Contract No:

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Space charge dynamics in CdZnTeSe radiation detectors

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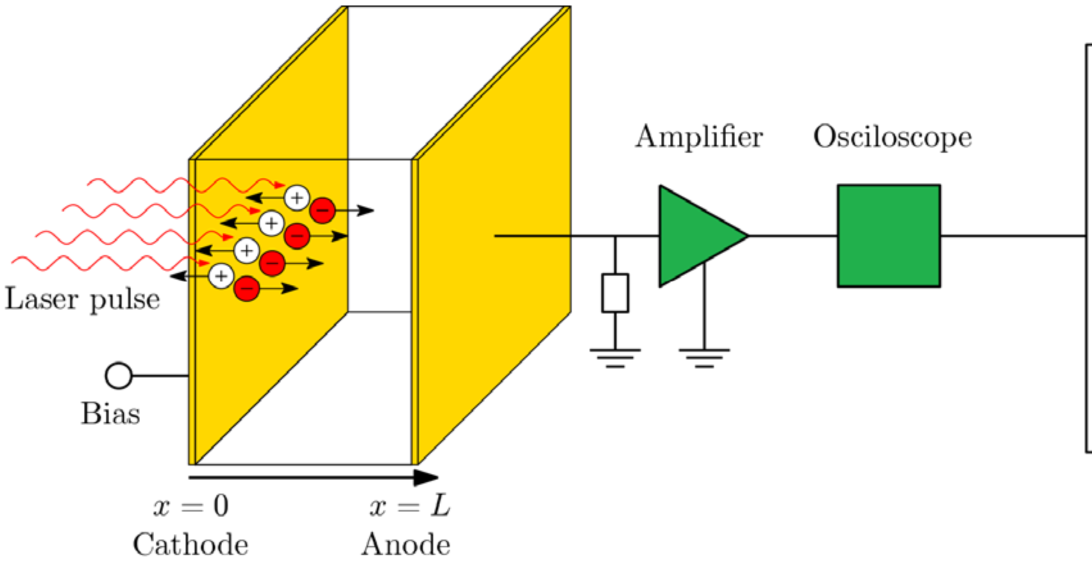
Motivation

- Cadmium zinc telluride selenide (CZTS) is room-temperature semiconducting material suitable for direct conversion of x-rays and gamma rays into electrical signals
- Selenium is found to be a very effective in reducing complications in cadmium zinc telluride (CZT) such as Te inclusions or precipitates which decreases yield and result in high cost of high-quality CZT radiation detectors
- Deep levels are responsible for charge trapping and space charge formation which decreases detector performance
- Study of space charge dynamics and deep levels is critical for improving charge collection efficiency of radiation detectors

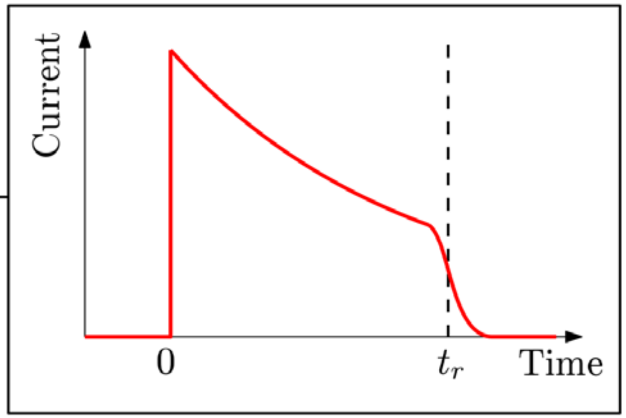
Laser Induced Transient Current Technique (L-TCT)

- Based on measuring the current response of the detector to a laser pulse
- Allows to characterize the charge transport (mobility, lifetime, electric field profile)
- Bias polarity selects which carrier type drift thought detector

