Semi-insulating GaAs Detectors Degraded by 8 MeV Electrons up to 1500 kGy

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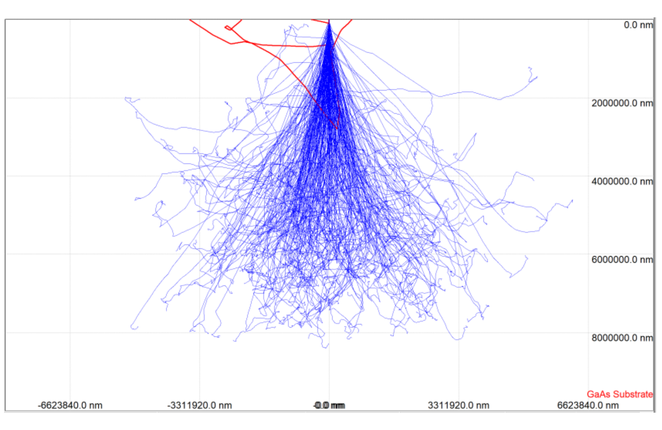
Motivation

- Our previous radiation hardness studies of semi-insulating (SI) GaAs detectors [1] showed decrease of charge carrier mobility and charge collection efficiency, increase of resistivity and breakdown voltage with increasing dose.
- Radiation induced defects would act as traps for charge carriers, which shortens their lifetime and decreases their mobility leading to observed change of detector parameters.
- This study links the radiation induced degradation of detector parameters (electrical and spectrometric) to the concentration of monovacancies generated in GaAs substrate, revealed by positron annihilation spectroscopy.

Substrate Degradation by 8 MeV Electrons

SI GaAs Substrates

VGF (Vertical Gradient Freeze) SI (semi-insulating) GaAs substrate made by Freiberger Compound Materials Ltd, Germany: thickness 450 μm, size 1 × 1 cm²

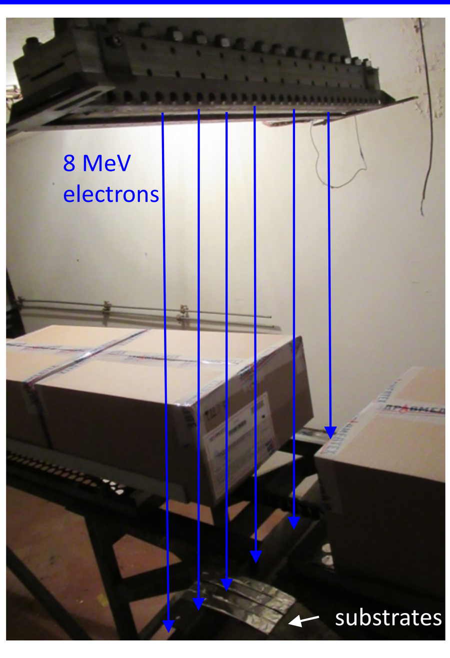


Trajectories of 8 MeV electrons in 10 mm thick GaAs according to CASINO.

Irradiation

At Department of Experimental Physics, Ural Federal University, Ekaterinburg, Russia:
Electron LINAC
Energy 8 MeV
Current 1 mA
Power 10 kW
Scanning width 40 cm

Dose (kGy)	Time (s)	Flux (e/cm²s)	Fluence (e/cm²)
200	600	1.86E+12	1.12E+15
500	1500	1.86E+12	2.79E+15
1000	3000	1.86E+12	5.58E+15
1500	4500	1.86E+12	8.37E+15

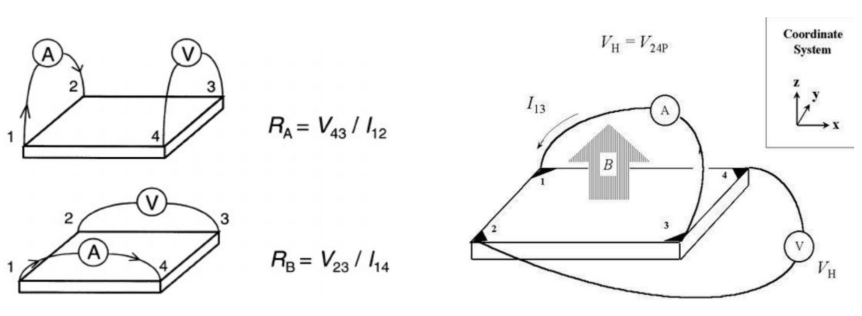


Measurements

Positron Annihilation Spectroscopy (PAS)

