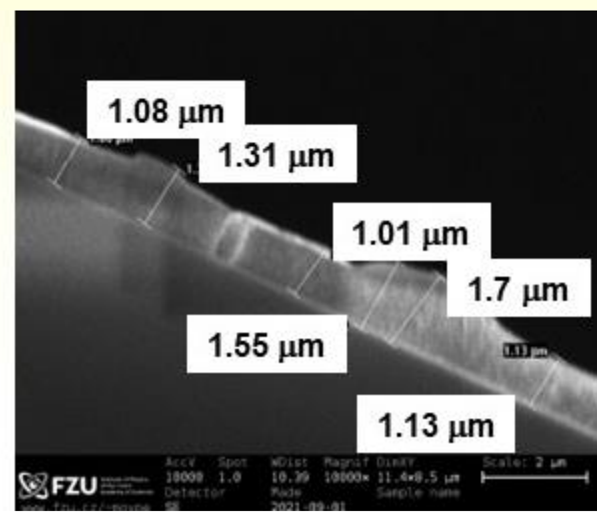


Much better homogeneity

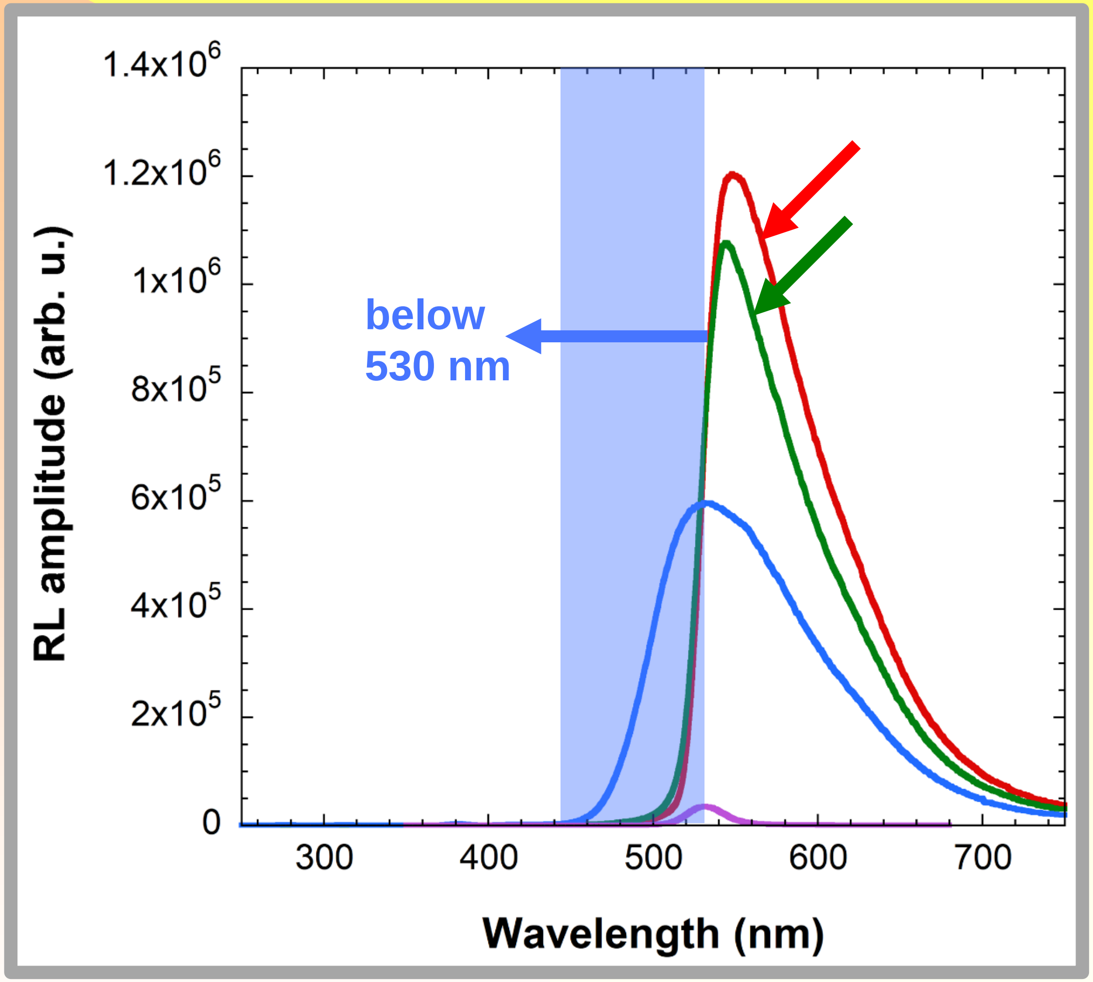
Dynamic process **0.6 mL** Mean thickness: ~ 3 μm