L-TCT setup



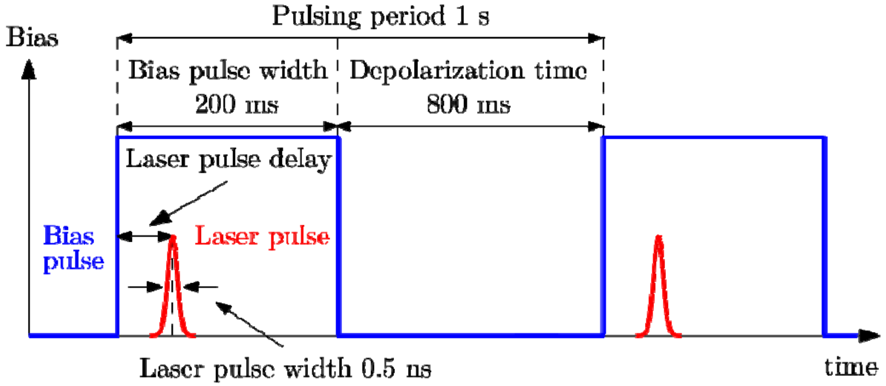
Current waveform



Experimental results

- In this study a semi-insulating p-type $\mathbf{Cd_{0.9}Zn_{0.1}Te_{0.96}Se_{0.04}}$ sample is used
- L-TCT is combined with pulsed bias to study space charge dynamics

Synchronization of laser pulse and bias pulse



- Without bias the detector is neutral without any space charge
- Space charge formation starts after bias application
- Changing the laser pulse delay allows study of space charge dynamics
- Space charge can be eliminated using pulsed bias and then effects of space charge can be distinguished from effects of traps

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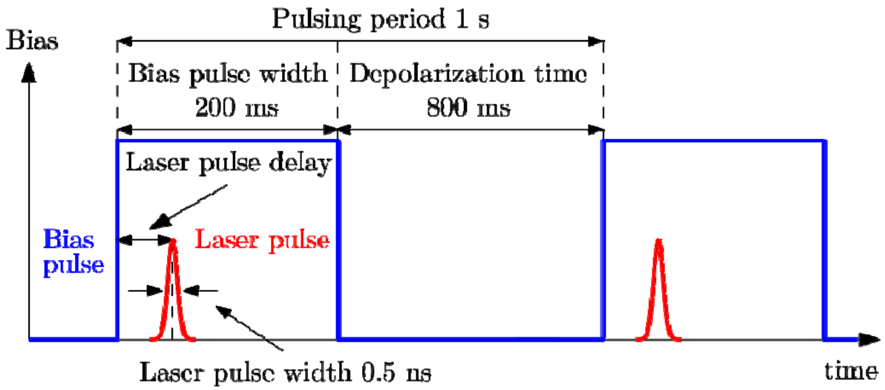

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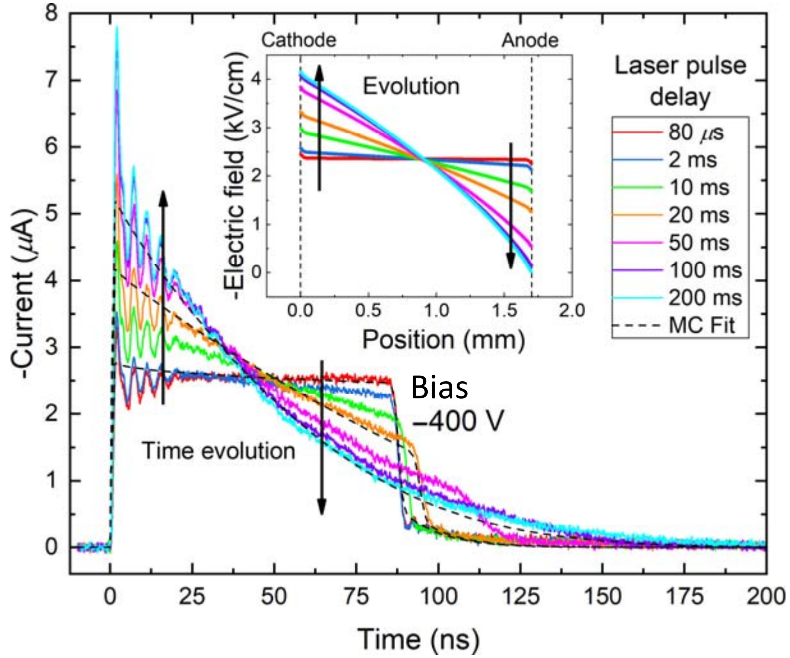
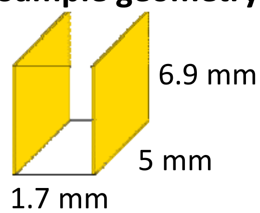
Electron-current waveforms



