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Nanoengineered $Gd_3Al_2Ga_3O_{12}$ scintillation materials with disordered garnet structure for novel detectors of ionizing radiation

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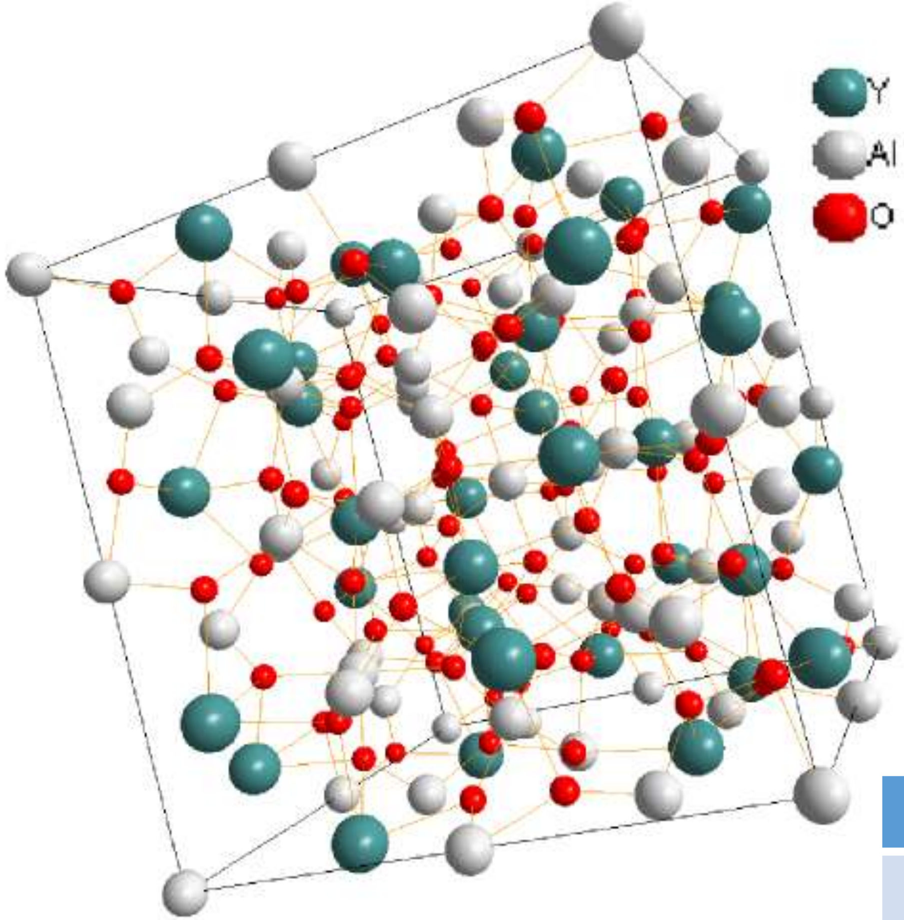
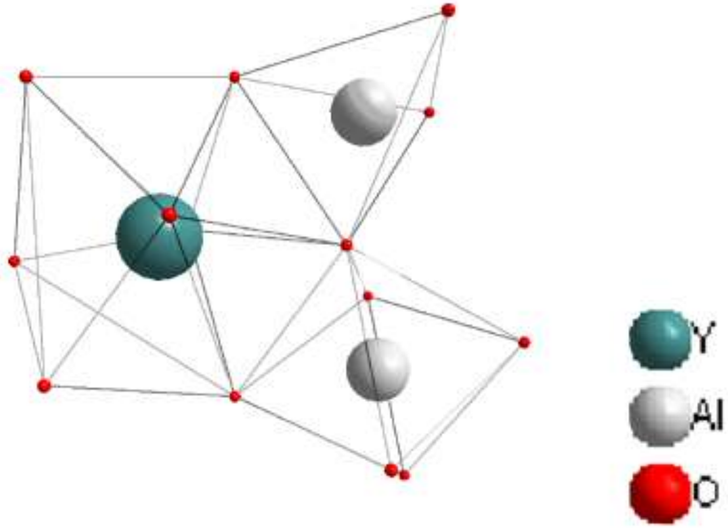
Main requirements to scintillators

- high stopping power
- high scintillation yield
- high energy resolution
- minimal level of afterglow
- multifunctionality

Garnet structure and its possibilities





Y = Lu, Gd, Ca, Mg,
Li, Zr, Hf .....

Al = Ga, Sc, In, Si,
Ge, Fe, Cr, Mg.....