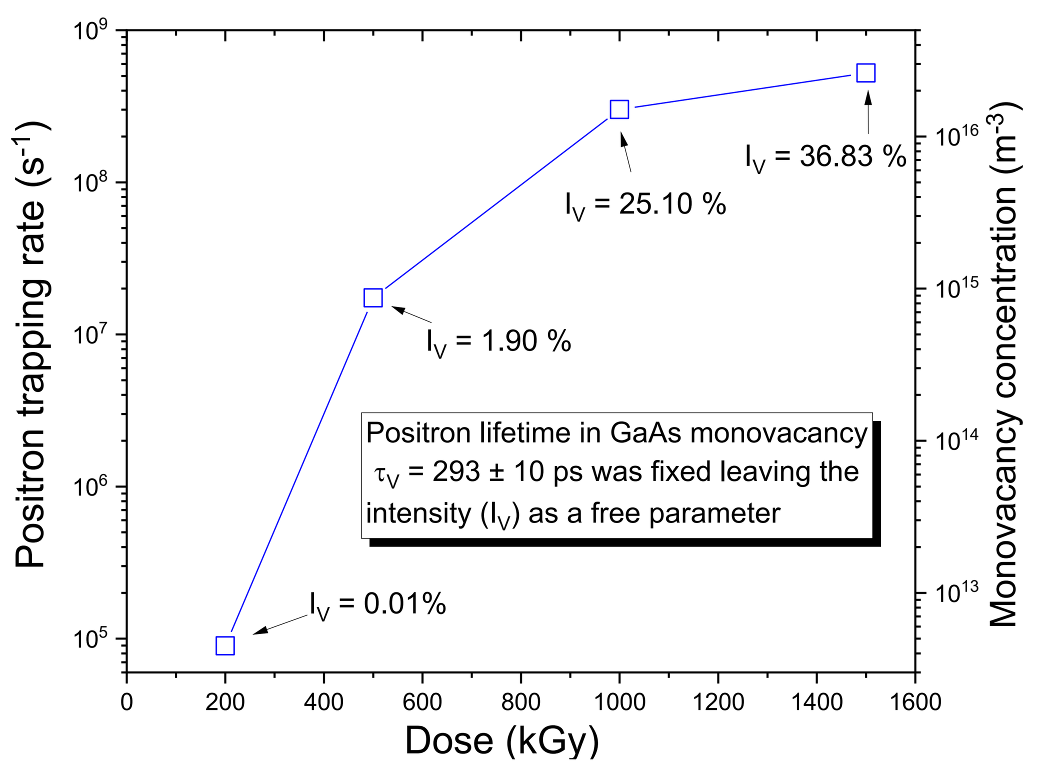
- Positrons from radioactive source (²²Na) annihilate in substrate sample emitting 2 annihilation photons in 180° angle.
- Vacancies and sub-nanometer defects in material lattice strongly influence positron lifetime (increase it due to low electron density).