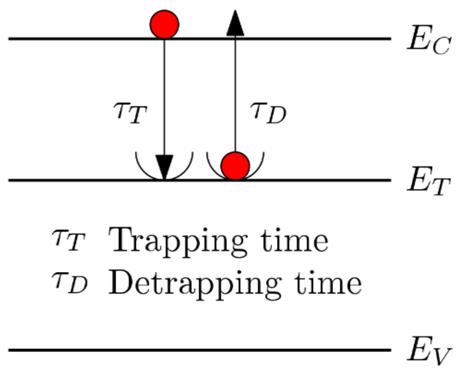
Sample geometry



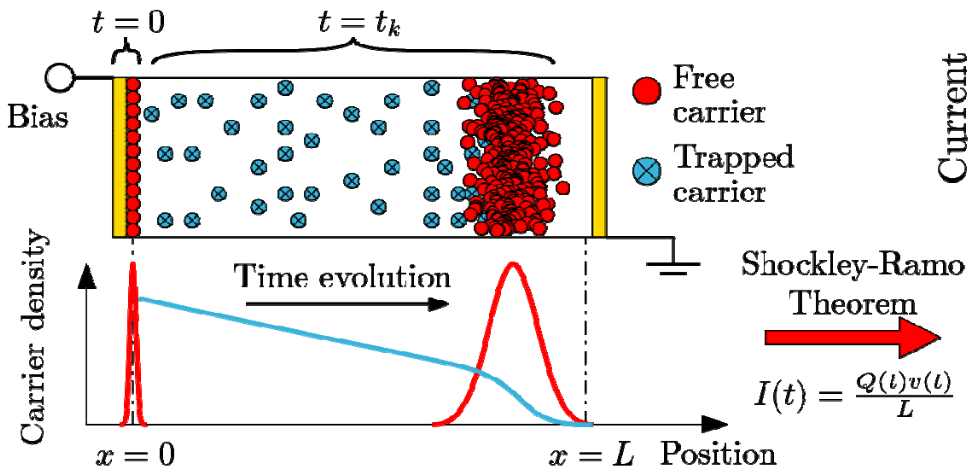
Monte Carlo Simulation

- 1D numerical simulation of charge transport in semiconductor detector
- Combined with numerical solution of drift-diffusion equation and Poisson's equation
- allows study of charge transport and space charge dynamics

