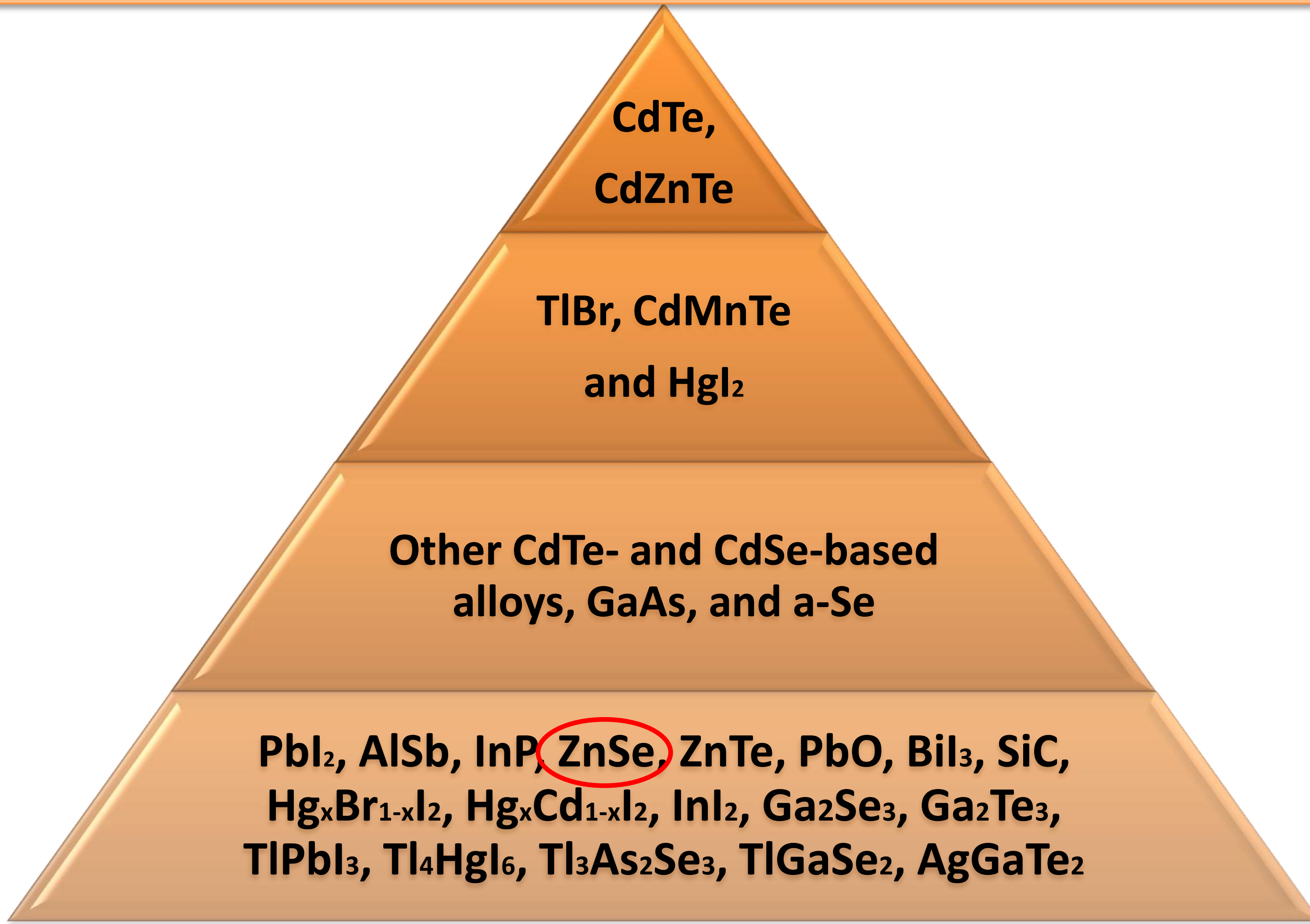
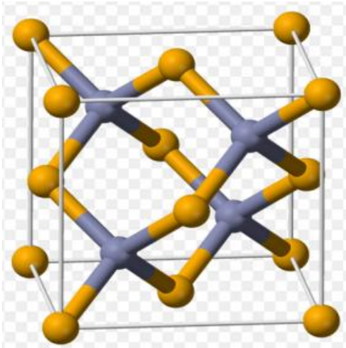
ZnSe crystal as a semiconductor detector

Reporter: Vladyslav Litichevskyi

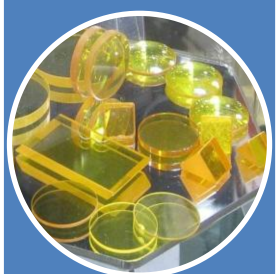
LNGS-2015, April

Interest in wide band gap semiconductor detector materials has been sustained for over three decades.



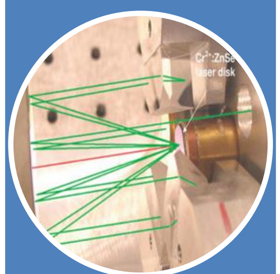


Zinc selenide (ZnSe) is an intrinsic semiconductor with a band gap of about 2.72 eV at 25 °C

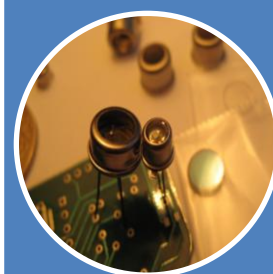


Infrared optical material with a remarkably wide transmission wavelength range (0.45 µm to 21.5 µm)

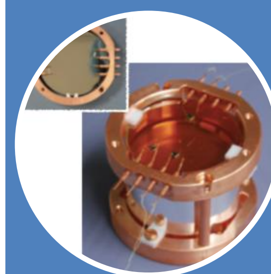
Scintillation material for X-Ray and gamma ray detectors



Light-emitting diodes and diode lasers



Material for UV detectors



Material for scintillation bolometers

Material for semiconductors detector

1994

Conf-941061--10

BNL-61058

Properties of Melt-Grown ZnSe Solid-State Radiation Detectors

E.E. Eissler*, K.G. Lynn**
* eV PRODUCTS, div. of II-VI Incorporated, 375 Saxonburg Blvd., Saxonburg, PA 16056
** Brookhaven National Laboratory[1], Department of Physics, Upton, NY 11973

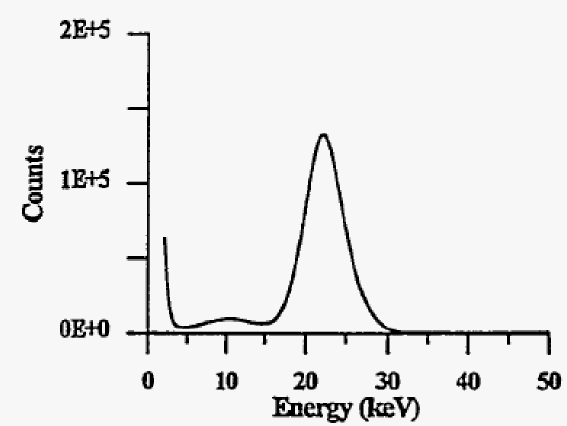
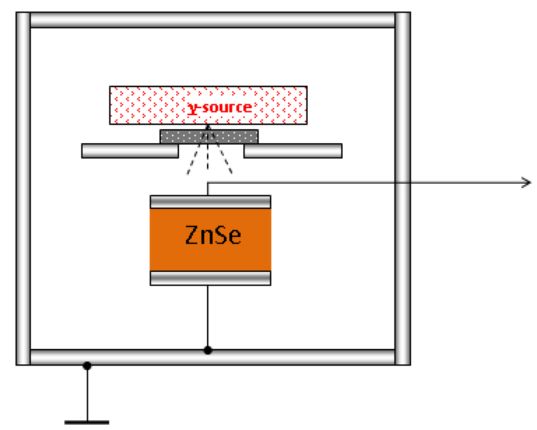


Fig. 6 Spectrum of device with 25% resolution at 22.1 keV. Bias = 2000V, shaping time = 1.5 usec, T = 25°C

25% @ 22 keV



ZnSe crystal <111> oriented

10×10×2 mm^3

Au-ZnSe-Au

9000 V/cm

2010-2014

11th European Conference on Non-Destructive Testing (ECNDT 2014), October 6-10, 2014, Prague, Czech Republic

Evaluation of monocrystalline ZnSe as a high-temperature radiation detector

Andrii SOFIIENKO [1], Volodymyr DEGODA [2], David M. PONCE-MARQUEZ [3], Geir A. JOHANSEN [4]

Science and Innovation. 2014. V. 10. No. 2. P. 45—49

Brodyn[1], M.S., Vesna[1], V.T., Degoda[1], V.Ya., Zaitsevskiy[2], I.L., and Kozhushko[1], B.V.

[1] Institute of Physics of NAS of Ukraine, Kyiv
[2] Institute for Problems of Safety of Nuclear Power Plants of NAS of Ukraine, Kyiv

DUAL-ENERGY SEMICONDUCTOR DETECTOR OF X-RAYS AND GAMMA RADIATION

ISSN 2071-0194. Ukr. J. Phys. 2012. Vol. 57, No. 9

ANOMALOUS CONDUCTIVITY IN ZnSe SINGLE CRYSTALS BY X-RAY IRRADIATION

V.YA. DEGODA,[1] V.T. VESNA,[1] B.V. KOZHUSHKO,[2] G.P. PODUST[1]