C.N.	8	6	4
Y	1.019	0,9	-
Gd	1.053	0.938	-
Al	-	0.535	0.39
Ga	-	0,62	0.47

n + ^{155}Gd → ^{156}Gd + γ (8.5 MeV)
n + ^{157}Gd → ^{158}Gd + γ (7.9 MeV).
cross section of the neutron capture:
^{155}Gd - 61000 barn, ^{157}Gd 254,000 barn

Mixed Garnets scintillators properties

Material	Density, g/cm3	LY	Emission	Decay
Gd3Al3Ga2O12 :Ce		46000		~80 ns
Y3Al5O12:Ce (YAG)	4.6	16000	550	100
YGd2Ga3Al2O12:Ce		44000		50(90%); 120 (10%)

Enchance the ability for recombination of geminate pairs due to the local micro-nonuniformity related with modification of local structure of mixed garnets;

Diminish the thermo-activation energy of deep traps due to the shift of the bottom of the conduction band leads to covering some shallow traps located below of this band.

Influence of the synthesis approach on afterglow

Synthesis methods	Particle size	Homogeneity	Morphology	Synthesis temperatures (°C)	Afterglow time
Solid-solid reaction	Micrometer-scale	Bad	Bad	>1000	Long
Sol-gel method	Nano to micrometer-scale	Medium	Bad	≤1000	Medium
Combustion method	Nano to micrometer-scale	Medium	Medium	>1000	Short
Hydrothermal method	Nano to micrometer-scale	Good	Medium	<1000	Short
Co-precipitation	Nano to micrometer-scale	Good	Medium	>1000	Short
Template method	Nano to micrometer-scale	Good	Good	<1000	Short
Electrospinning	Nano to micrometer-scale	Medium	Medium	>1000	Short
Laser technique	Nano to micrometer-scale	Medium	Medium	none	Medium
Electron beam irradiation	Nano to micrometer-scale	Medium	Medium	none	Medium

- Table gives a comparison of synthesis methods in terms of particle size, required temperature, homogeneity, morphology, and afterglow time.

The development of approach for suppression of afterglow in GGAG crystals is crutial task!

We used 2 approaches:
Co precipitation (CP)
and
Solid-state (SSS)

Sample	Raw material	Co-doping
SSR1	SSS	-
SSR2	SSS	Mg, 10ppm
SSR3	SSS	Mg, 50ppm
CP1	CP	-
CP2	CP	Mg, 50ppm

JSM-7800F Schottky FE-SEM

Extreme-high resolution imaging and full analytical capabilities

Specifications:

Mag: 25 to 1,000,000X
kV: 10V to 30kV
SEI: 1.0 nm (15kV)
0.8 nm (15kV, GB)
1.5 nm (1kV)
1.2 nm (1kV, GB)
3.0 nm (0.1kV, GB)
BEI: 1.5 nm (3kV)
STEM: 0.8 nm (30kV), 0.6 nm attainable
Analytical: 3.0 nm (15kV, 5nA, WD=10mm)

Standard features:

Through the lens detector with energy filter
In-chamber E/T SE detector
Aperture angle control lens (ACL)
Easy to use, remote-enabled GUI

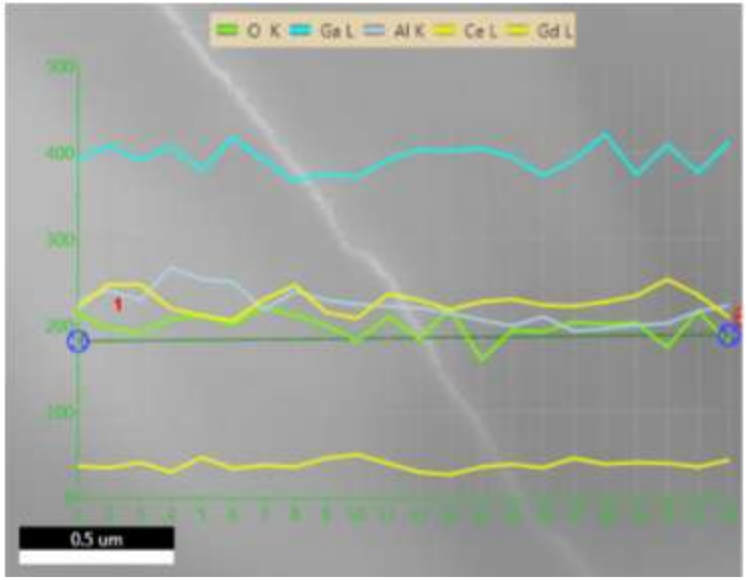
Optional items:

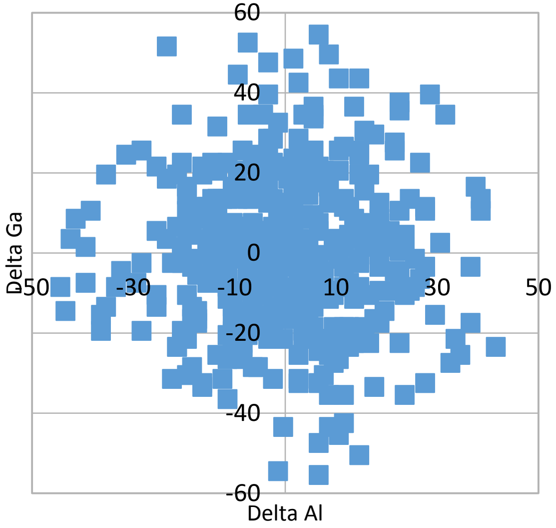
Short WD retractable BE detector
LV attachment (up to 300 Pa), LV BSE, LV SE
GBSH – GB up to 5kV

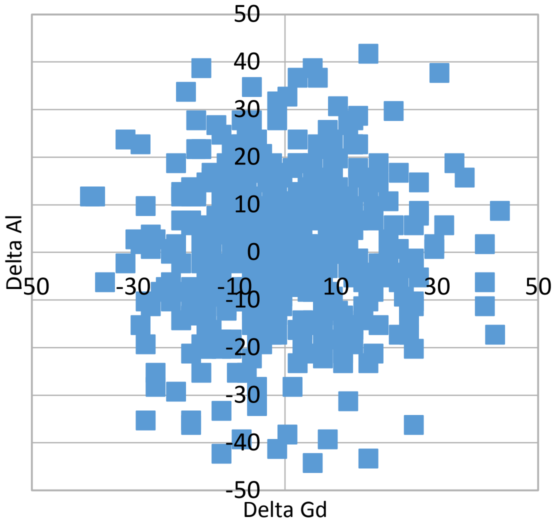
Typical accessories:

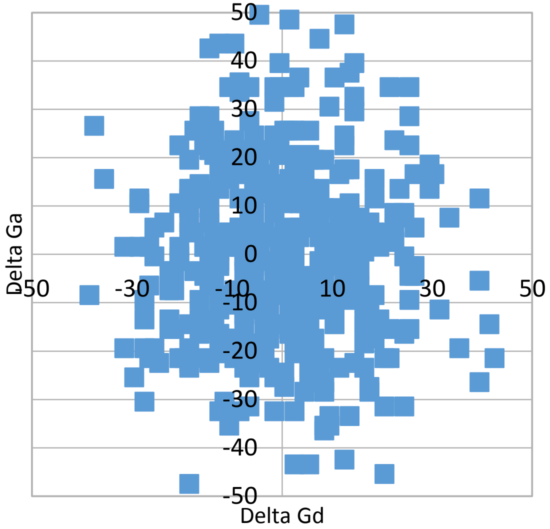
EDS, WDS, CL, EBSD, STEM, PCD

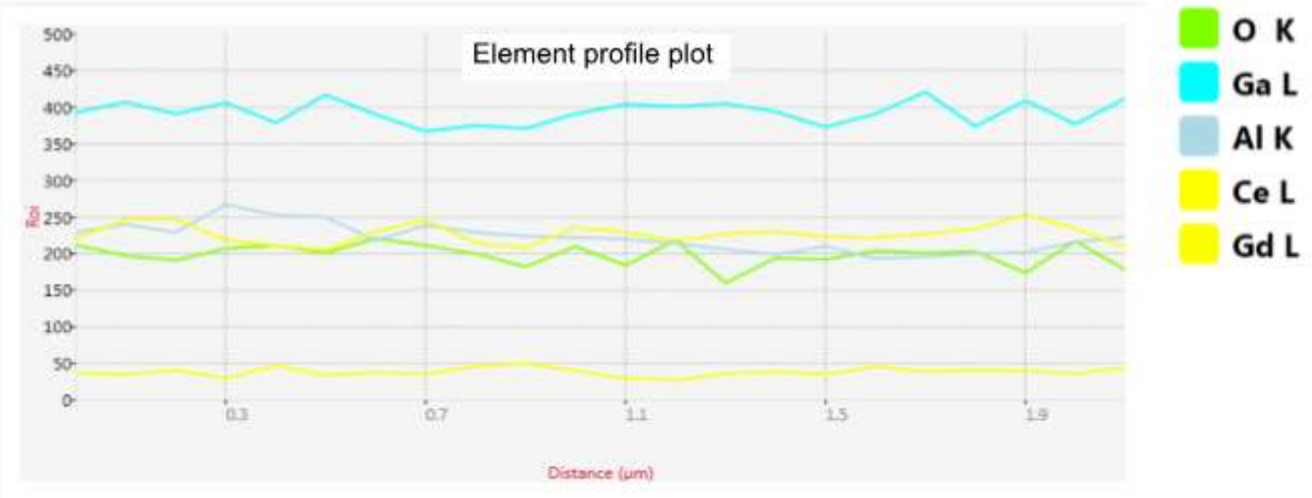
Line Scan – Magnification 25000X



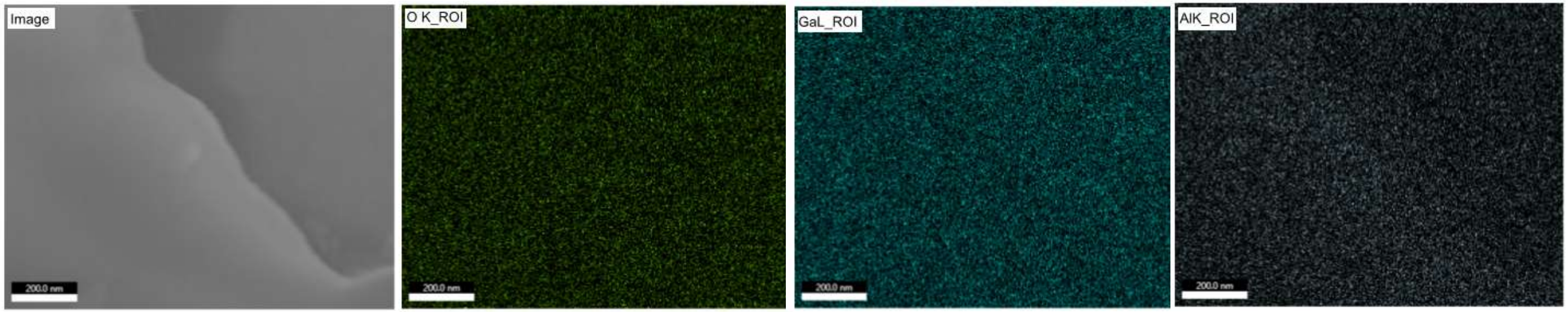


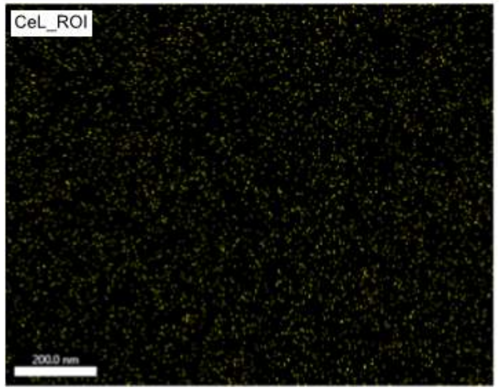


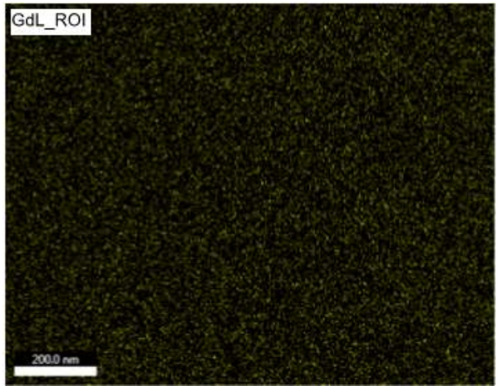




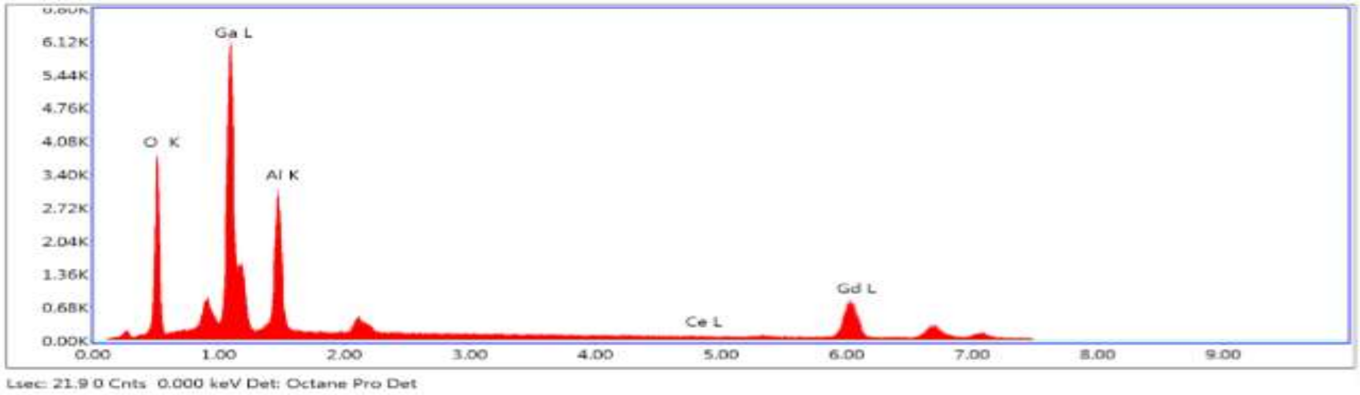
Mapping - Magnification 50000 X