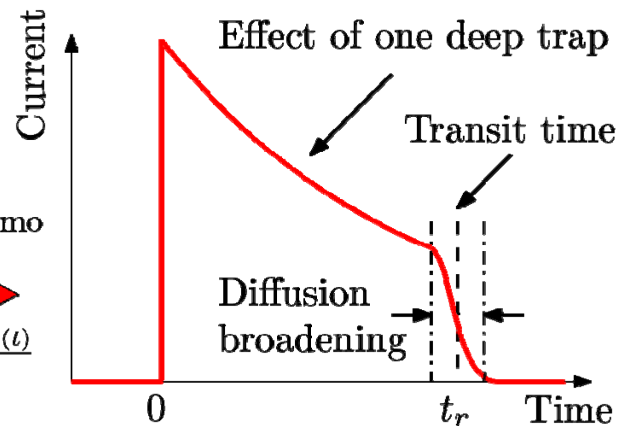
Band diagram



Detector

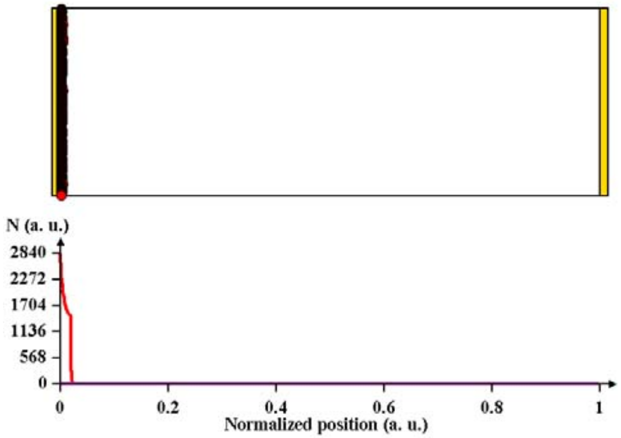


Current response

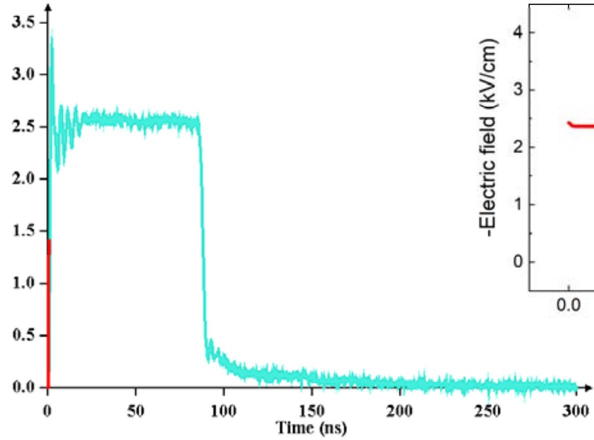


Monte Carlo simulations - electrons

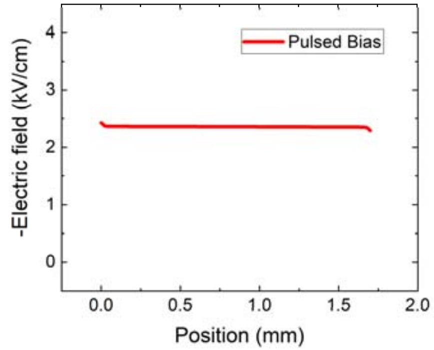
Detector - Pulsed bias



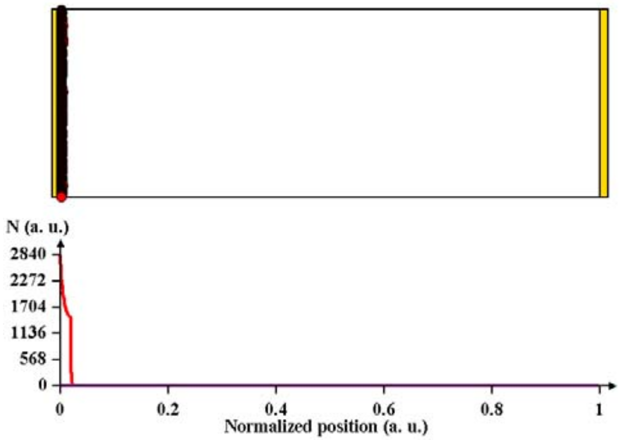
Current (µA)



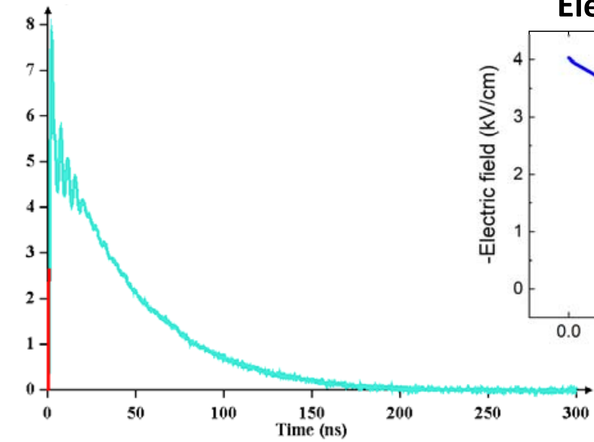
Electric field profile



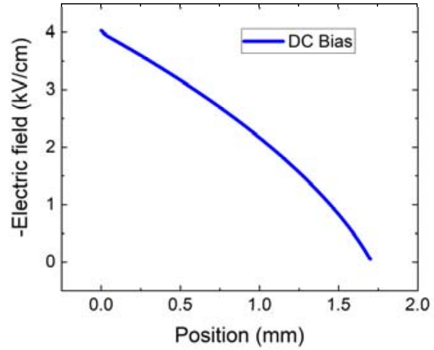
Detector - DC bias



Current (µA)