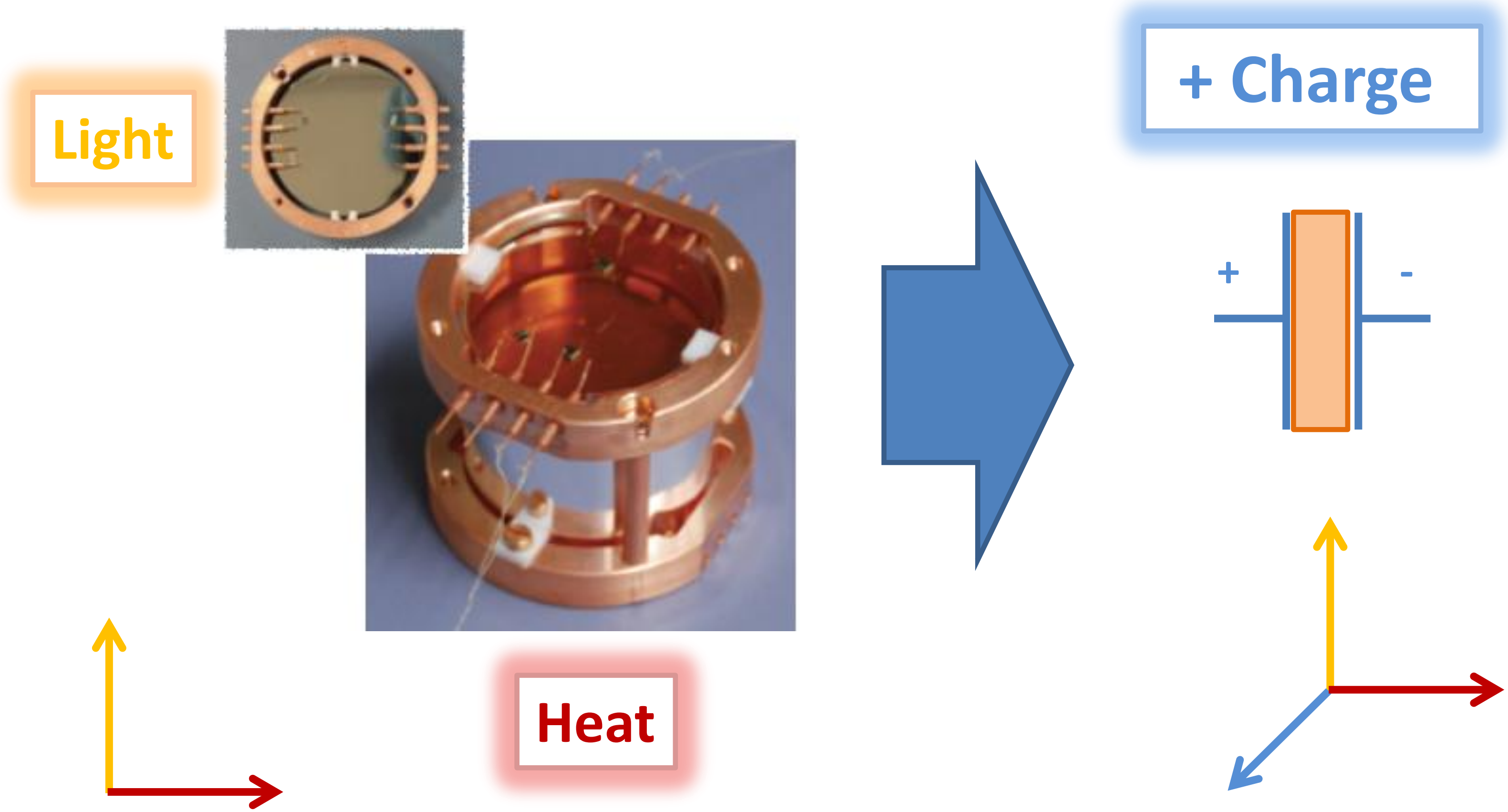
Radiation Measurements – under review - Manuscript Number: “*RADMEAS-D-11-00134*”

Research of X-ray induced conductivity of ZnSe sensors for their application in isotopic thickness gauges

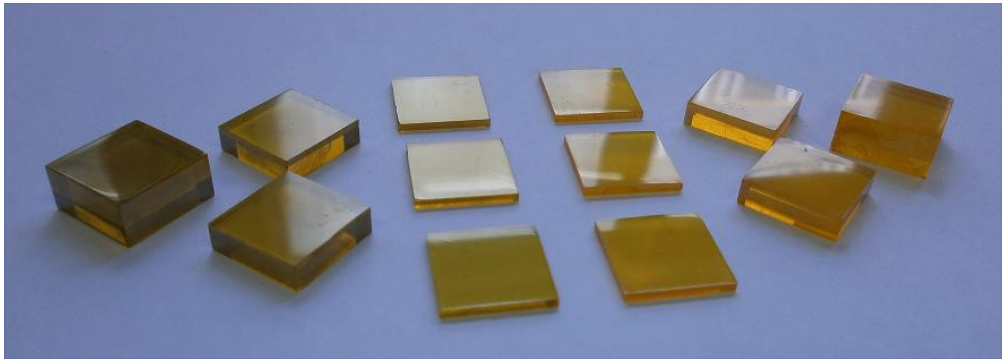
A.O. Sofiienko *, V.Ya. Degoda **

V Ya Degoda, A O Sofiienko, ‘Specific Features of the Luminescence and Conductivity of Zinc Selenide on Exposure to X-Ray and Optical Excitation’, Semicond. 44, 5, pp 1-7, 2010.

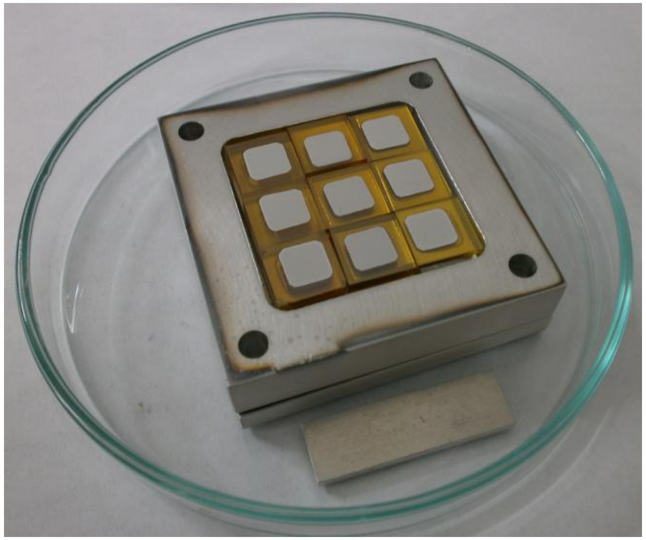
2012
Triple read-out channels with ZnSe scintillating bolometer



ZnSe crystal samples

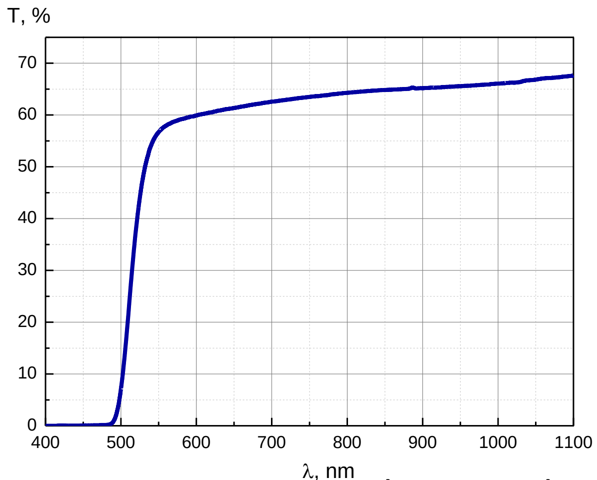


ZnSe "as-grown" crystals
10×10×1, ×3, ×5, ×10 mm^3

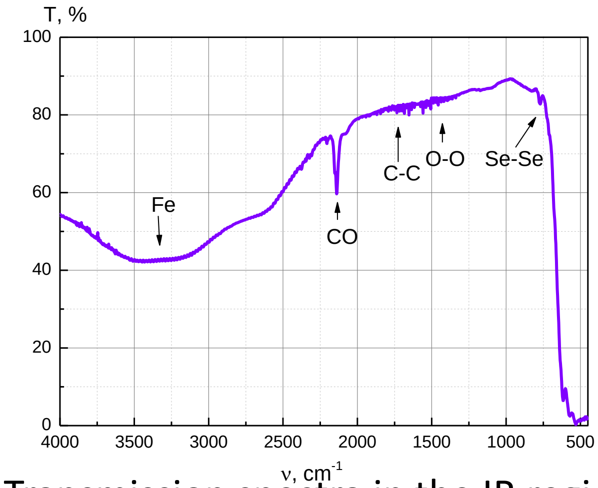


Deposited on both sides
In/Ni contacts (7×7 mm^2)

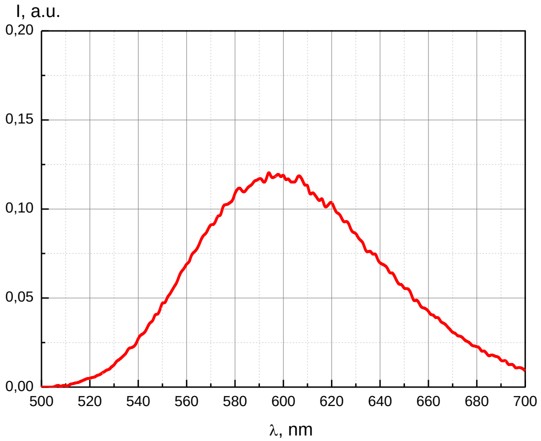
Optical and luminescence characteristics of “as-grown” ZnSe