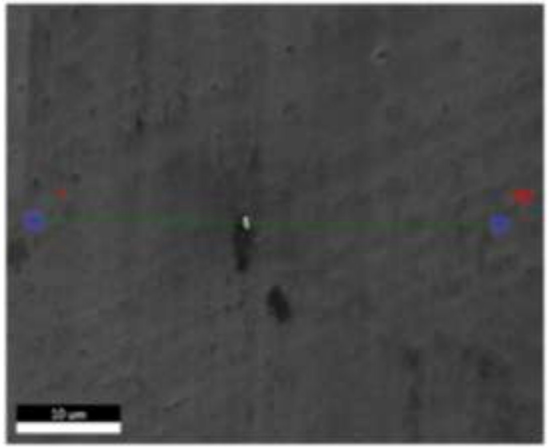


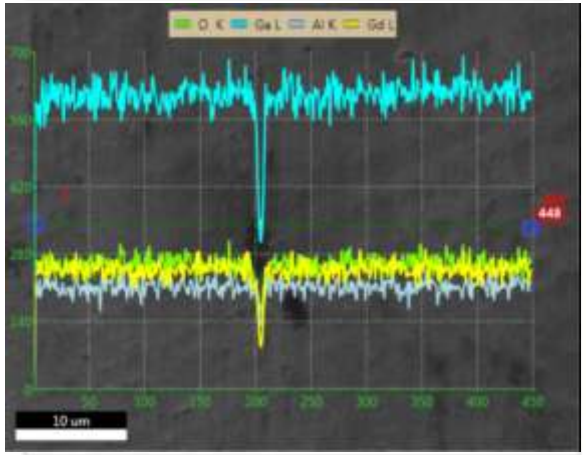


Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
GaL	26.65	14.82	2705.2	7.90	0.26	0.94	1.02	0.93	1.00
AlK	11.07	15.90	1704.1	2.51	0.06	1.17	0.90	0.42	1.00
CeL	0.83	0.23	32.1	35.67	0.01	0.79	1.13	1.03	1.07
GdL	36.69	9.05	930.8	4.40	0.33	0.75	1.12	1.03	1.05
Oxygen	24.76	60.00	0	0.00	0.00	0.00	0.00	0.00	0.00