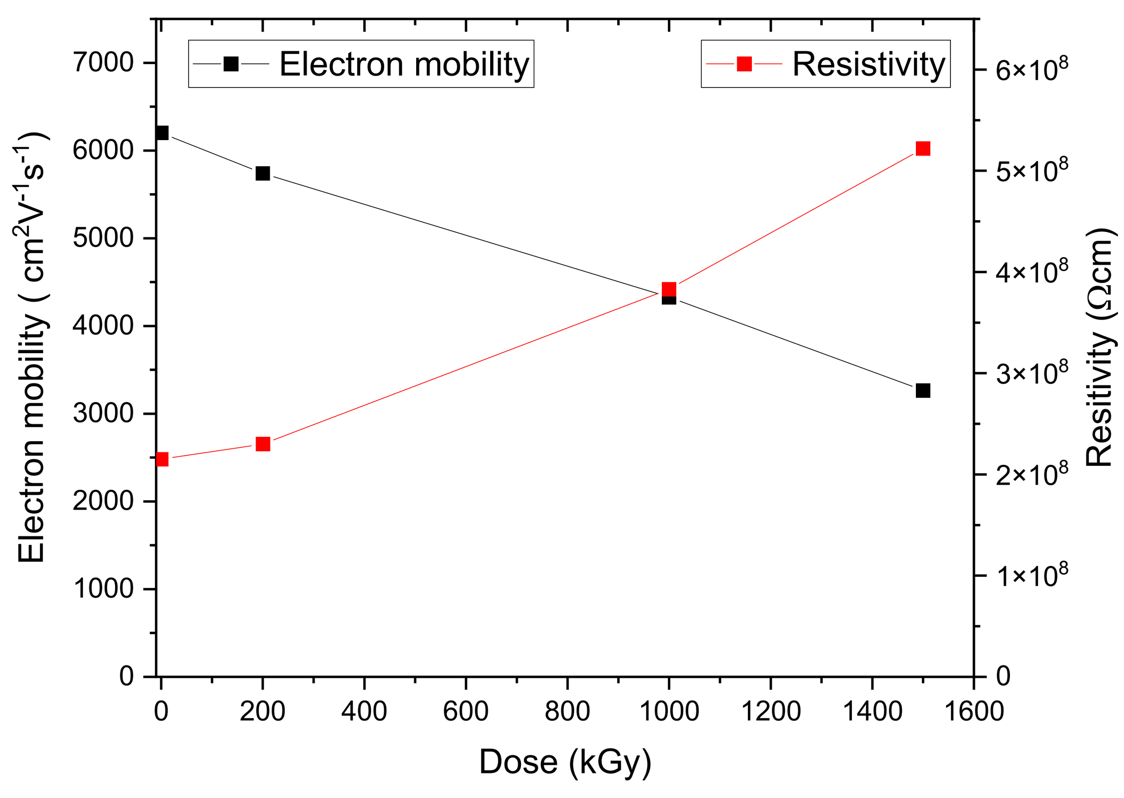
Van der Pauw Resistivity & Hall Mobility



Resistivity Rs: $\exp(-\pi R_A / R_S) + \exp(-\pi R_B / R_S) = 1$

Hall mobility: $\mu = |V_H| / R_S IB$

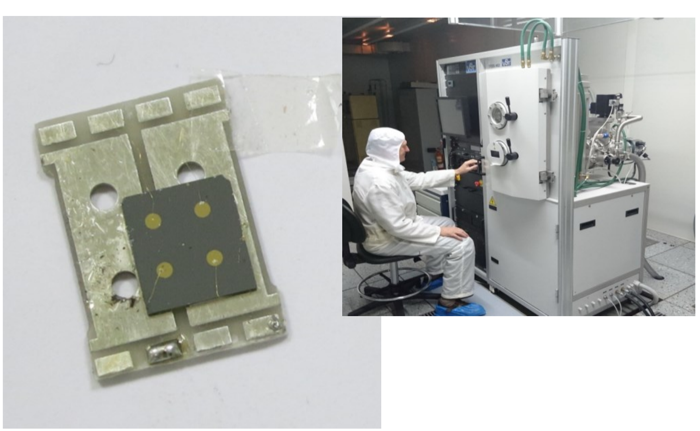


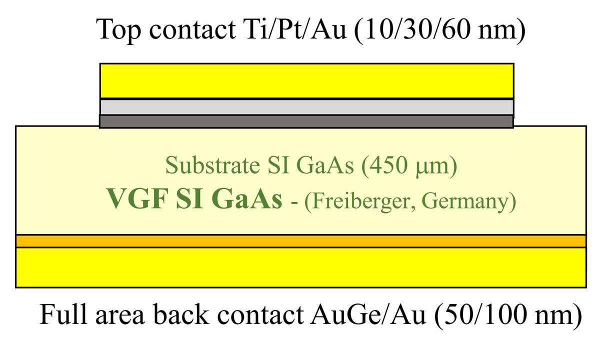


Radiation generates monovacancy defects in GaAs lattice (their concentration increases with dose) which act as traps for charge carriers and shorten their lifetime causing decrease of charge carrier mobility. The shorter carrier lifetime leads to higher detector resistivity.