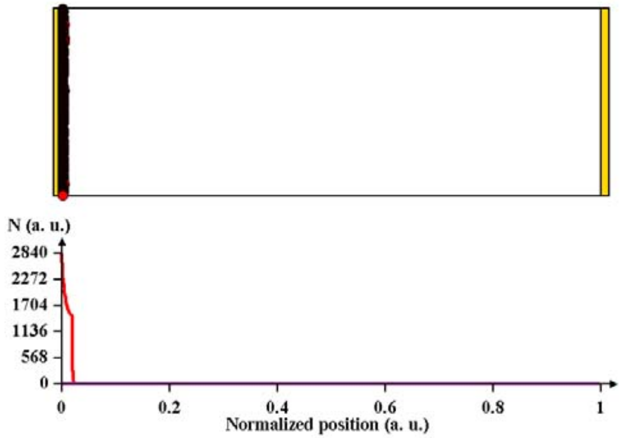


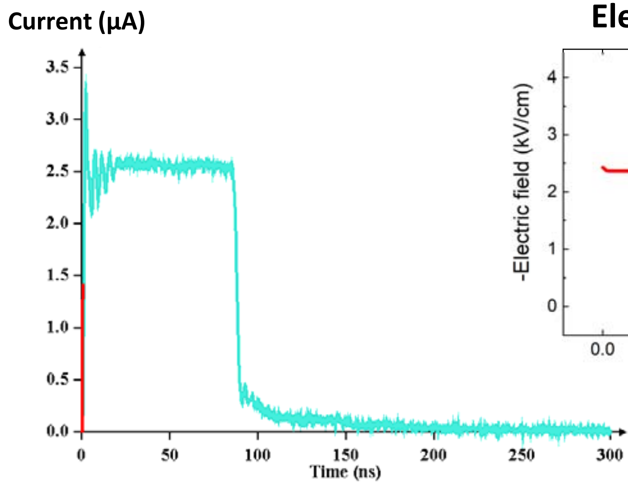
Electric field profile



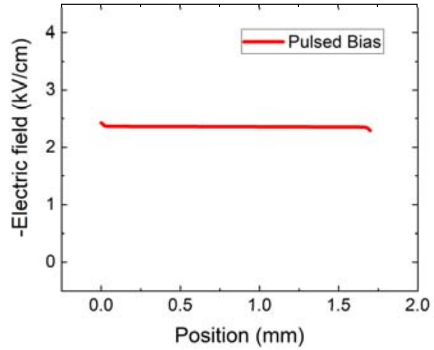
Monte Carlo simulations - electrons

Detector - Pulsed bias

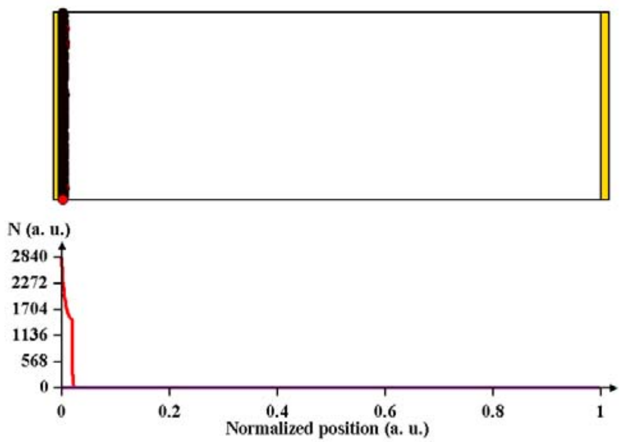


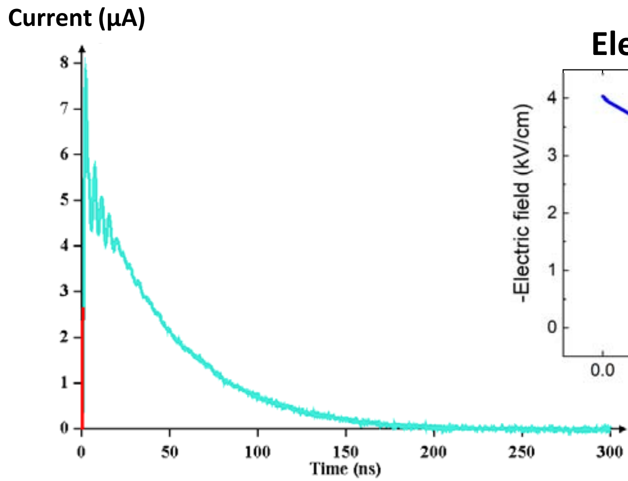


Electric field profile

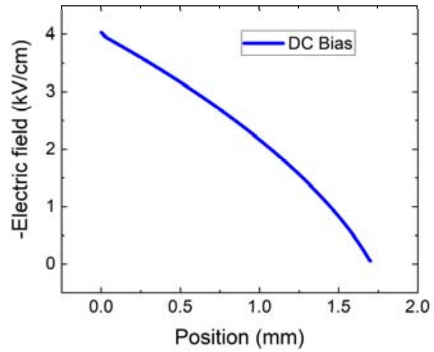