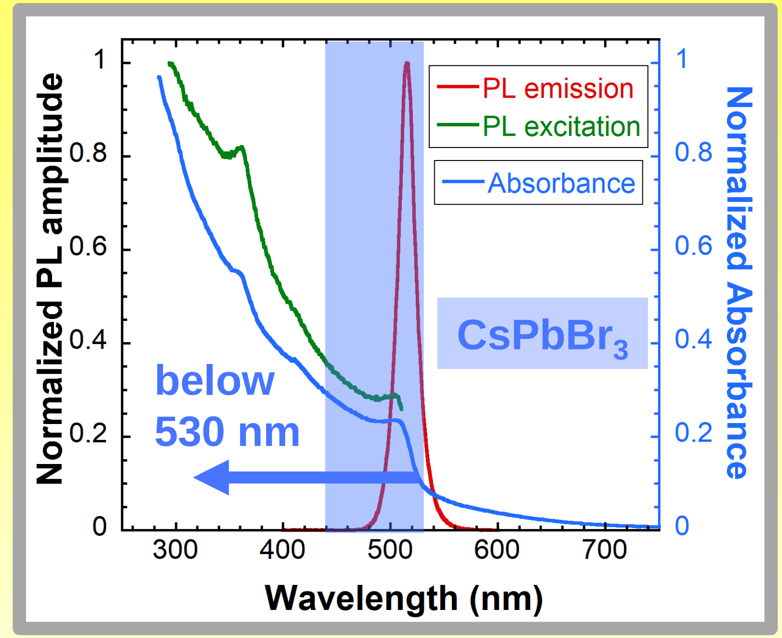






Radioluminescence of $CsPbBr_3$ thin films





GGAG:Ce wafer

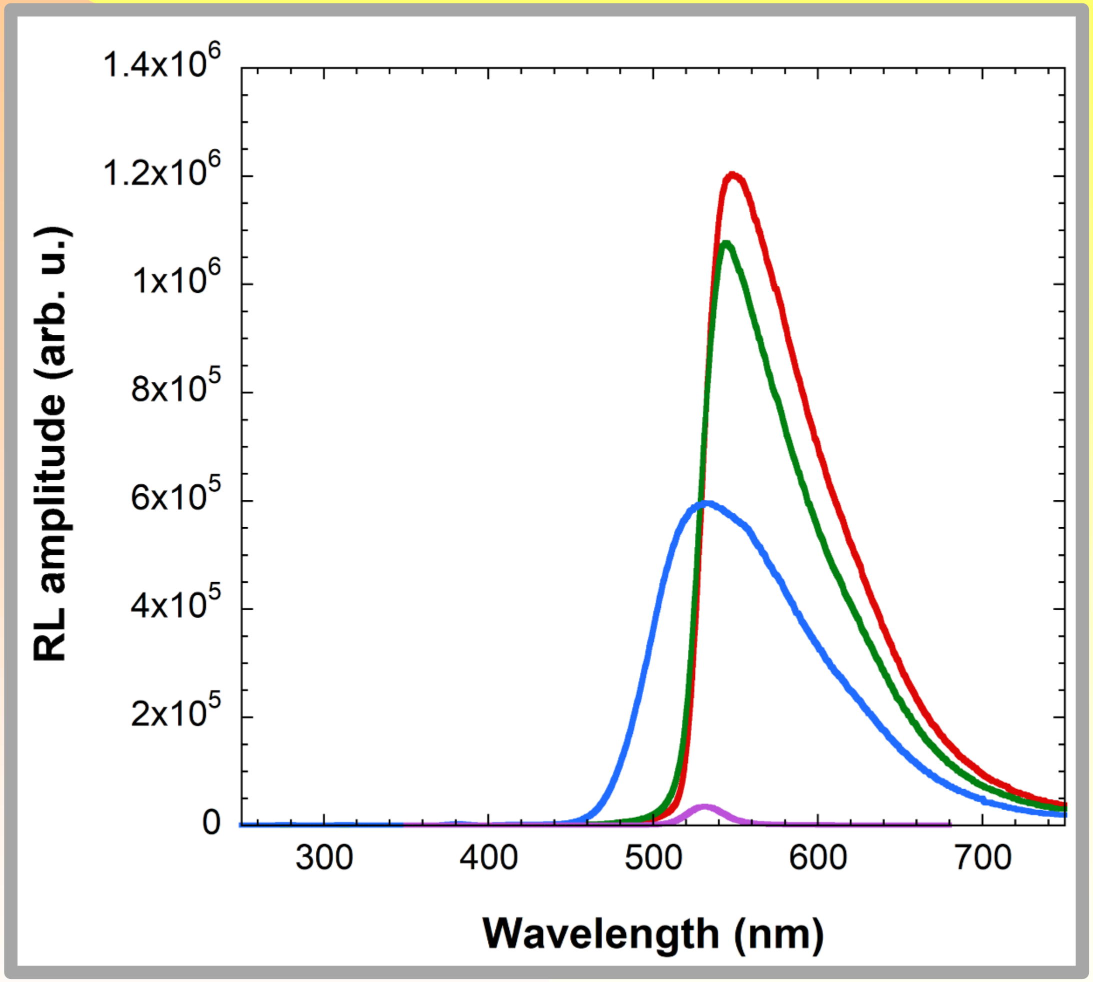
$CsPbBr_3$ on GGAG:Ce
Dynamic process

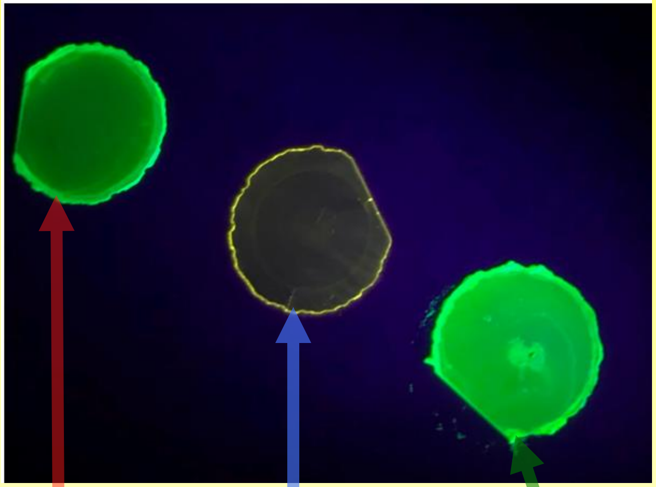
$CsPbBr_3$ on GGAG:Ce
Static process

$CsPbBr_3$ on glass
Static process