SI GaAs Detector Preparation

SI GaAs Detectors



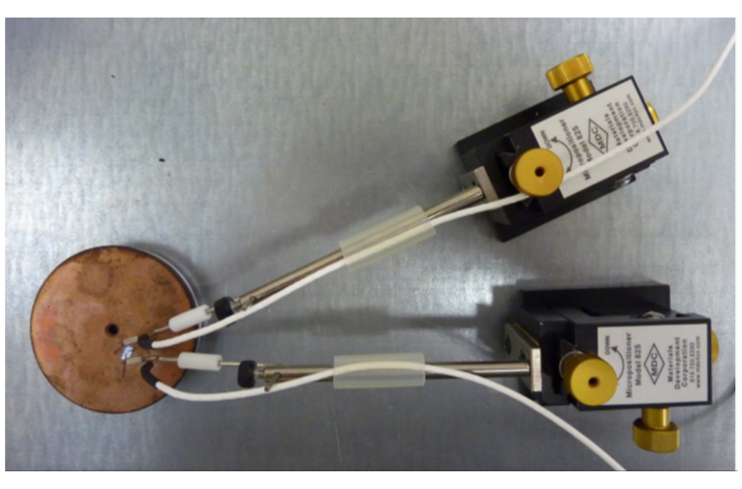


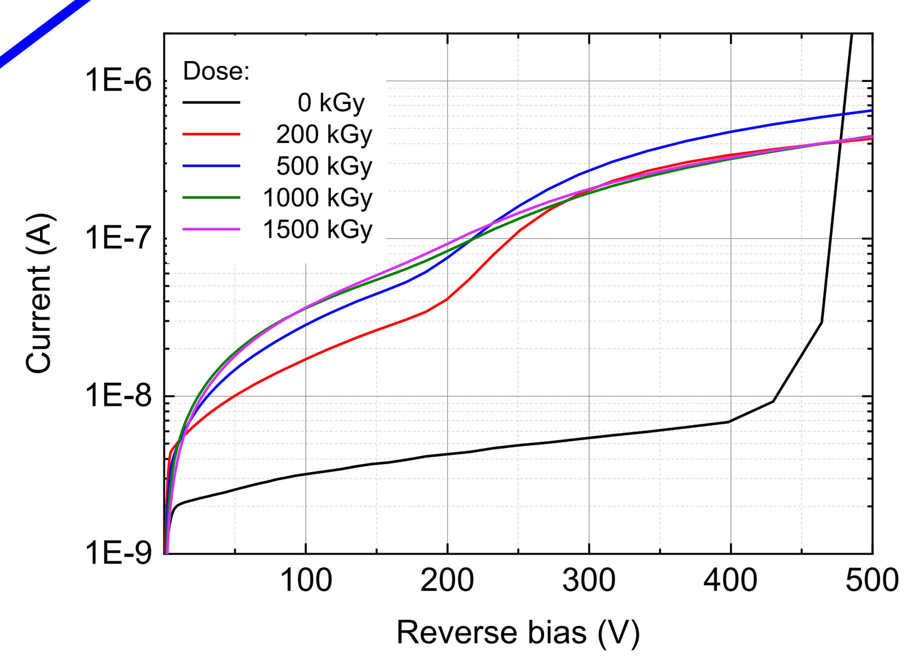
Preparation Technology

- *Photolithography*
- *Top Schottky circle contact:* ∅ 1 mm, Ti/Pt/Au (10/30/60 nm)
  4 pc on 1 × 1 cm² substrate
- *Back ohmic contact:* full-back-side, AuGe/Au (50/100 nm)
- *Prepared at:* Institute of Electrical Engineering SAS in Bratislava, Slovakia