Detector - DC bias



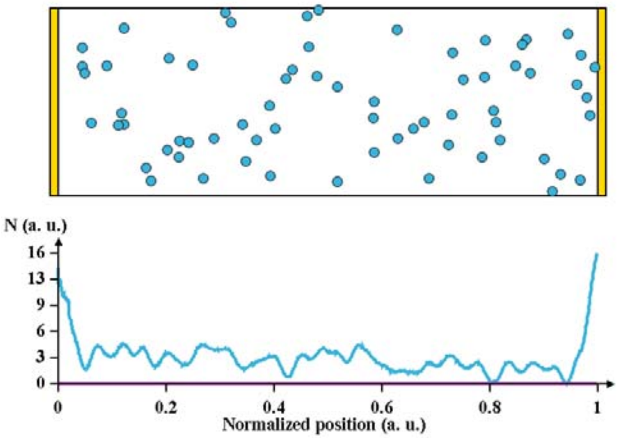


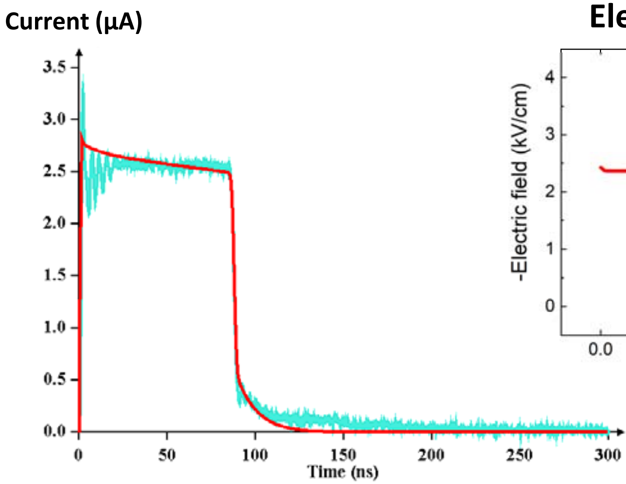
Electric field profile



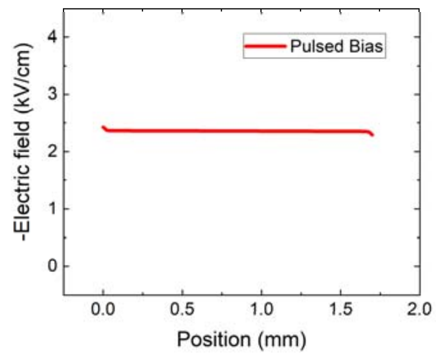
Monte Carlo simulations - electrons

Detector - Pulsed bias

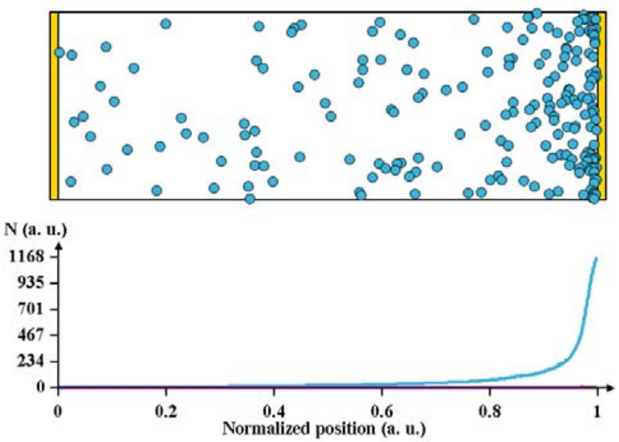


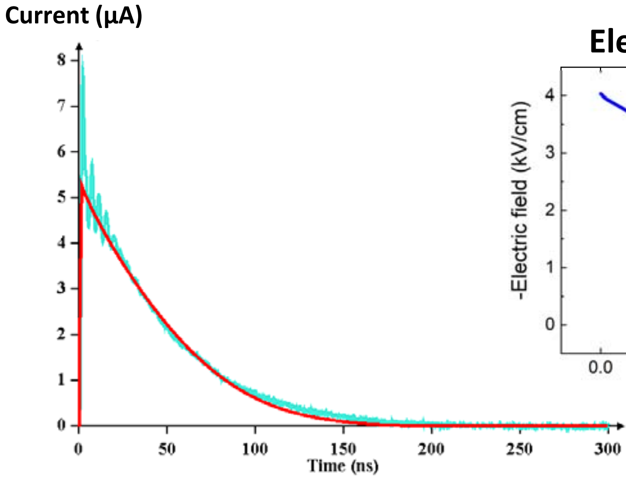


Electric field profile

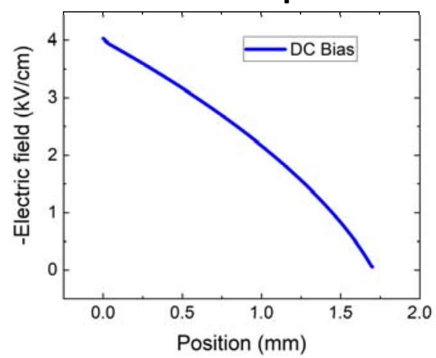


Detector - DC bias





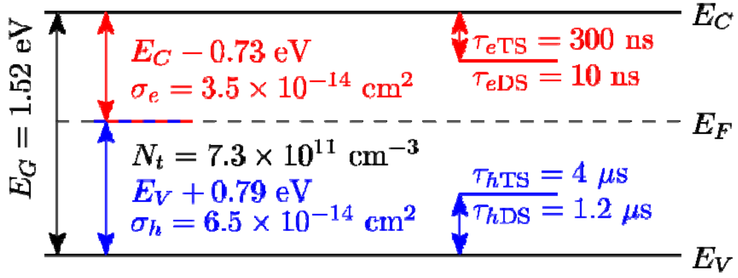
Electric field profile



Space charge dynamics

- Three defect levels are sufficient to describe all observed effects
- Positive space charge forms due to hole injection from anode combined with **recombination level** near Fermi level
- Shallow levels do not contribute to space charge