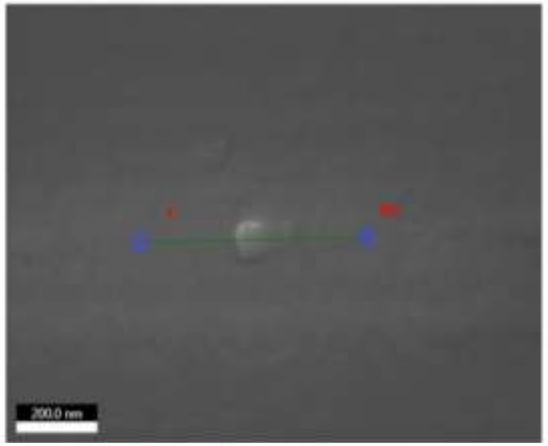


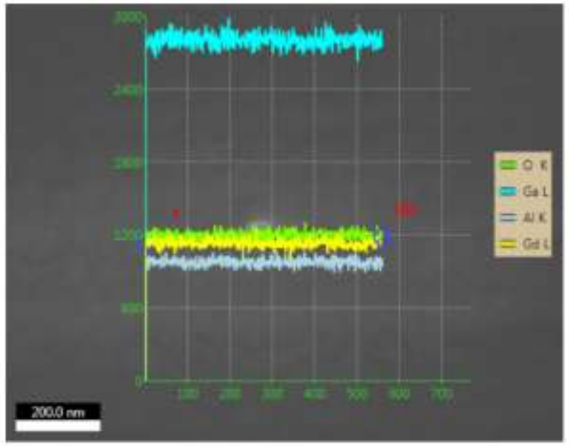
Line Scan analysis





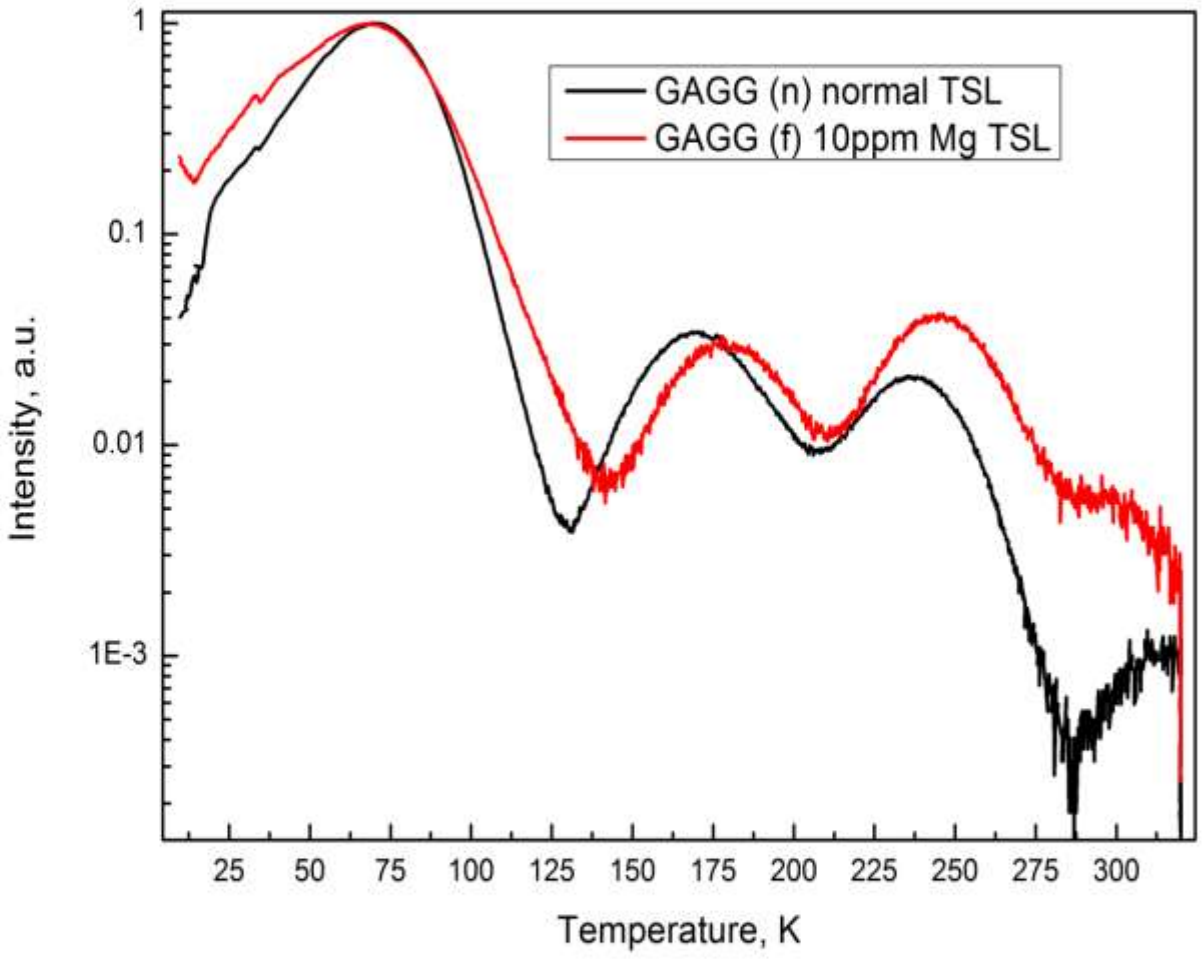
Element	Weight %	Atomic %	Net. Inten.	Error %	K-ratio
O K	15.9	51.3	843.9	7.6	7.60246
GaL	25.7	19.1	1300.3	1.9	1.9112
AlK	6.6	12.6	435.3	8.2	8.20768
GdL	51.8	17	629.6	3.8	3.76808