Quantitative comparison of RL not appropriate glass wafer is larger

Radioluminescence of $CsPbBr_3$ thin films





GGAG:Ce wafer

$CsPbBr_3$ on GGAG:Ce
Dynamic process

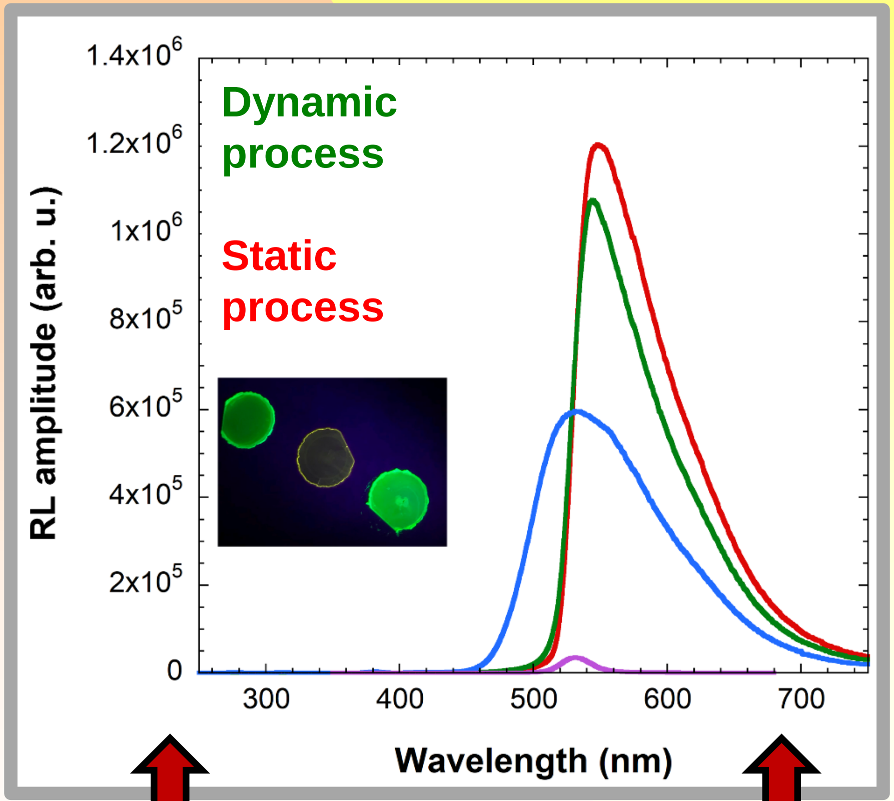
$CsPbBr_3$ on GGAG:Ce
Static process

$CsPbBr_3$ on glass
Static process

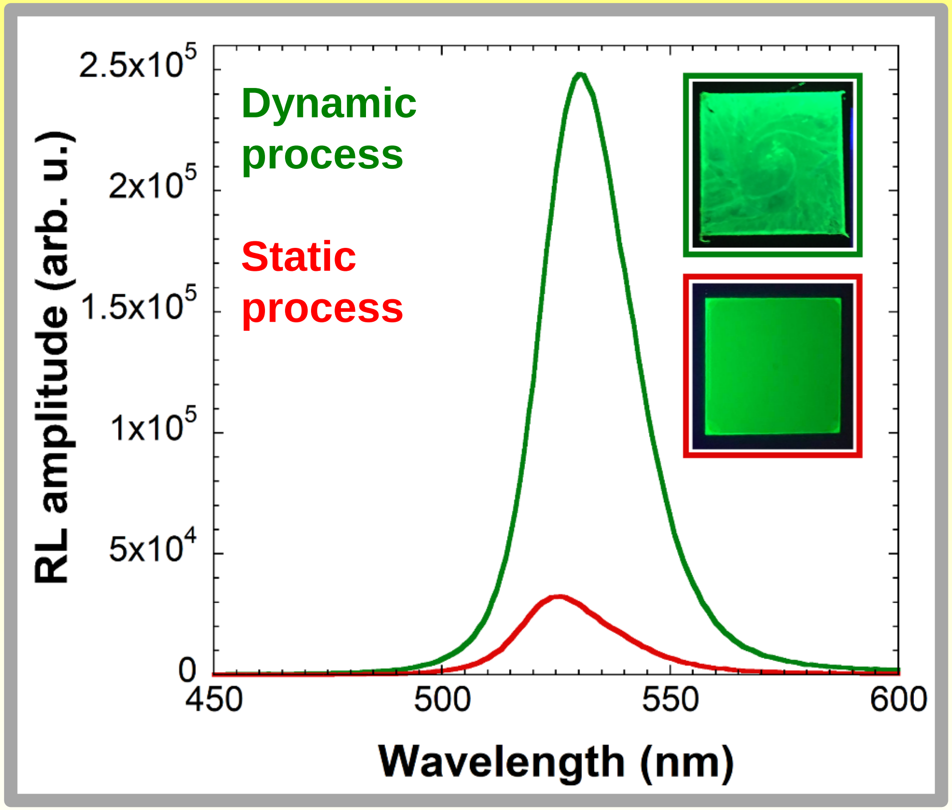
Quantitative comparison of RL not appropriate