Transmission spectra in the optical region

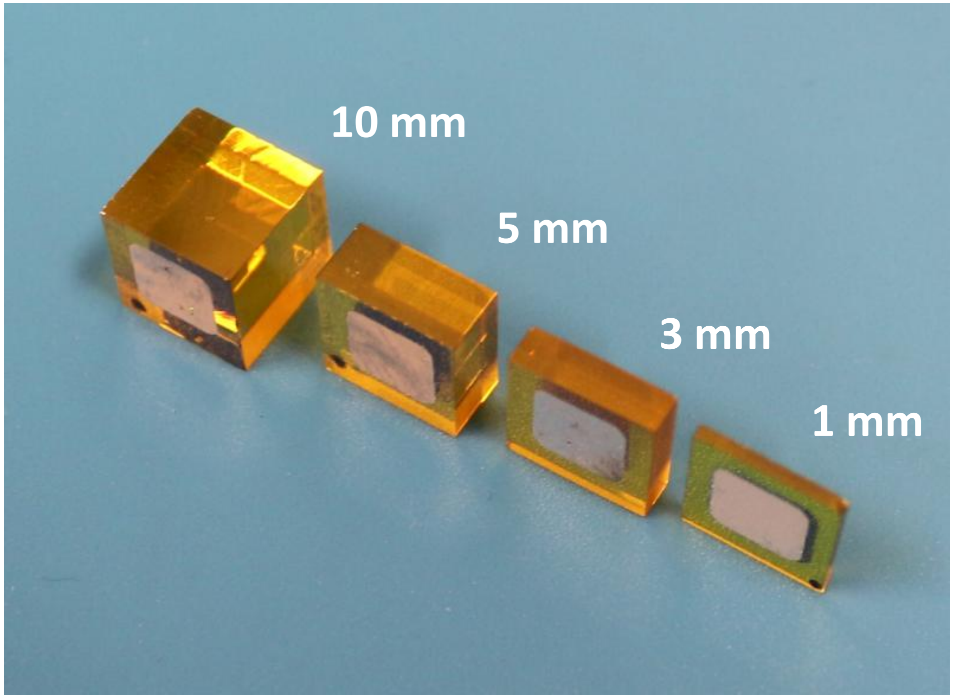


Transmission spectra in the IR region



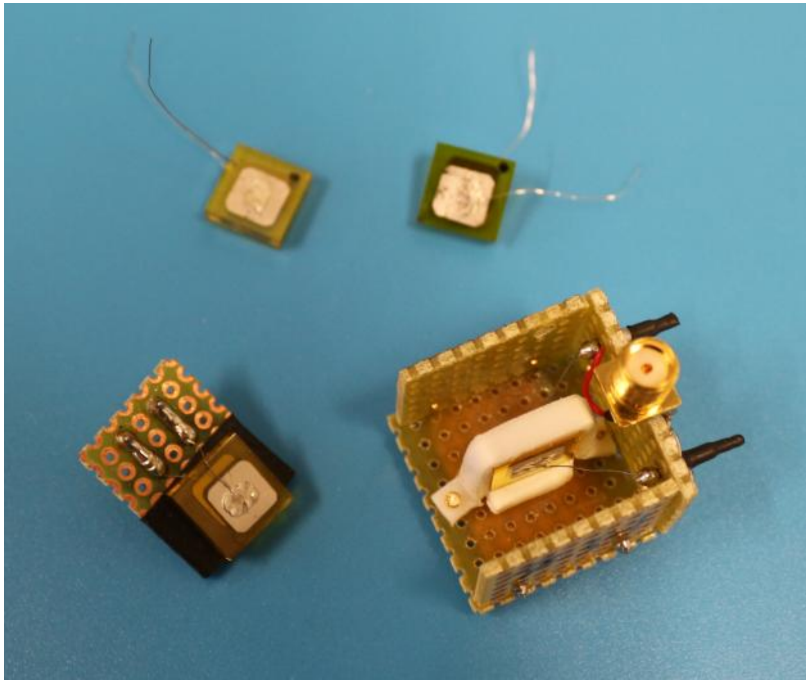
X-Ray luminescence spectra

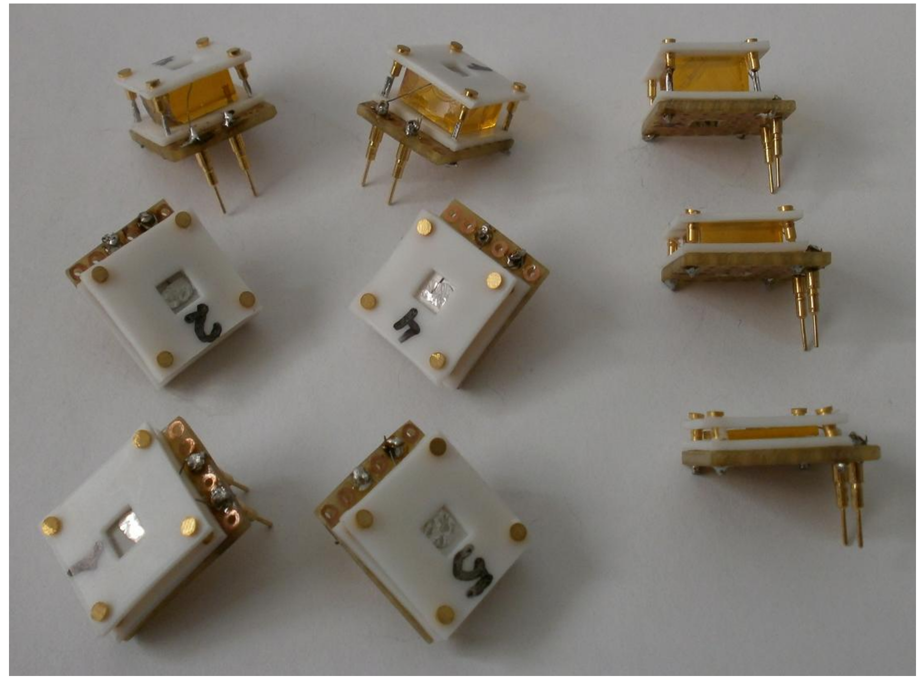
ZnSe crystal samples



with Ohmic contacts	**In-ZnSe-In**
as a Schottky diode in opposite inclusion	**In-ZnSe-Ni**

Prehistoric ZnSe detector design

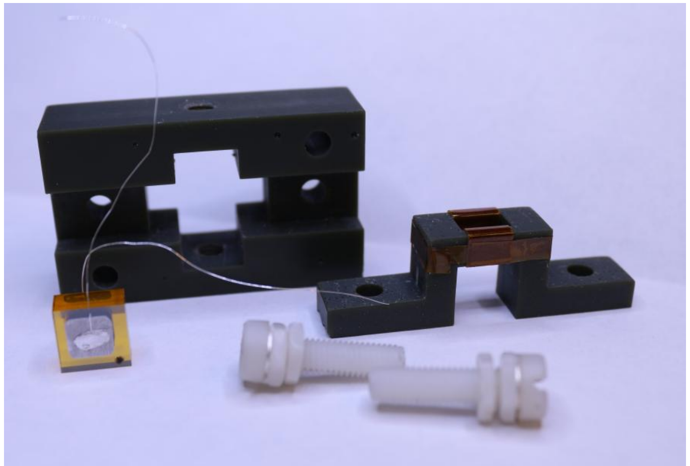


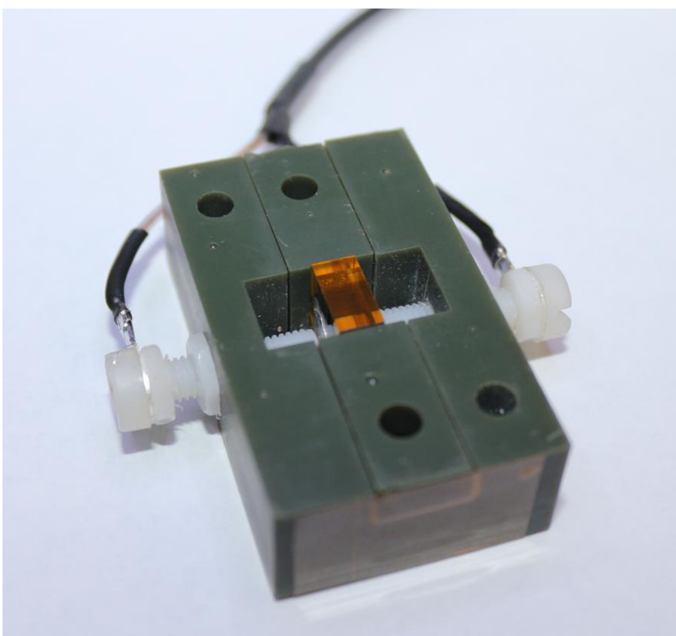


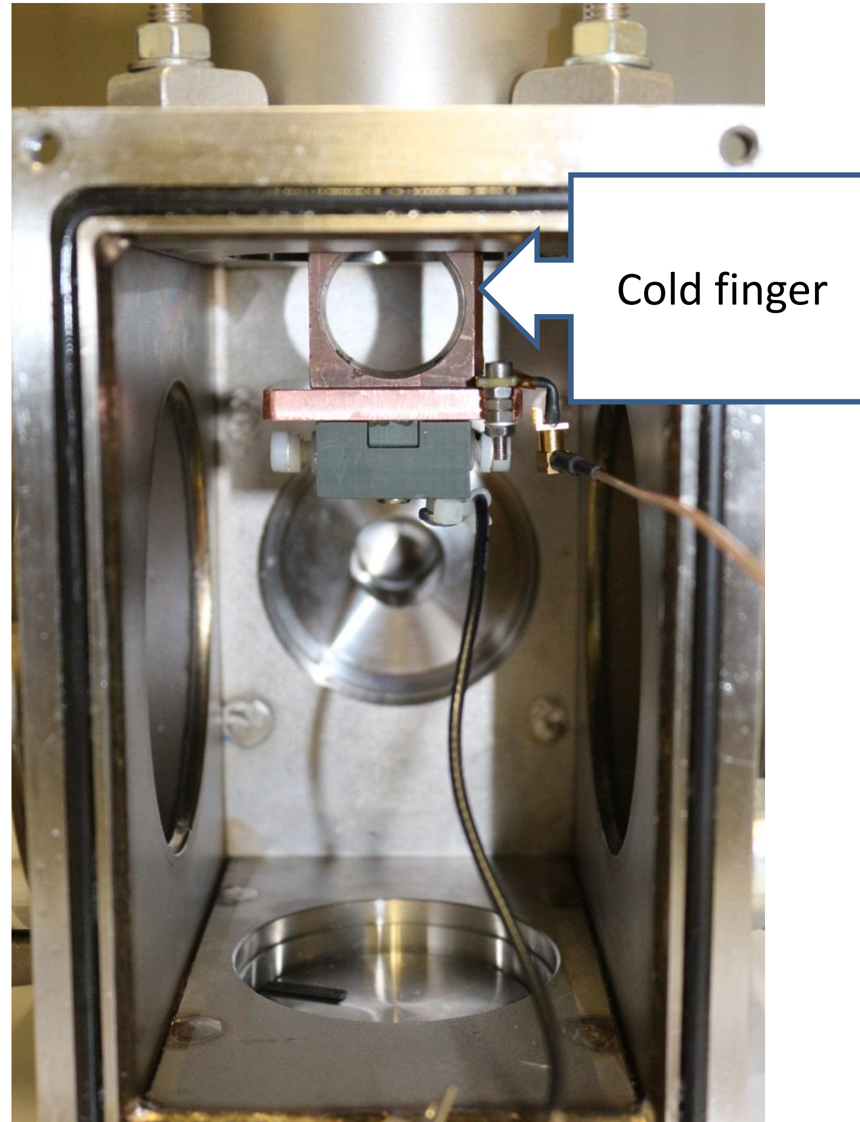
ZnSe detector parameters

Parameter	Value
Approximate amount of charge on the contacts, pC	~ 0.01 – 0.001
Pulse decay time, µs	~ 0.5
Pulse rise time, ns	~ 10-50
Resistivity of the crystal, Ohm	~ 10^{11}
Dark current through the crystal, nAmp	less than 10
Bias voltage, kV	1-3
Capacity of the detector, pF	1-10