Measurements

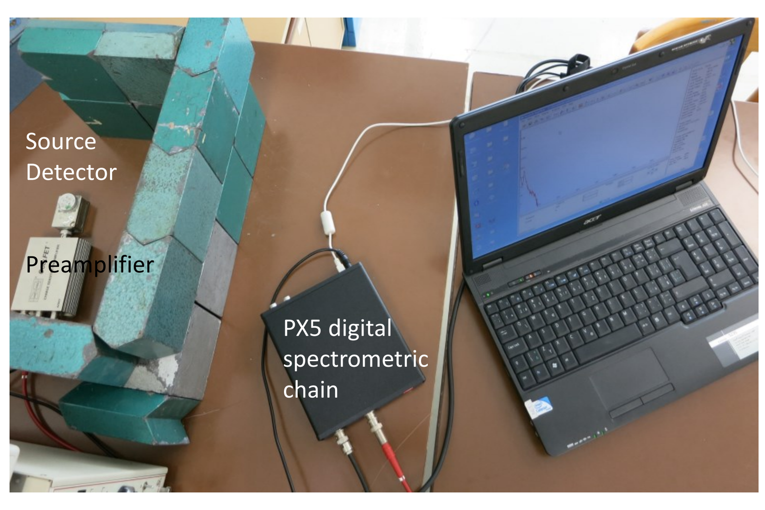
Current-Voltage Characteristics

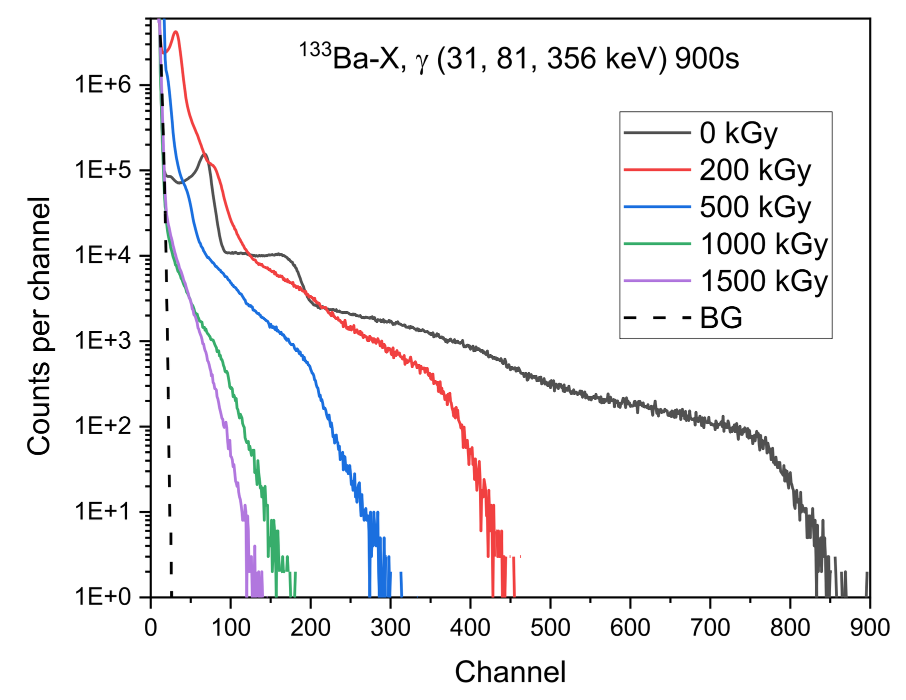


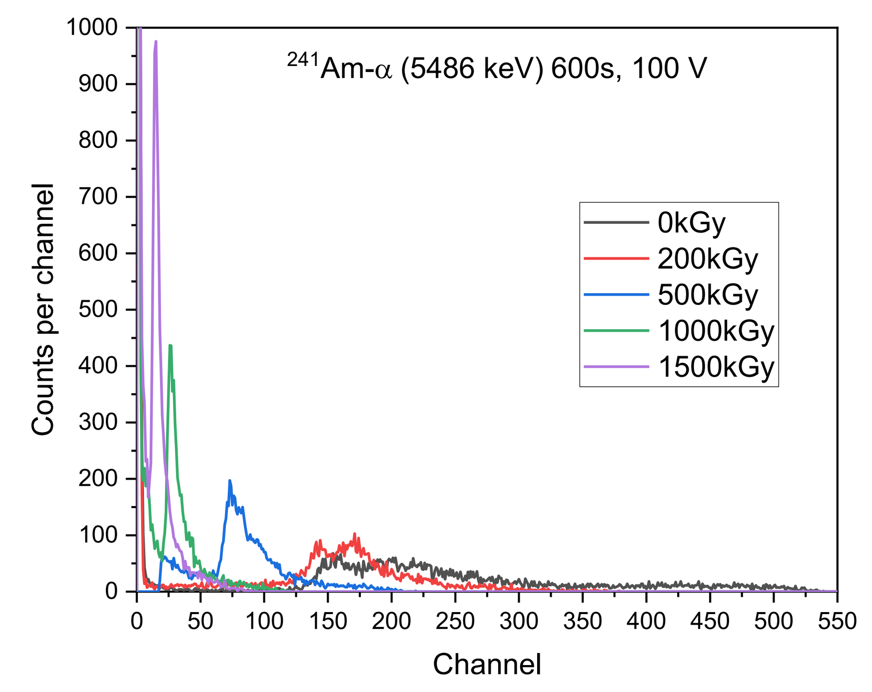


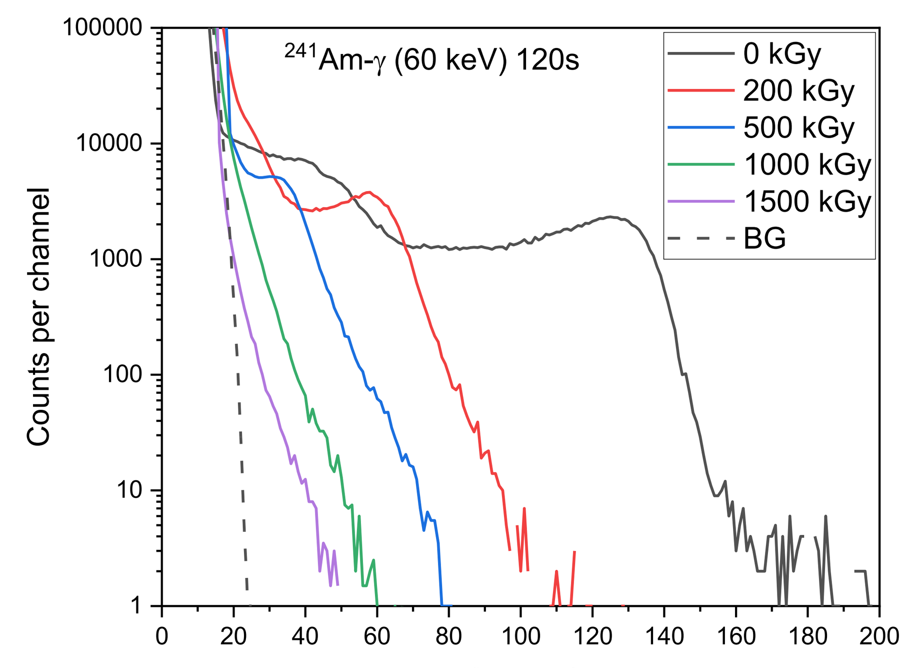
Radiation induced monovacancy defects in GaAs lattice as traps for charge carriers shorten their lifetime shifting the breakdown voltage higher. With an increasing dose, an increase of the reverse current in the voltage range up to 450 V is observed as well as the reduction of the barrier height of the Schottky contact, which almost totally disappears at a dose of 1 MGy (the current almost linearly increases with the reverse bias without any saturation) as well as vanishing of the breakdown behaviour beneath 500 V.