Radioluminescence of $CsPbBr_3$ thin films

GGAG:Ce wafer



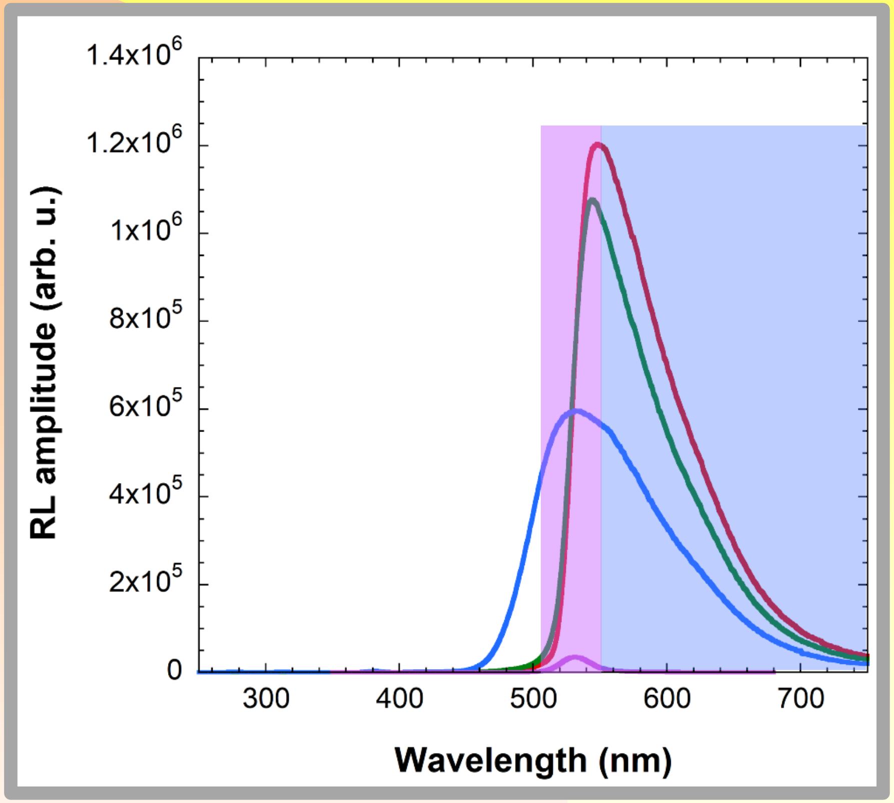
glass wafer

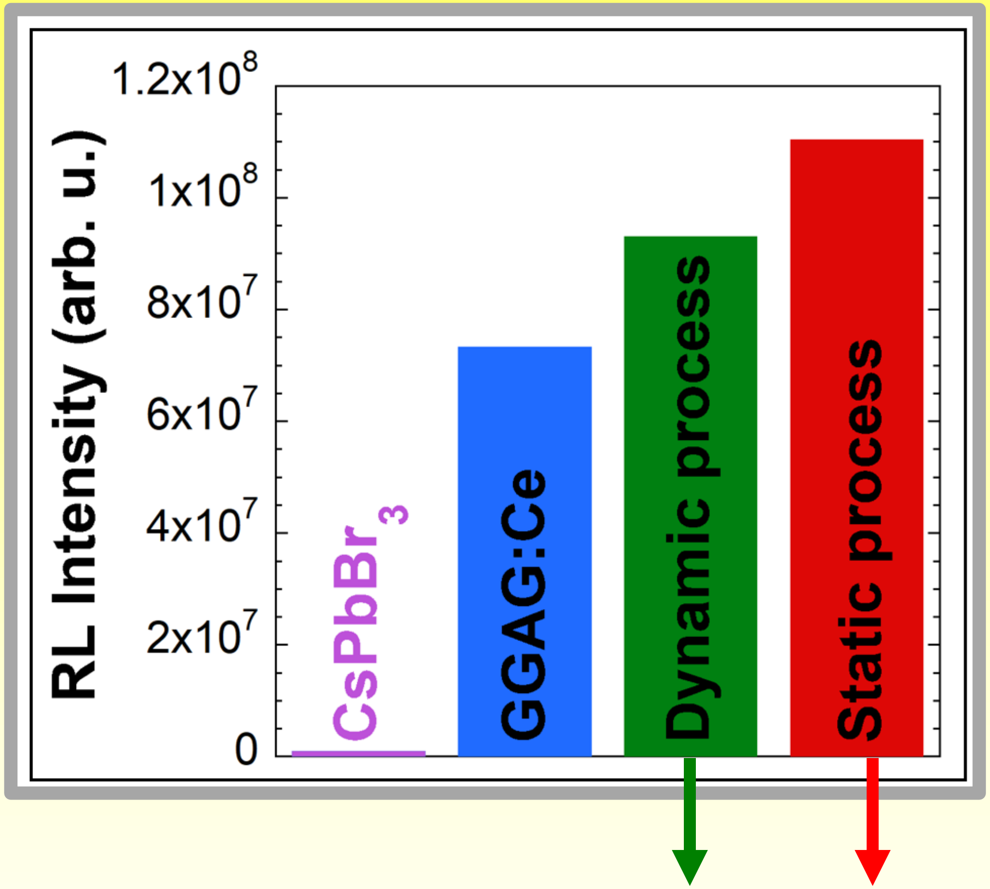


Not too different RL intensity of thin films prepared by different methods
static process results in **higher RL**

Homogeneity of the film not too significant in the RL intensity of nanocomposite ?