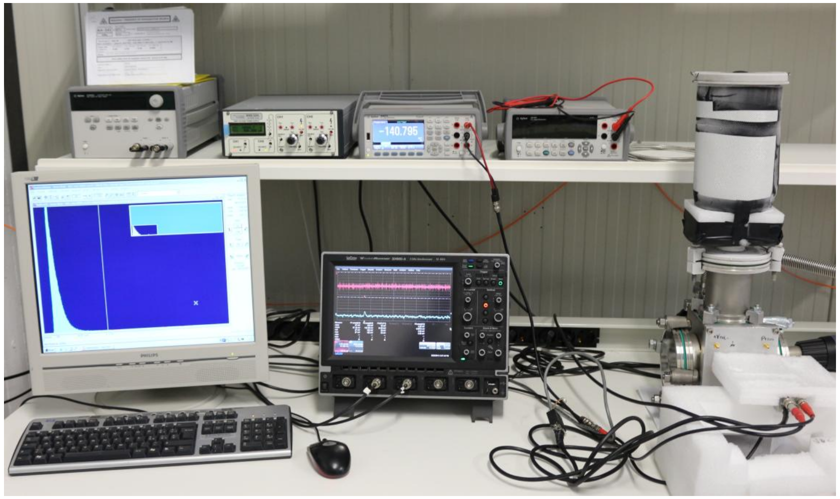
Contemporary ZnSe detector design



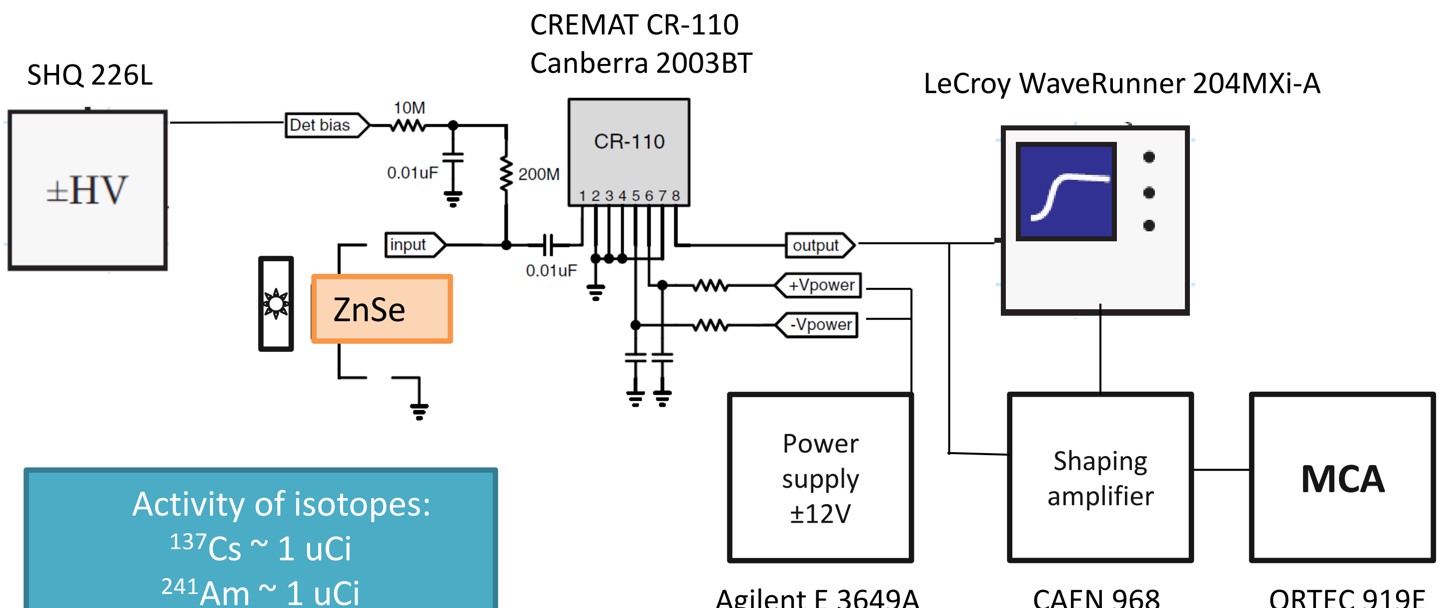




Experimental setup for ZnSe detector characterization

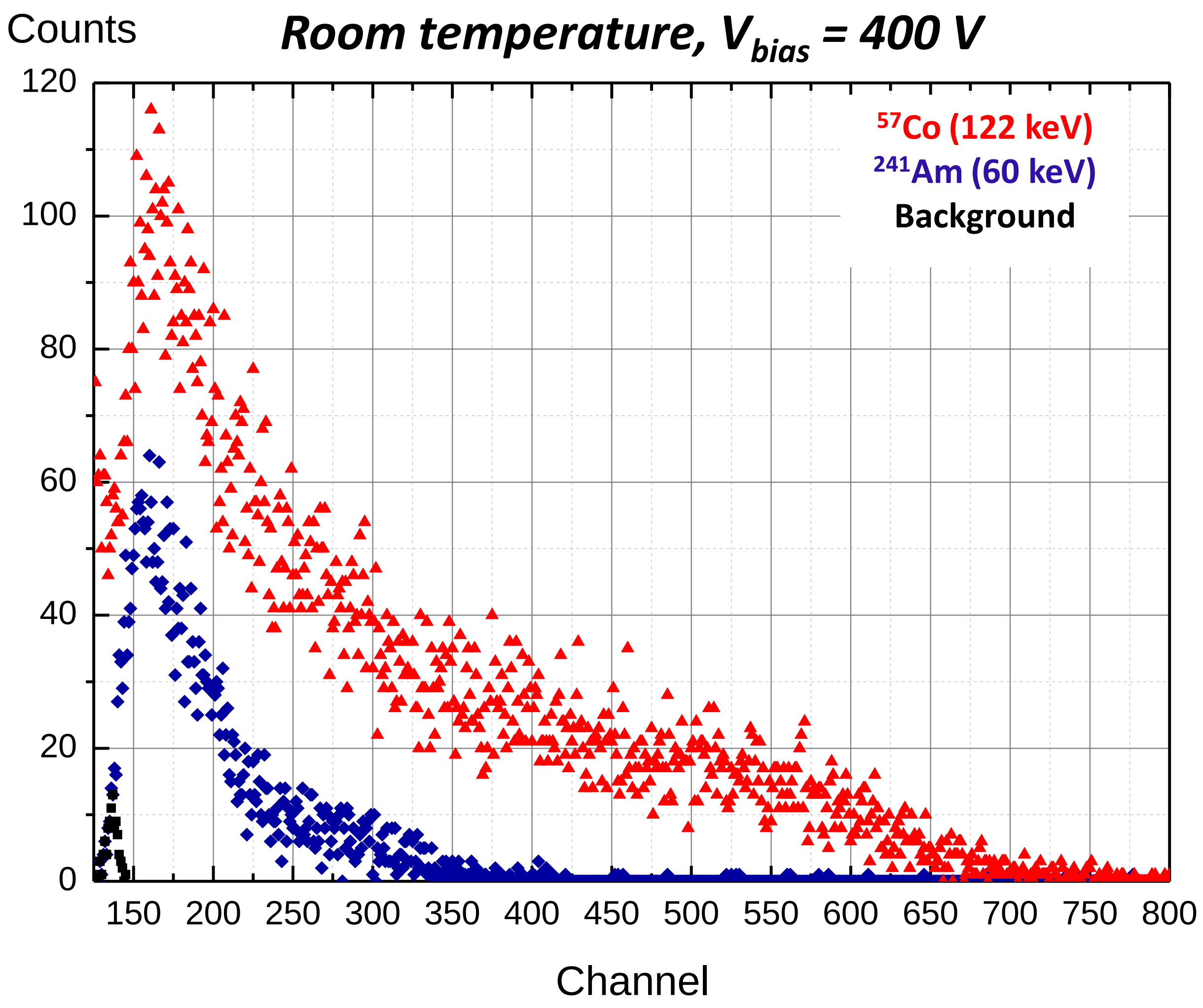


Dark Side CryoLab lead by A. Rozeto



Activity of isotopes:
^{137}Cs ~ 1 uCi
^{241}Am ~ 1 uCi

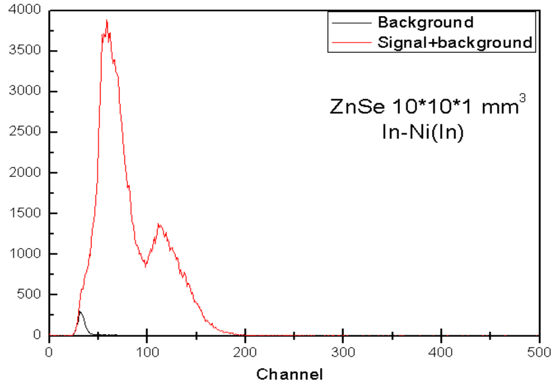
Pulse-height spectrum of ZnSe detector



ZnSe 10×10×1 mm^3

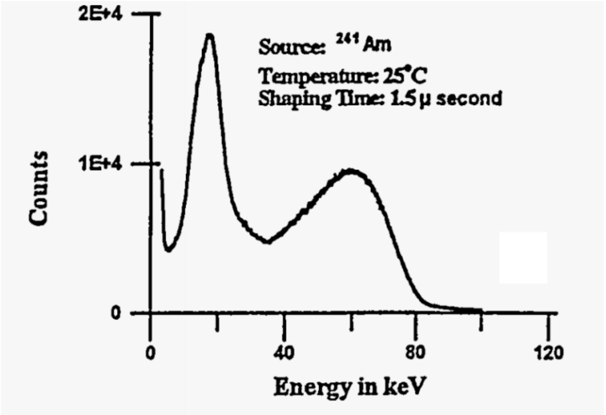
Geometry effect on spectrometric characteristics (1)

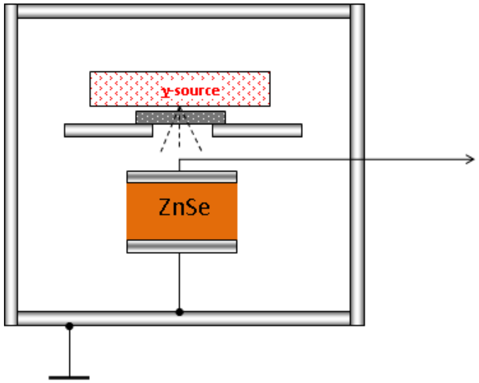
Room temperature.
Shaping time – 1 us.
Bias voltage – 1000 V.



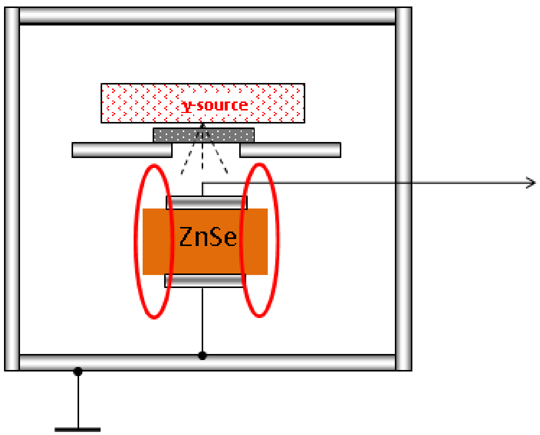
Properties of Melt-Grown ZnSe Solid-State Radiation Detectors

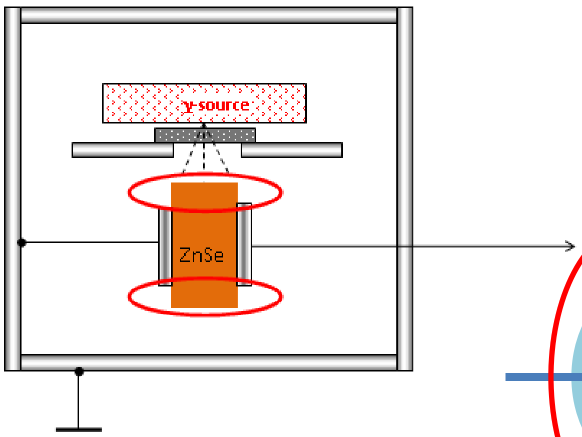
E.E. Eissler*, K.G. Lynn**
* eV PRODUCTS, div. of II-VI Incorporated, 375 Saxonburg Blvd., Saxonburg, PA 16056
** Brookhaven National Laboratory[1], Department of Physics, Upton, NY 11973