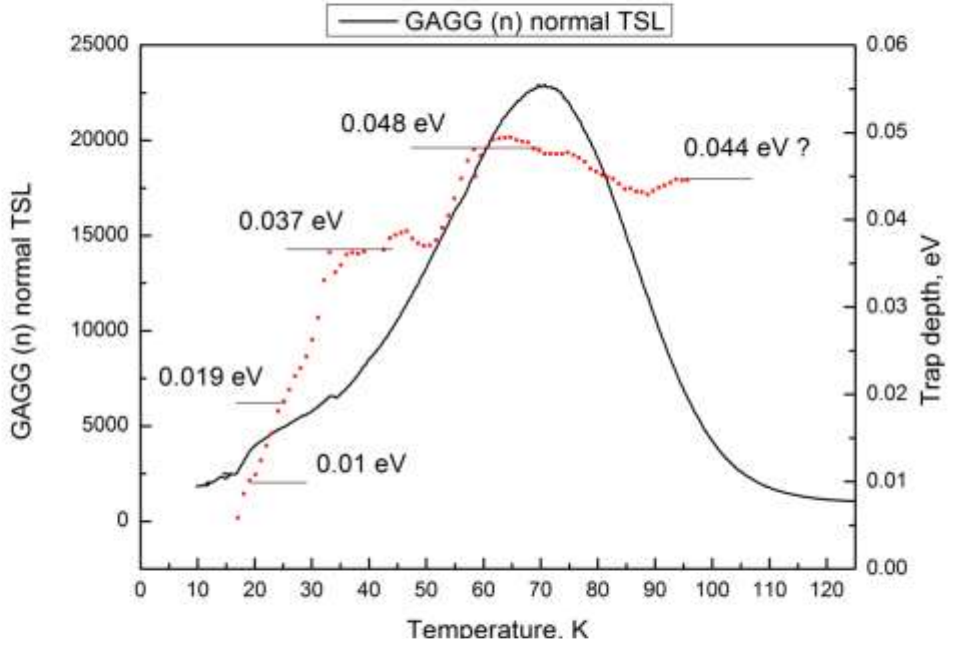


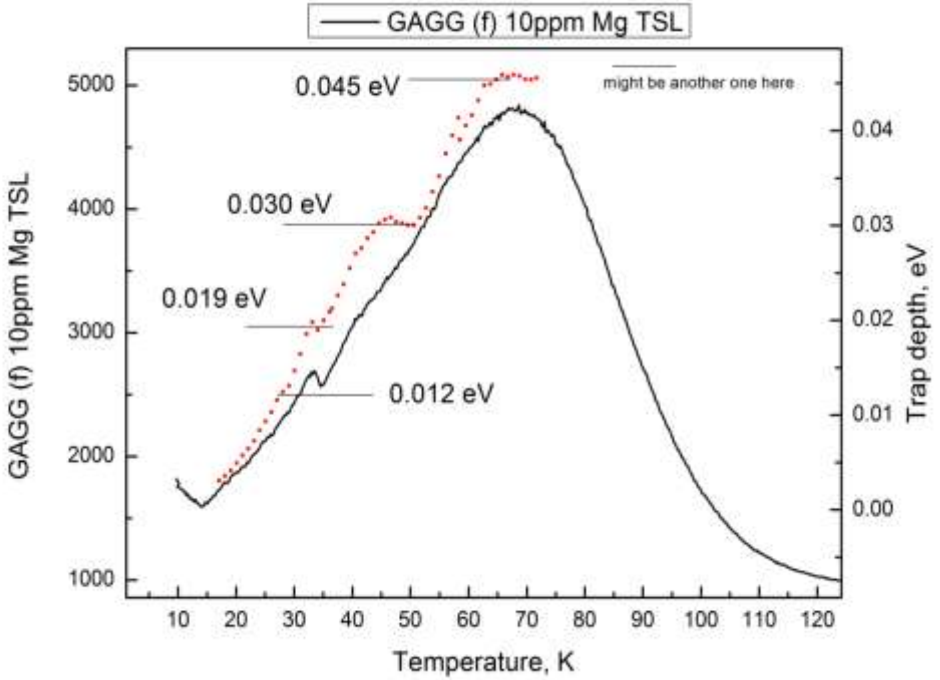


Element	Weight %	Atomic %	Net. Inten.	Error %	K-ratio
O K	16.1	51.4	662.5	7.4	7.42228
GaL	26.1	19.1	1020.2	1.7	1.74292
AlK	6.8	13	351.7	7.8	7.76984
GdL	50.9	16.5	477.8	2.9	2.92237