Radioluminescence of $CsPbBr_3$ thin films





Overall RL intensity of nanocomposite $CsPbBr_3$ on GGAG:Ce is higher than a simple sum of two emissions

Both emissions are enhanced

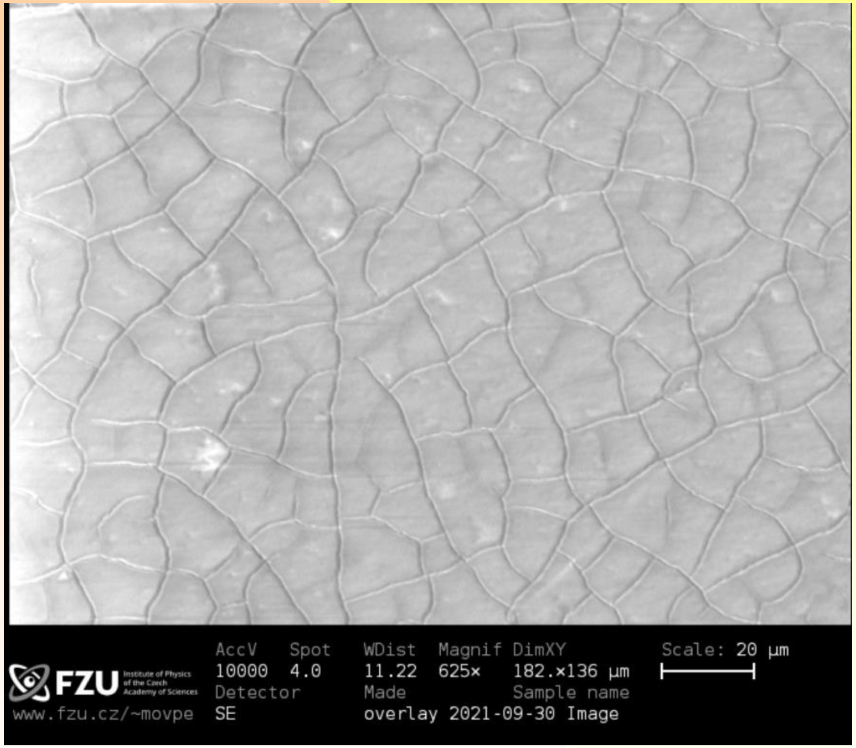
$CsPbBr_3$ probably enhanced by absorption and subsequent reemission of GGAG:Ce light