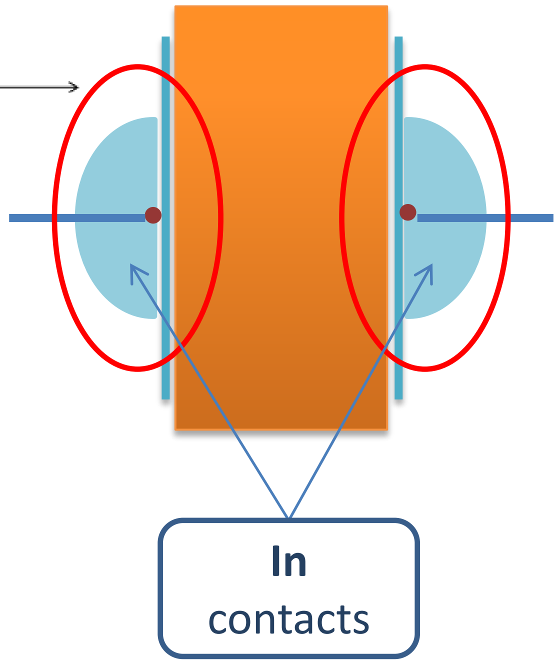


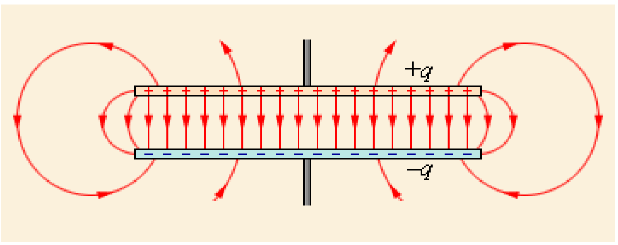


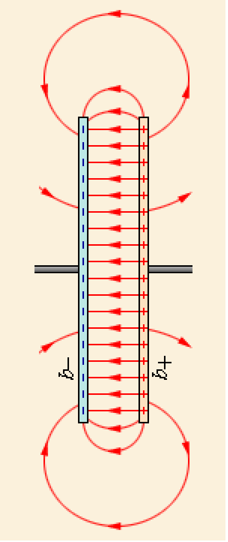
Geometry effect
on spectrometric characteristics (2)



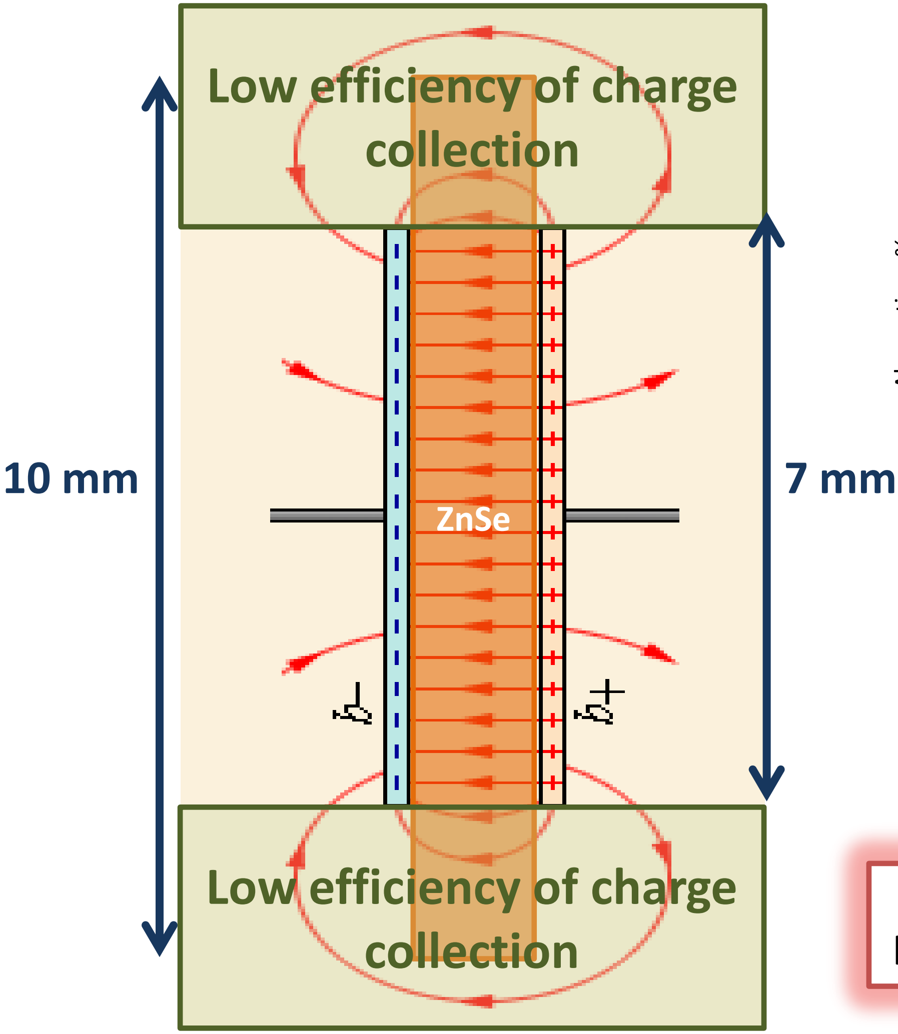


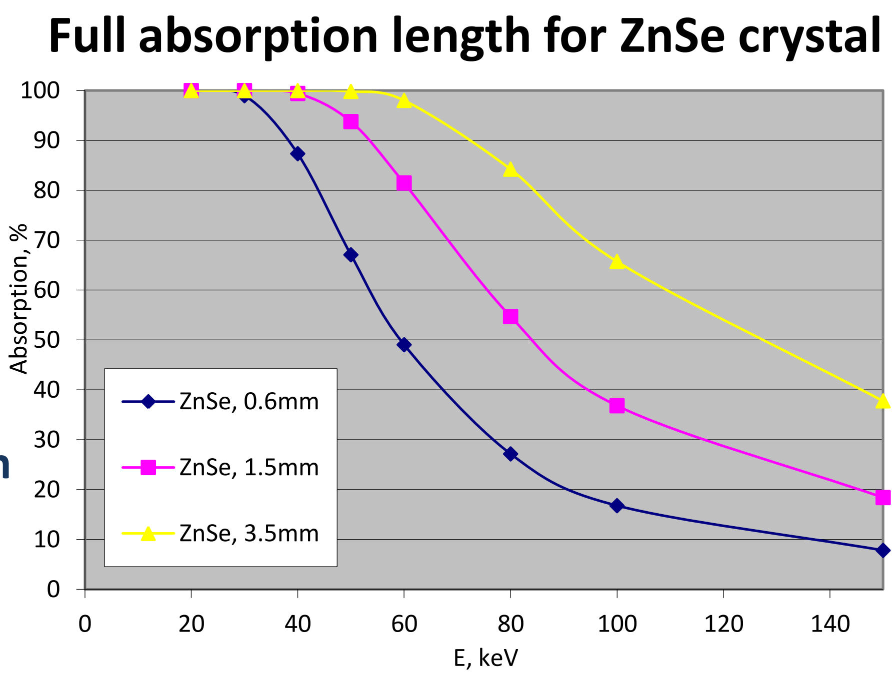






Geometry effect on spectrometric characteristics (3)

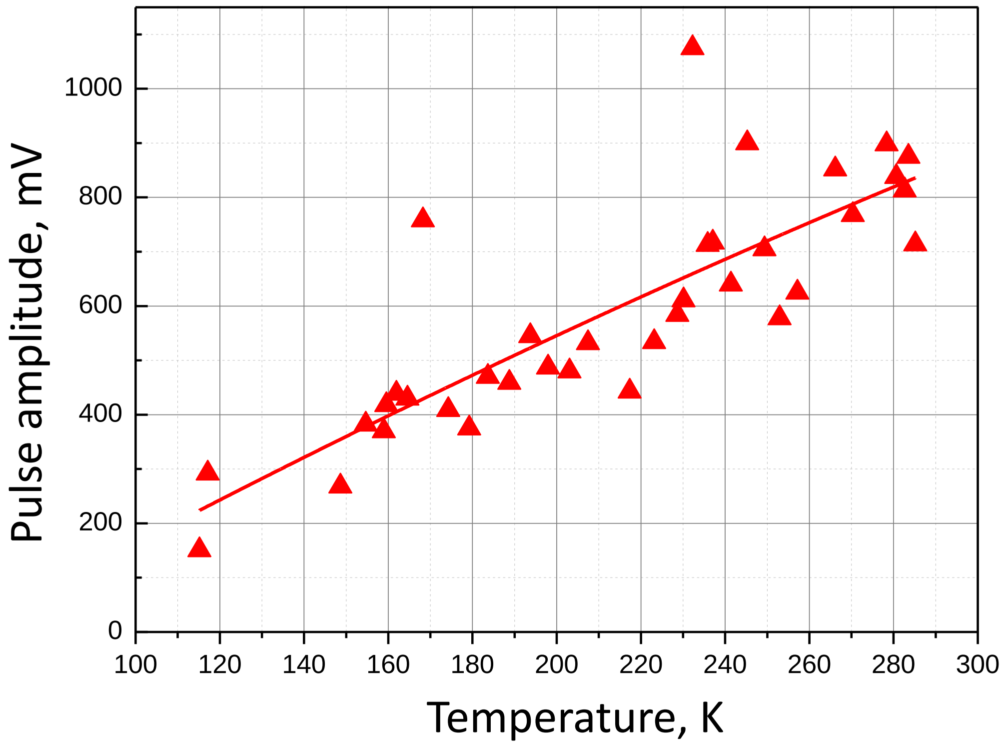




Not optimized measurement geometry leads to degradation of spectroscopic characteristics

Low temperature test

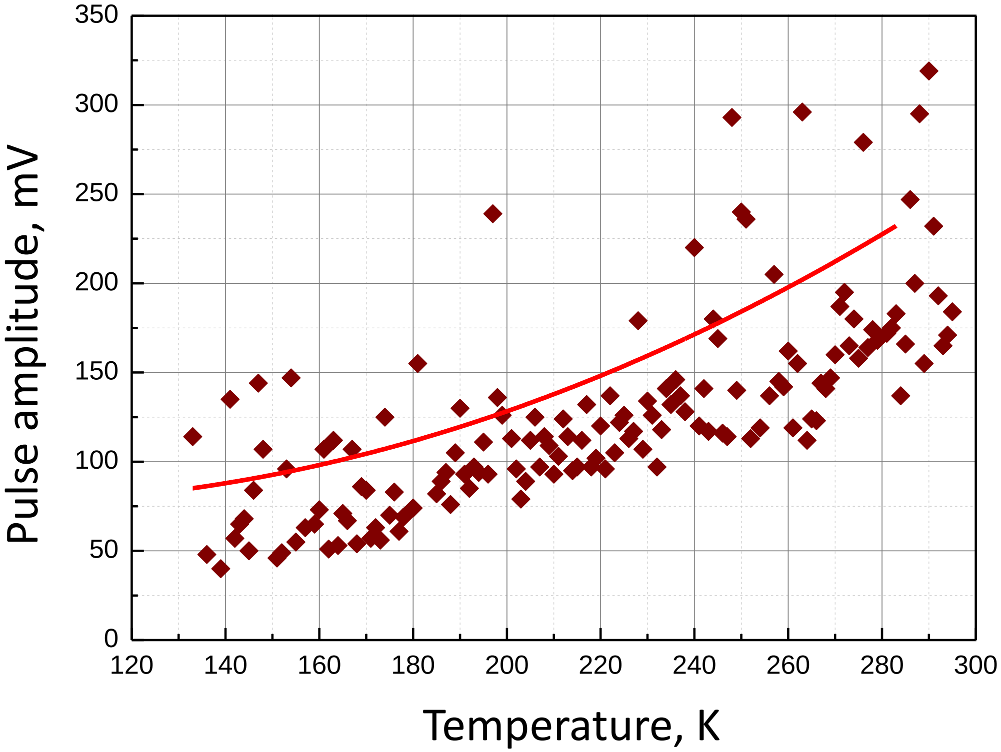
ZnSe "as-grown", ohmic contacts, 10×10×1 mm^3 , ^{137}Cs source