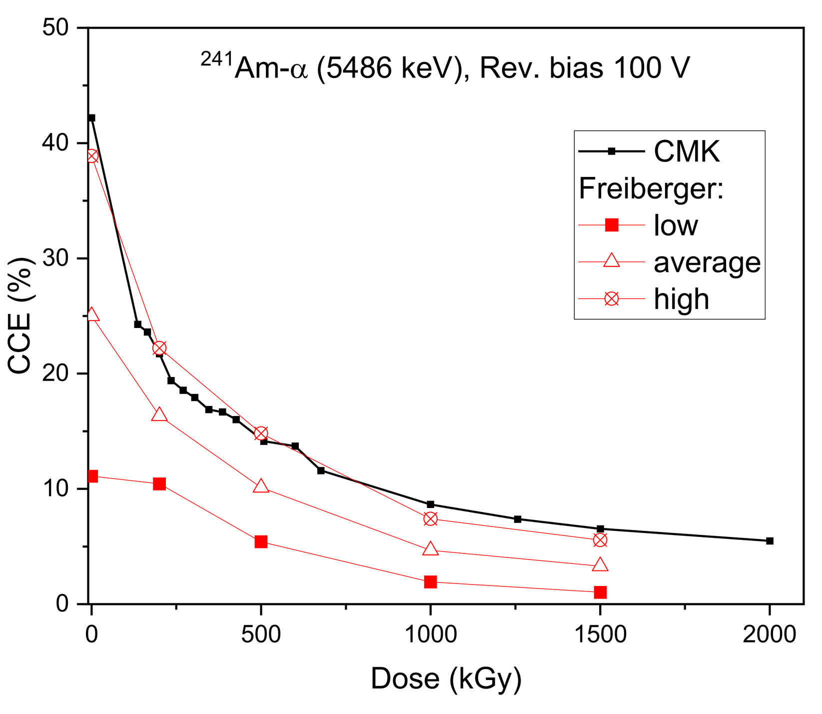
Spectra measurements

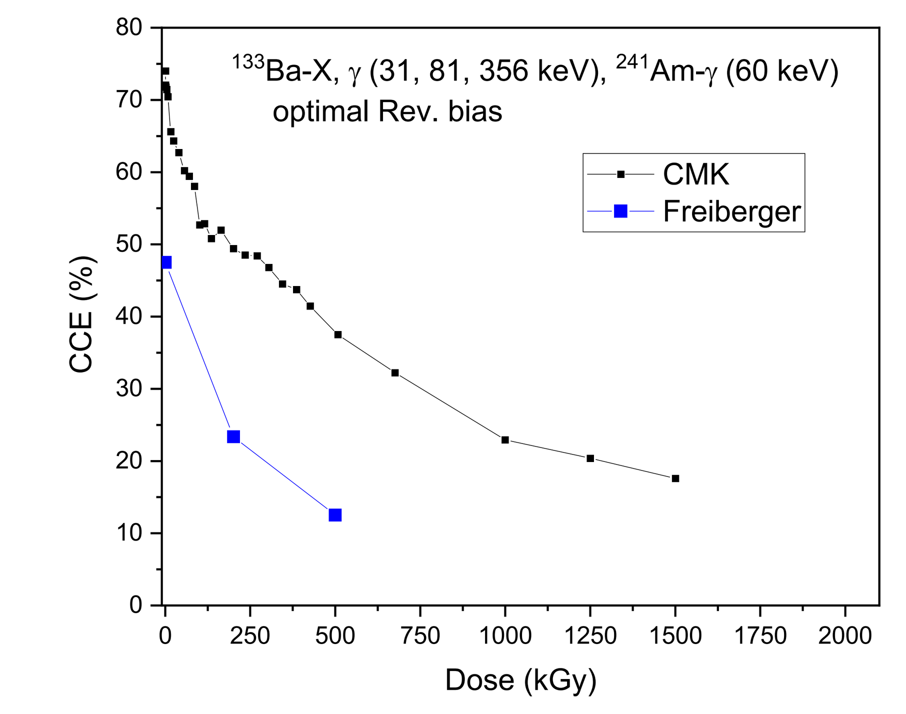












Radiation induced monovacancy defects in GaAs lattice act as traps for charge carriers leading to decrease in detector CCE (Charge Collection Efficiency).

Conclusions

- SI GaAs detectors degraded by high-energy electrons exhibited similar behaviour in electrical and spectrometric properties like our previous research showed.
- Increasing concentration of monovacancy defects in GaAs lattice with applied dose was proven by PAS.

Previous studies [2]:
Detector degraded by 5 MeV electrons as a whole.
High quality CMK substrate (Resistivity 2×10^7 Ωcm, Hall mobility 7219 cm²/Vs) of lower thickness of 230 μm.
Recent results: detector substrate degraded by 8 MeV electrons before contact evaporation (sole degradation of bulk material).
Lower quality of Freiberger substrate (Resistivity 2×10^8 Ωcm, Hall mobility 6200 cm²/Vs) of higher thickness of 450 μm.

References: [1] A. Sagatova *et al.*, Applied Surface Science **395**(2017), 66-71. [2] A. Sagatova *et al.*, JINST **15**(2020), C01024.

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