Enhancement of GGAG:Ce cannot be easily explained

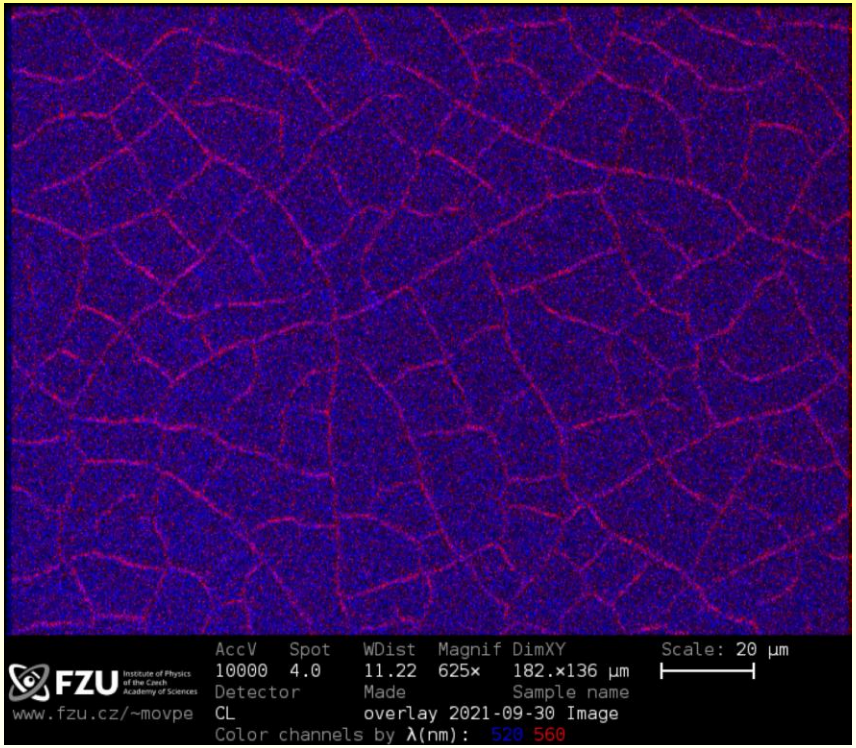
$CsPbBr_3$ thin film on GGAG:Ce

Enhancement of GGAG:Ce emission

SEM image, static method



CL image, static method



Thin film has cracks

520 nm light emitted by $CsPbBr_3$

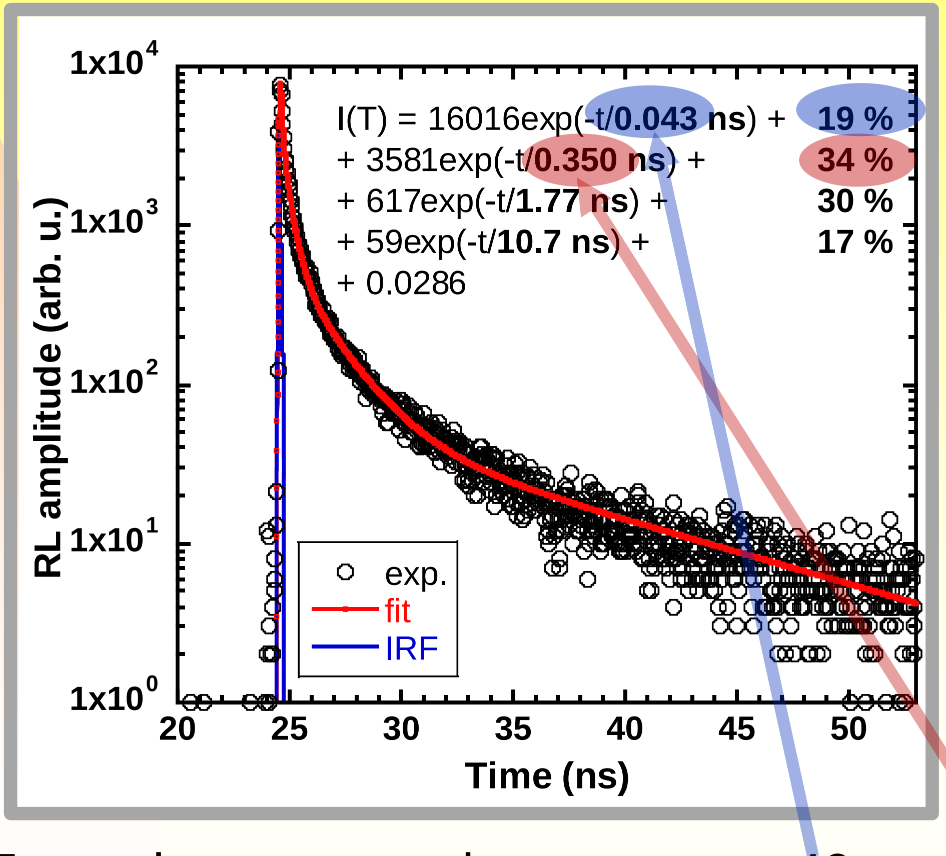
560 nm light emitted by GGAG:Ce

Cracks probably serve as light guide for GGAG:Ce emission

Scintillation decay

$CsPbBr_3$ on glass: static process (50 layers)

Short time window



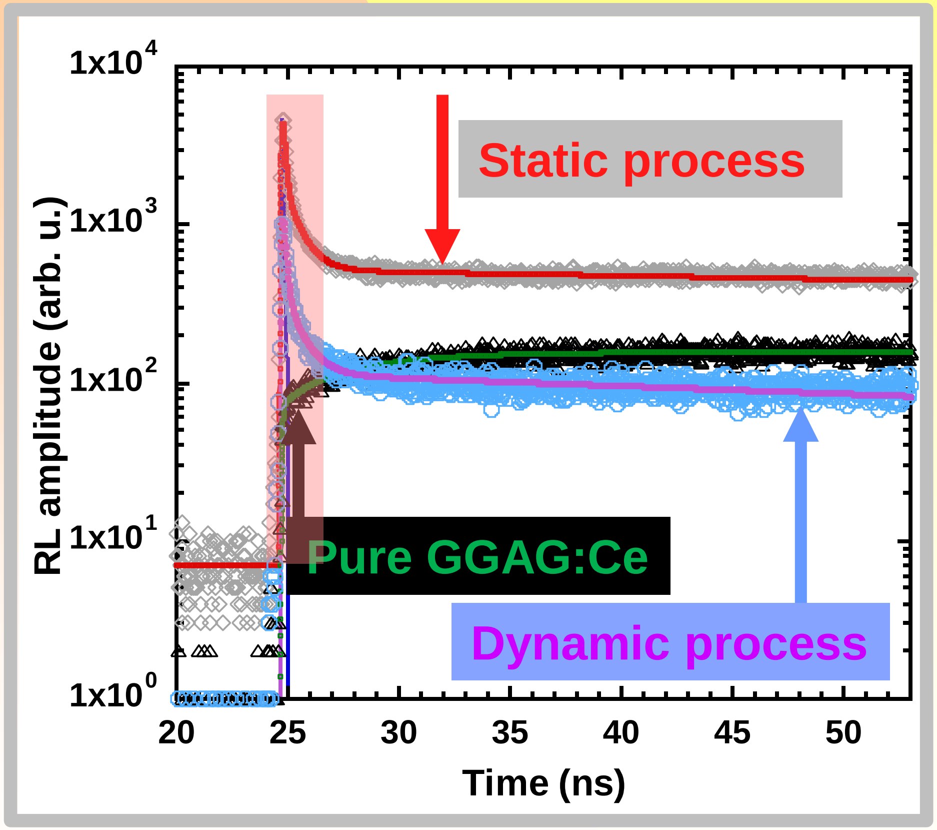
Two subnanosecond components 40 ps, 350 ps