V_{bias} = 250 V
PreAmp sensitivity 160 mV/MeV

Low temperature test

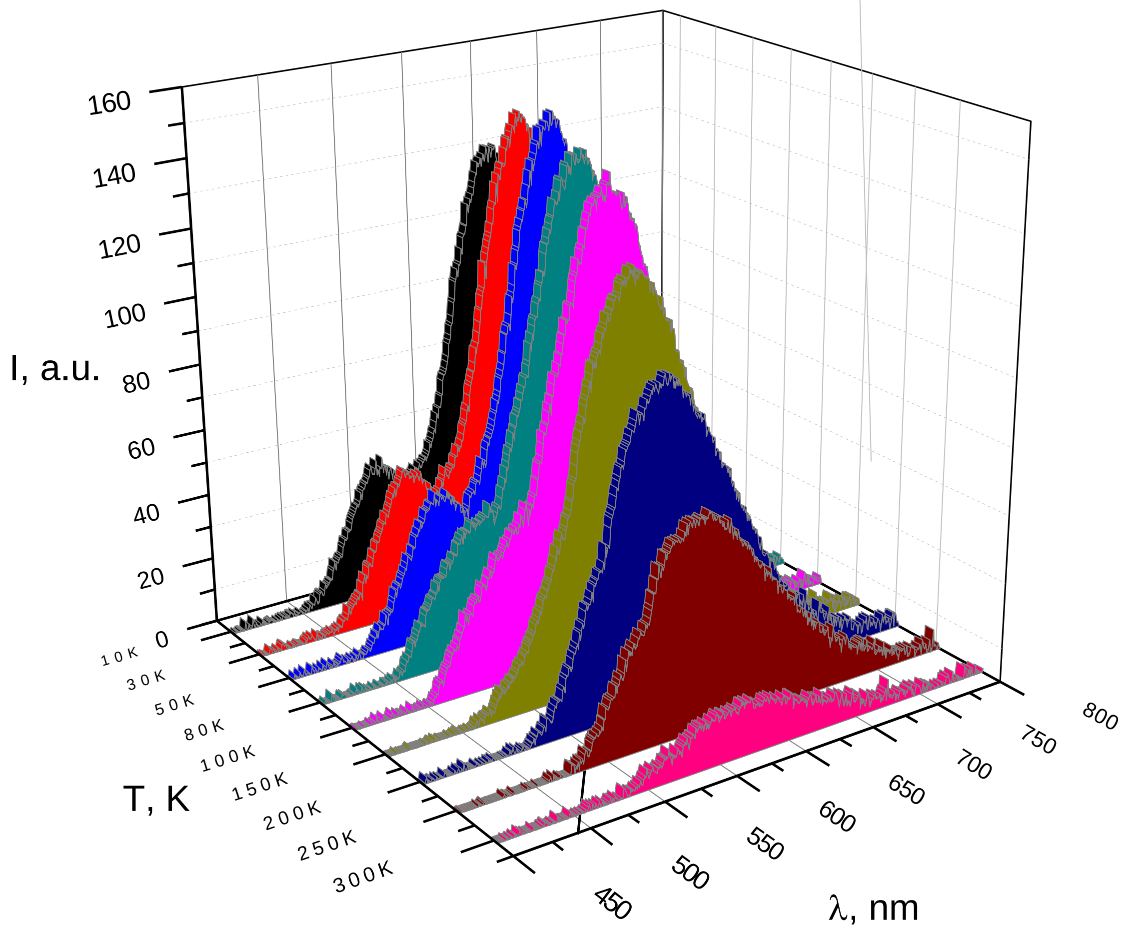
ZnSe "as-grown", ohmic contacts, 10×10×3 mm^3 , ^{137}Cs source



V_{bias} = 450 V
PreAmp sensitivity 80 mV/MeV

X-ray excited steady-state luminescence

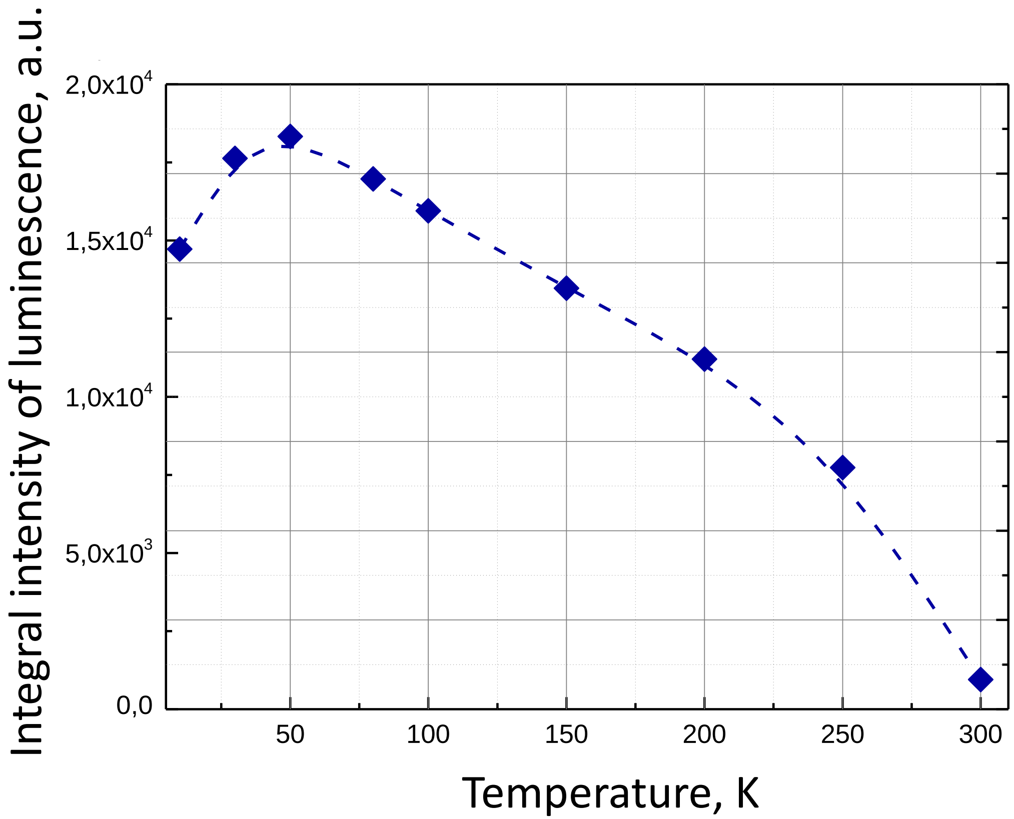
ZnSe "as-grown" 10×10×10 mm³ & Optical cryostat & X-ray source



done at Rome, Feb 2014

X-ray excited steady-state luminescence

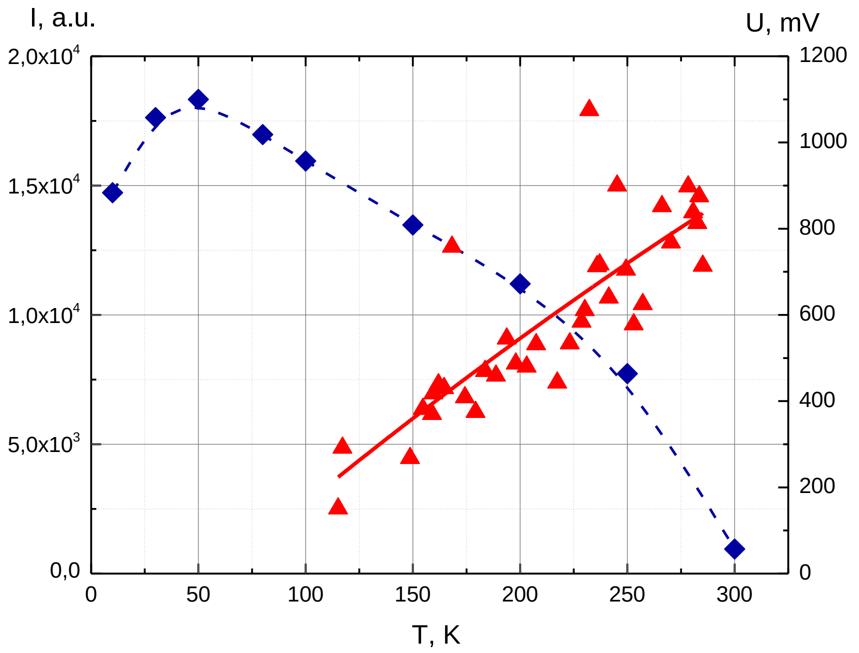
ZnSe "as-grown" 10×10×10 mm³ & Optical cryostat & X-ray source

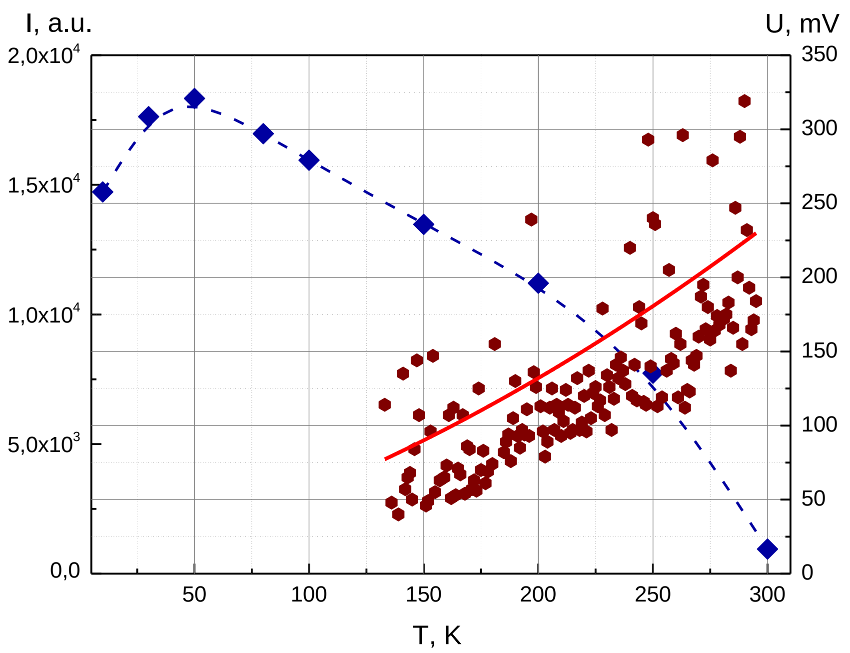


done at Rome, Feb 2014

Let`s put together!