TSL measurements for SSR samples

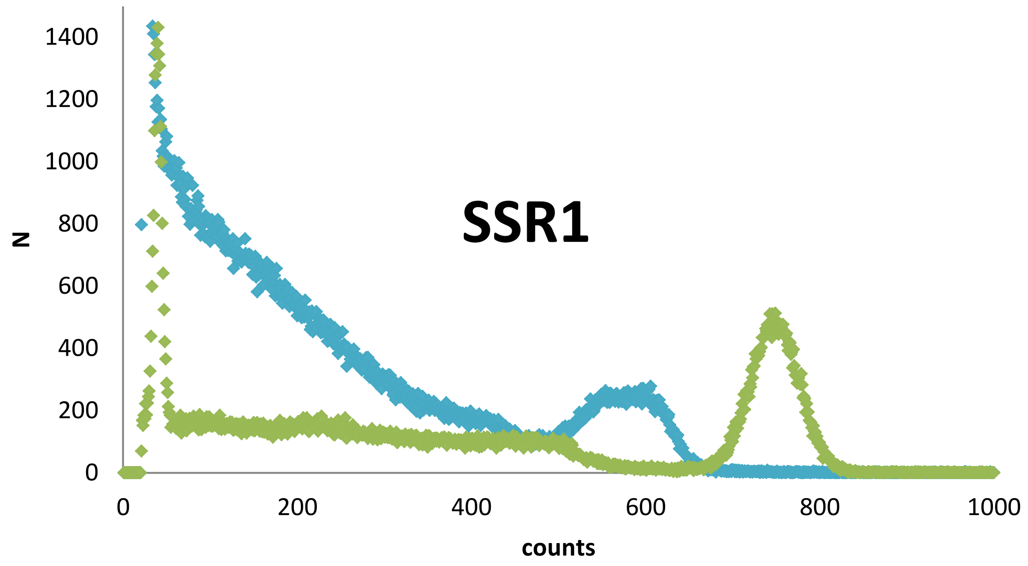


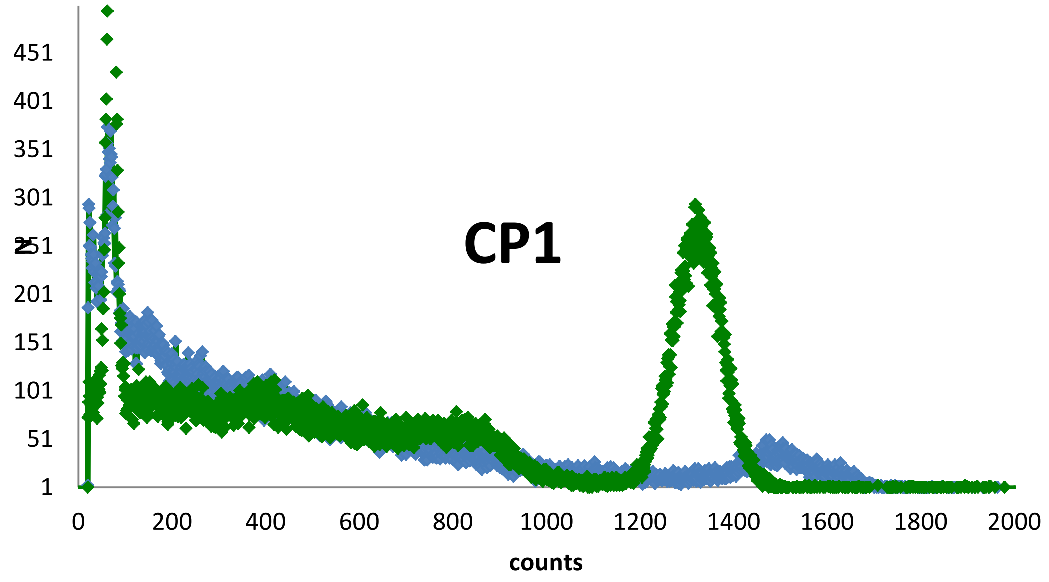




Co-doped sample shows TSL intensity at 5 times less

LY measurements





Sample	Raw material	Co-doping	LY
SSR1	SSS	-	42000
SSR2	SSS	Mg, 10ppm	41000
SSR3	SSS	Mg, 50ppm	32000
CP1	CP	-	59000
CP2	CP	Mg, 50ppm	44000

Conclusions

CP samples show higher LY values that most probably related with lower concentration of intrinsic defects due to the lesser Ga evaporation at crystals growth in comparison with SSR samples;

The possibility of using linear EDX scanning for investigation samples inhomogeneity is shown;

The technology for co-doped samples should be improved for increase the LY;

Co-doping decrease TSL intensity only and does not impact on the traps distribution.