More than **50% of light** emitted within subnanosecond time gate

Scintillation decay

$CsPbBr_3$ on GGAG:Ce

Short time window

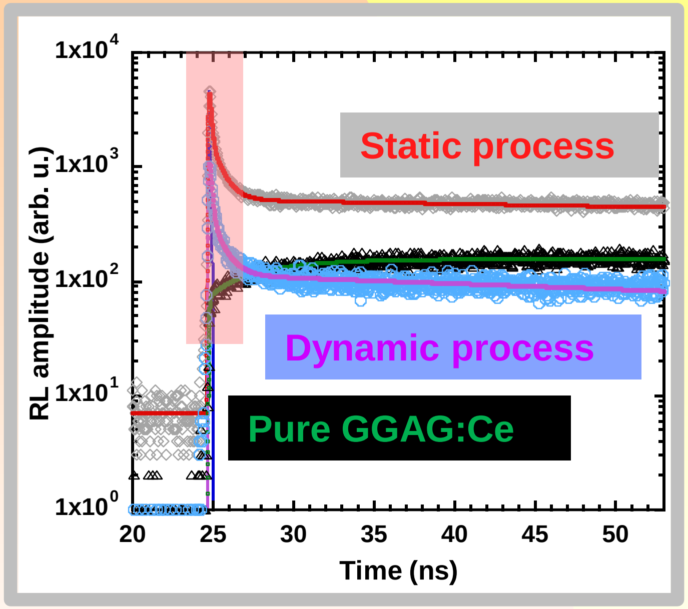


Ultrafast $CsPbBr_3$ emission preserved

Scintillation decay

$CsPbBr_3$ on GGAG:Ce

Short time window



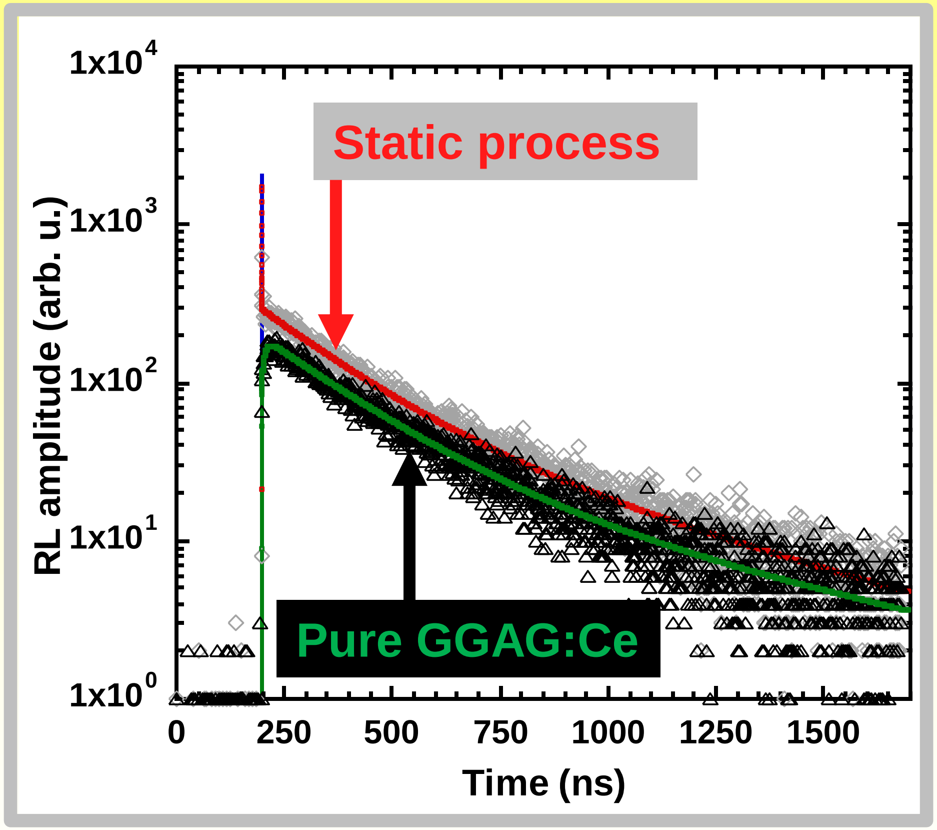
Sample	Rise time	Decay time	Light sum
GGAG:Ce	8 ns	200 ns	63 %
		660 ns	37 %
Static process	50 ps	80 ps	1 %
		700 ps	1 %
		long	98 %
Dynamic process	30 ps	120 ps	3 %
		770 ps	2 %
		long	95 %

Ultrafast $CsPbBr_3$ emission preserved

Scintillation decay

$CsPbBr_3$ on GGAG:Ce

Long time window

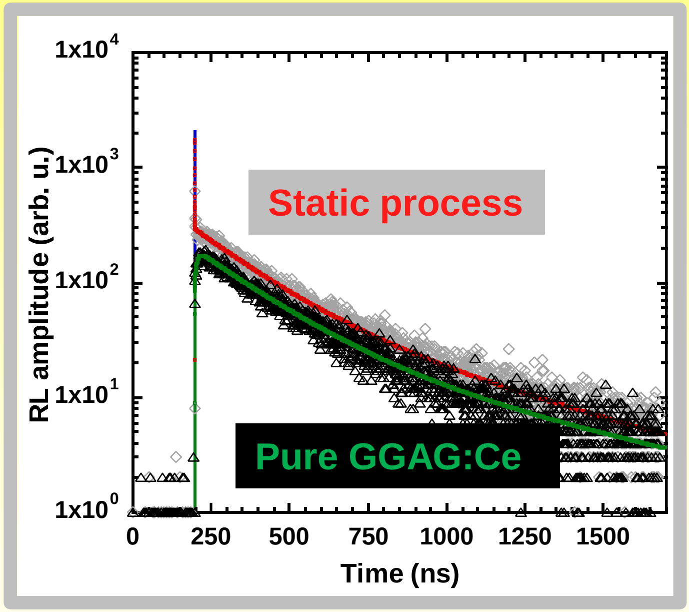


Scintillation decay

$CsPbBr_3$ on GGAG:Ce

Sample	Rise time	Decay time	Light sum
GGAG:Ce	8 ns	200 ns	63 %
		660 ns	37 %
Static process	50 ps	80 ps	1 %
		700 ps	1 %
		long	98 %
Dynamic process	30 ps	120 ps	3 %
		770 ps	2 %
		long	95 %