ZnSe "as-grown" 10×10×10 mm³ & Optical cryostat & X-ray source



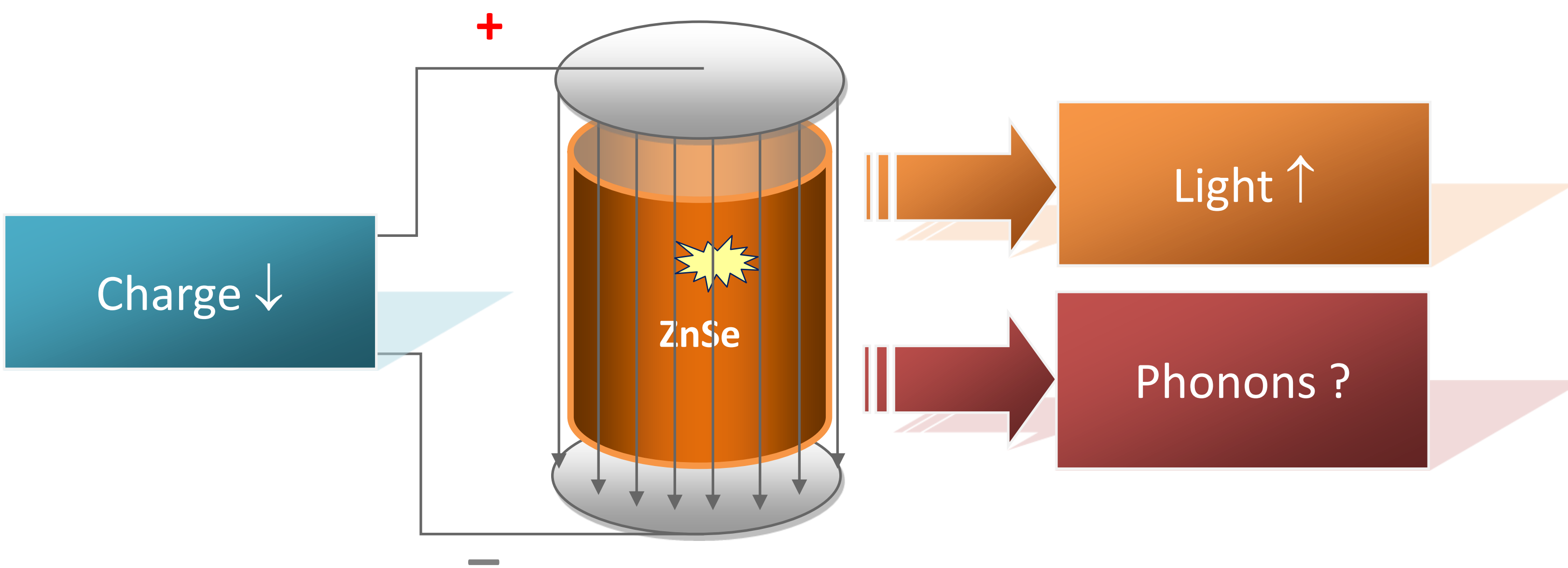


ZnSe "as-grown", ohmic contacts, 10×10×1 mm³, ¹³⁷Cs source

ZnSe "as-grown", ohmic contacts, 10×10×3 mm³, ¹³⁷Cs source

Energy balance in ZnSe crystal

with decreasing of temperature



With temperature decreasing

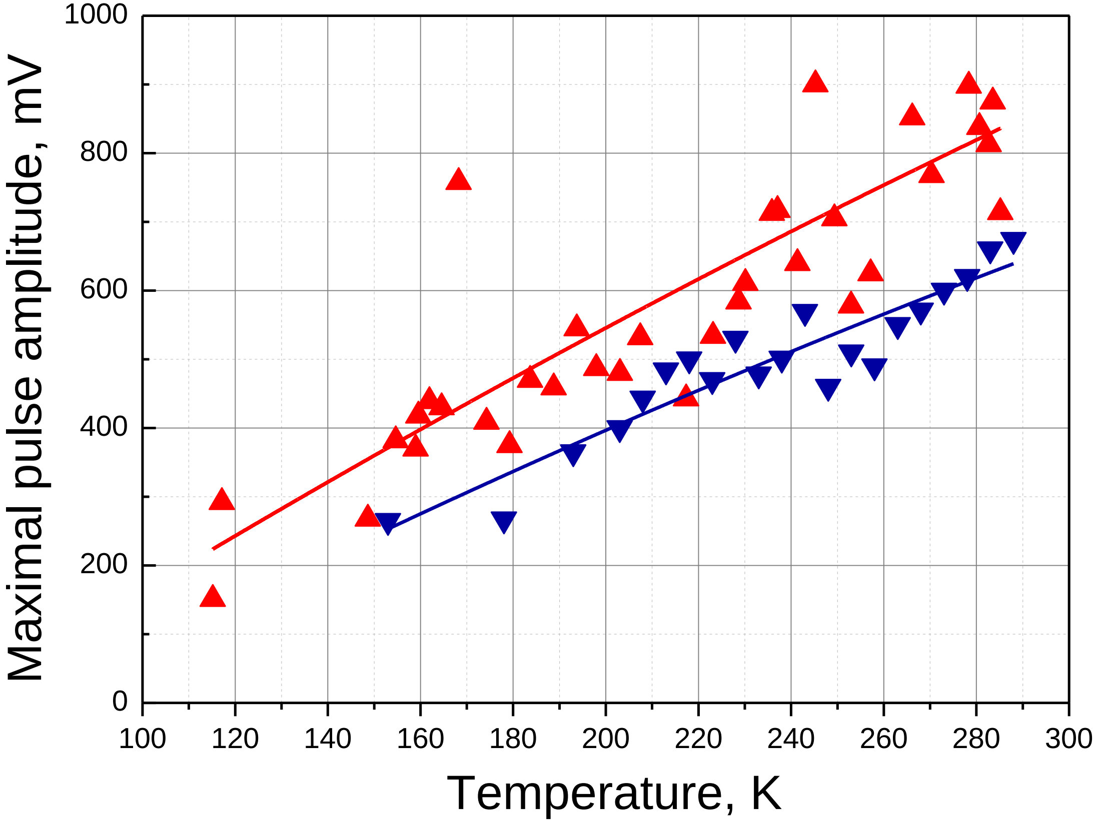
Light ⇧

- decrease of oscillations amplitude of crystalline lattice, and electron scattering on phonons
- deepening of traps and recombination centers energy level (donors, acceprors, vacansions,...)
- **increase of electron capture cross-section on luminescence centers and all type of defects**
- decrease of electron free path length
- increase of life-time of electron-hole pairs (excitons)
- **increase of probability of excitons recombination with light irradiation**

Charge ⇩

- deepening of traps and recombination centers energy level (donors, acceprors, vacansions,...)
- increase of electron capture cross-section on luminescence centers and all type of defects
- increase of life-time of electron-hole pairs (excitons)
- increase of probability of excitons recombination with light irradiation
- decrease of electron free path length
- **decrease of number of free charge carriers**

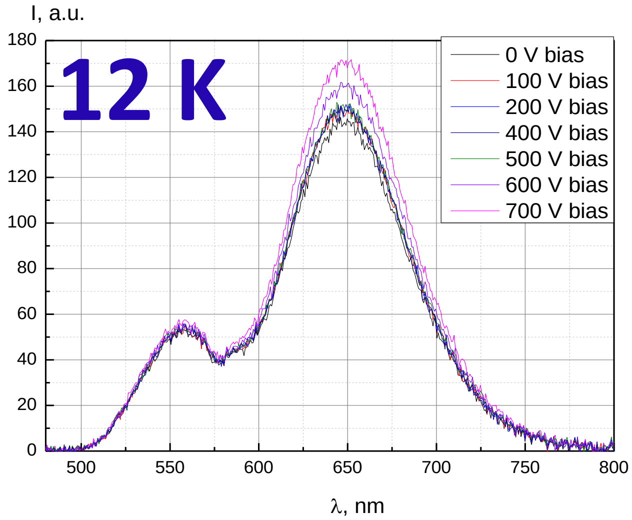
Number of charge carriers as function of bias voltage