Long time window

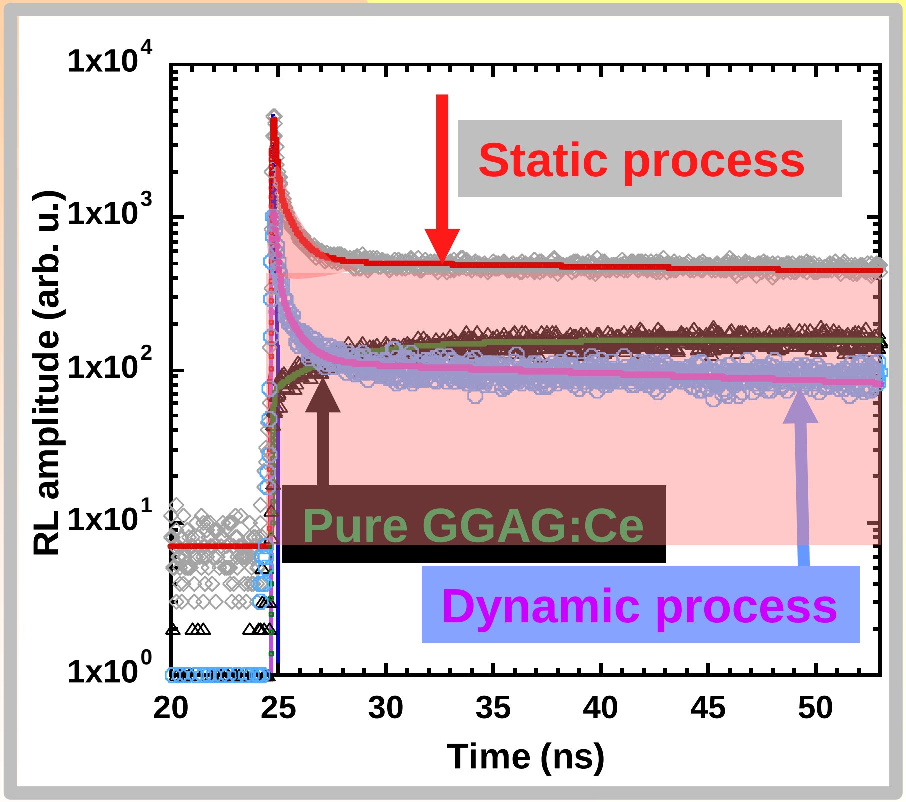


Slow emission of GGAG:Ce preserved

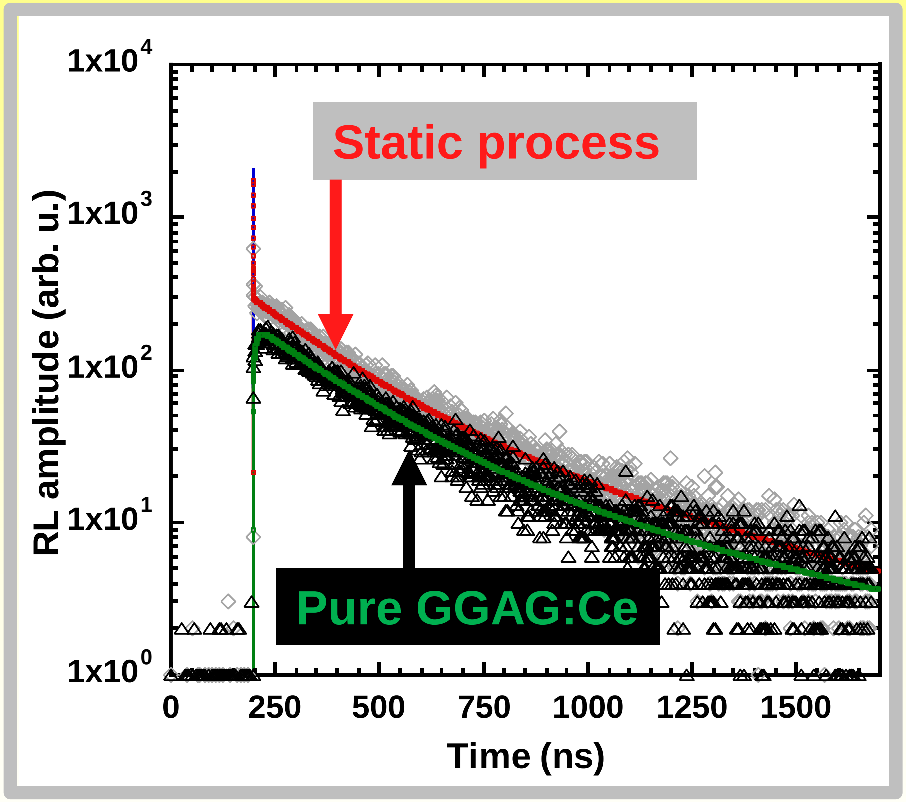
Scintillation decay

$CsPbBr_3$ on GGAG:Ce

Short time window



Long time window



Ultrafast $CsPBBr_3$ emission preserved

Slow emission of GGAG:Ce preserved

Static process results in higher overall RL intensity

Some level of the film homogeneity needed for light guiding effect

Summary

- We prepared $CsPbBr_3$ thin films on glass and GGAG:Ce scintillating wafer
- We compare two methods for the film preparation: Dynamic process is more effective in terms of material consumption, the static process yields much more homogeneous films
- Homogeneity of the film is important since the static films exhibited higher intensity in both the RL spectra and decays
- Synergic effect by combining $CsPbBr_3$ nanoscintillator with the bulk GGAG:Ce scintillator – resulting nanocomposite exhibited enhanced RL intensity while preserving ultrafast $CsPbBr_3$ decay
- Thin nanocomposite layer is able to perform as efficient time tagger in a sampling detector geometry

K. Děcká et al. K., Nanomaterials **12**, 14 (2021)

Thanks are expressed to all collaborators

and to

the audience for kind attention

Acknowledgements

- Czech Science Foundation, Grant No. GA20-06374S
- Ministry of Education Youth and Sports, project “Center for advanced applied science,” No. CZ.02.1.01/0.0/0.0/16_019/0000778
- Grant Agency of the Czech Technical University in Prague, Grant No. SGS20/185/OHK4/3T/14