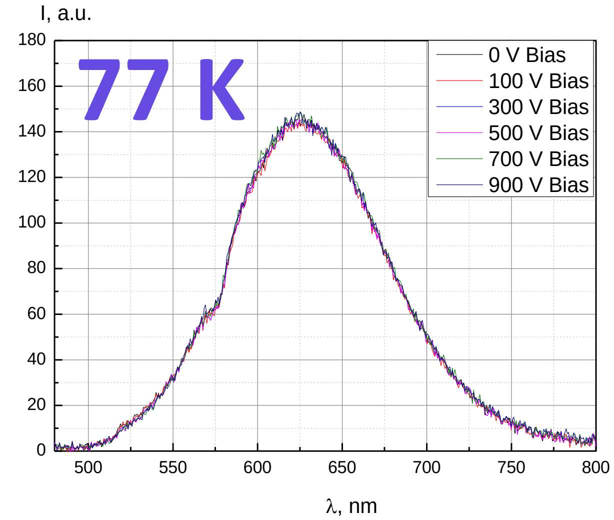


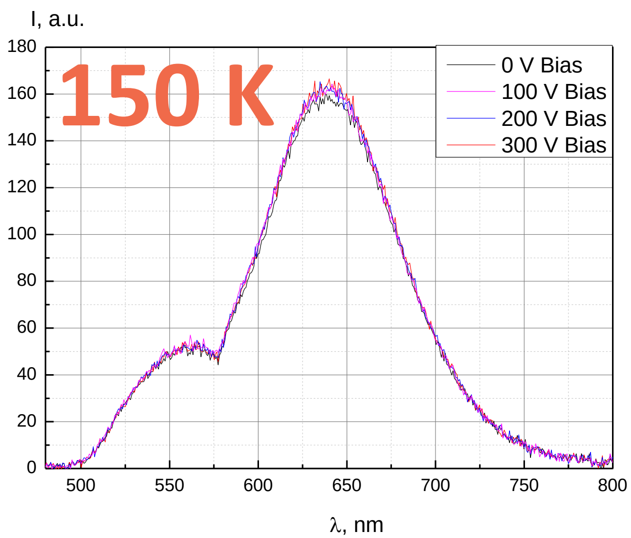
V_{bias} = 250 V

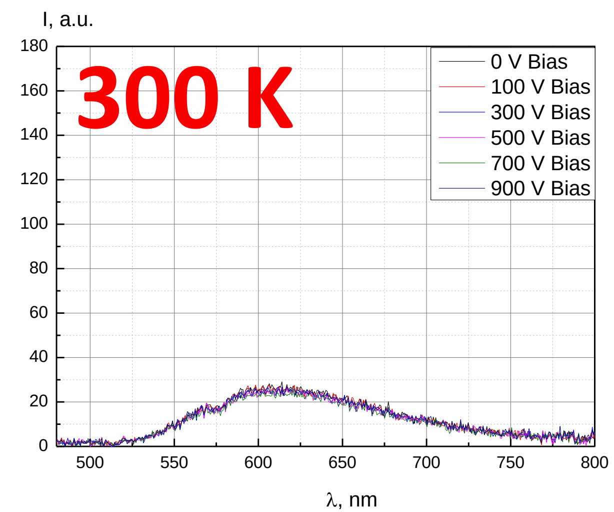
V_{bias} = 70 V

Luminescence-Bias Voltage-Temperature dependences





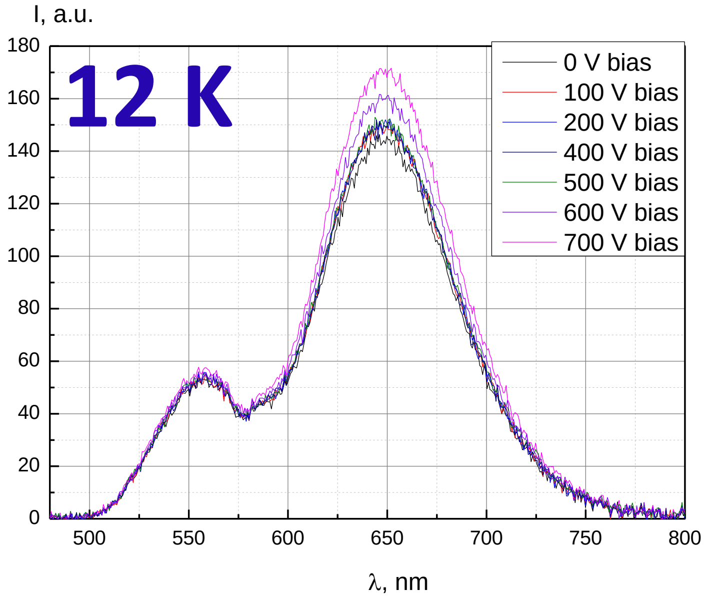




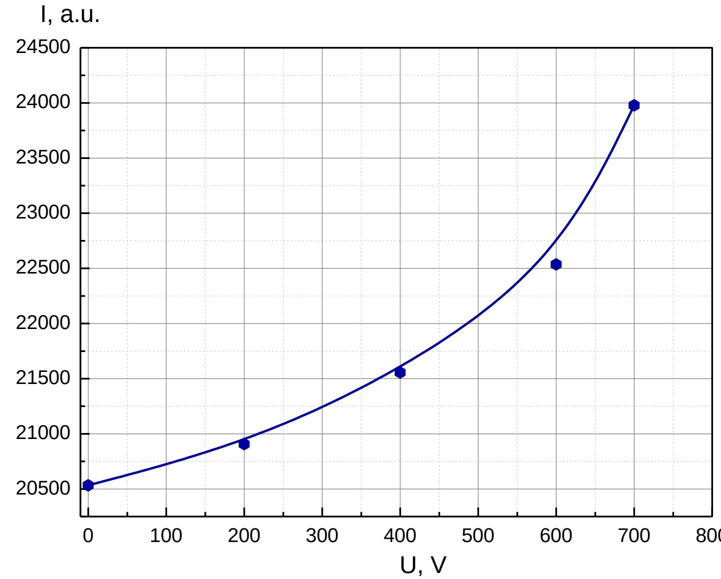
X-Ray tube parameters: U=60 kV, I=80 uAmp

done at Rome, April 2015

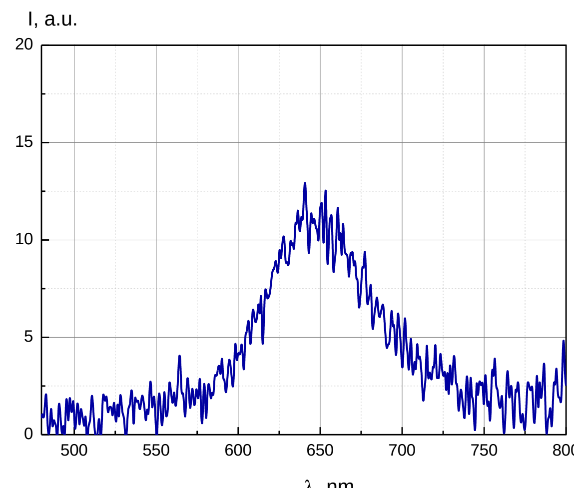
Luminescence-Bias Voltage-Temperature dependences



X-Ray excited luminescence spectra



Integral light yield from the crystal

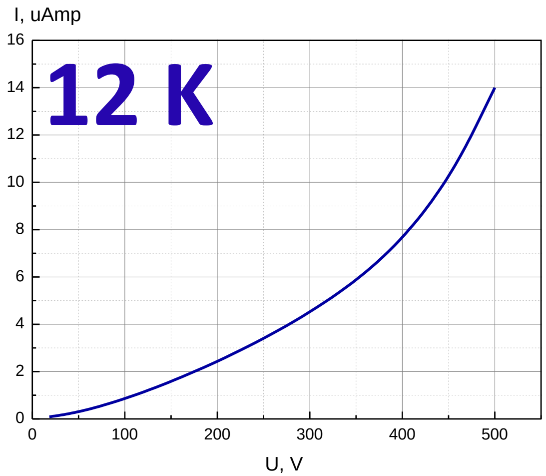


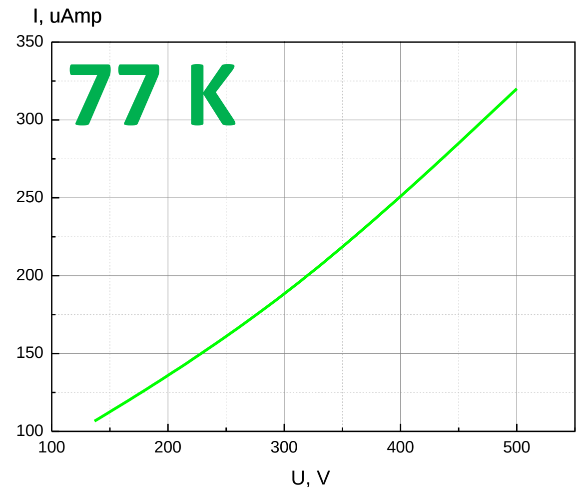
Trapped charge carriers

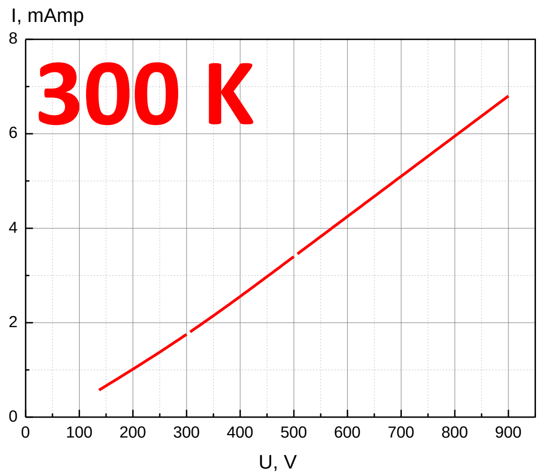
X-Ray tube parameters: U=60 kV, I=80 uAmp

done at Rome, April 2015

Current-voltage characteristic

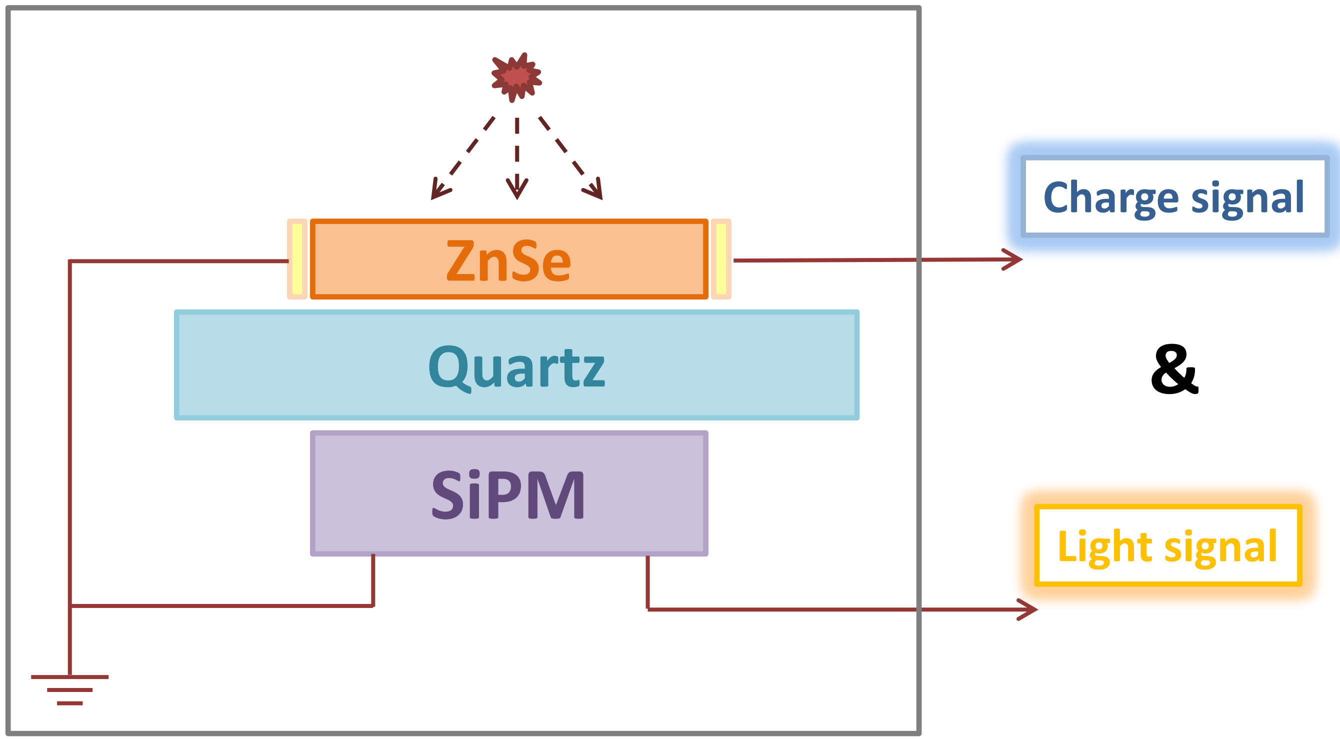






X-Ray tube parameters: U=60 kV, I=80 uAmp

Next evidential measurement



- ZnSe “as-grown”, oriented, polished, 10×10×3(1, 5) mm^3
- Gold/Aluminium contacts
- Read-out with high performance charge-sensitive Preamplifier
- Quartz insulation plate
- SiPM, 10×10 mm^2
- $^{241}Am/^{57}Co$ gamma source
- Cryostat 10-300K

Conclusions

- Charge and Light channels in ZnSe crystal are anti-correlated and strongly depend on temperature
- The average lifetime of the charge carriers in their free state until the moment of trapping depends on the trap concentration, the cross-section of the trapping and the thermal velocity. With temperature decrease, the thermal velocity decrease as well, the trap concentration remains the same, but cross-section of the trapping increases. This factors lead to the decrease of the free charge carriers concentration.
- With temperature decrease the dominant channel of energy release in ZnSe crystals is Scintillation Channel
- Applying of bias voltage at low temperatures partially compensate the thermal velocity decrease and increase average lifetime of the charge carriers.
- Charge collection efficiency can be improved by applying the higher strength of electric field to ZnSe crystal
- Further optimized measurements of charge and light channel double read-out is required

THANK YOU FOR ATTENTION