Band diagram



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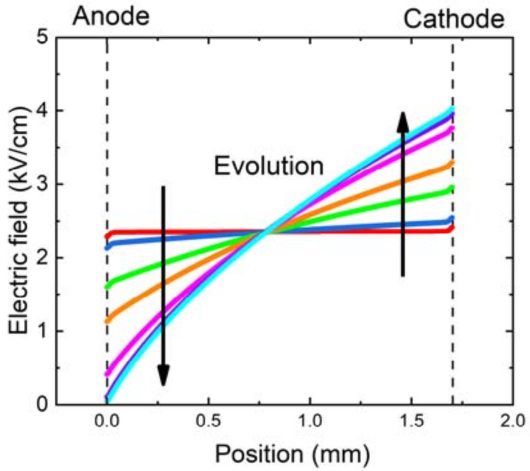
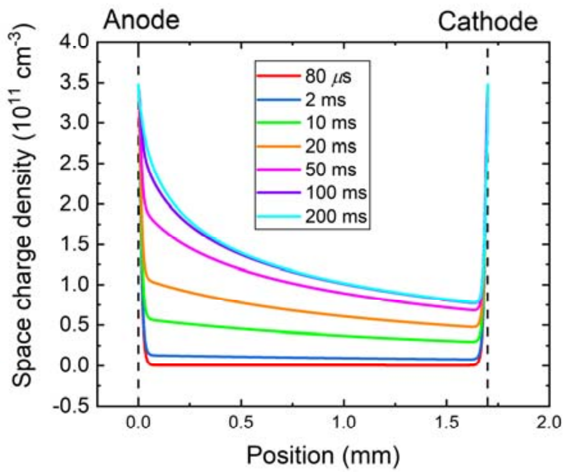
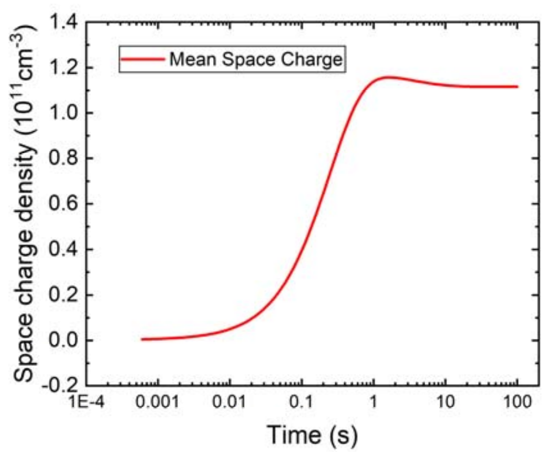


Space charge profile



Mean space charge evolution

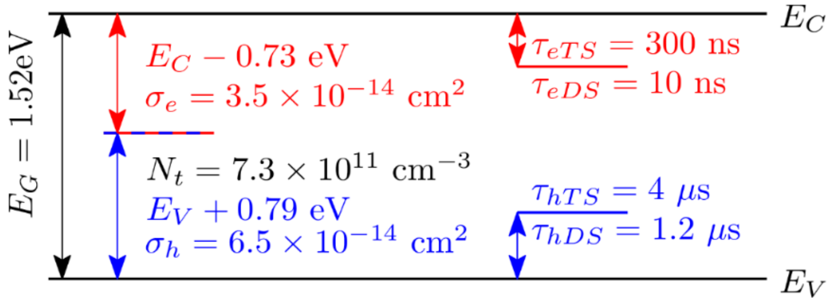


Evaluated parameters

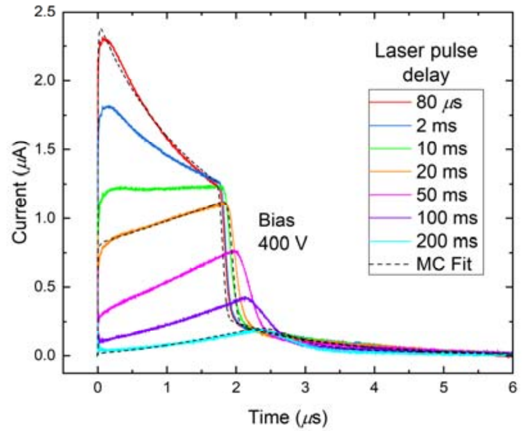
- Same experiment was measured with positive bias for holes
- Identical electric field profile is obtained

- **Evaluated parameters are:**
- Electron mobility $\mu_e = 830\ \mathrm{cm^2/Vs}$
- Hole mobility $\mu_h = 40\ \mathrm{cm^2/Vs}$
- Electron lifetime $\tau_e = 2.3\ \mu\mathrm{s}$
- Hole lifetime $\tau_h = 3.6\ \mu\mathrm{s}$
- Three defect levels:

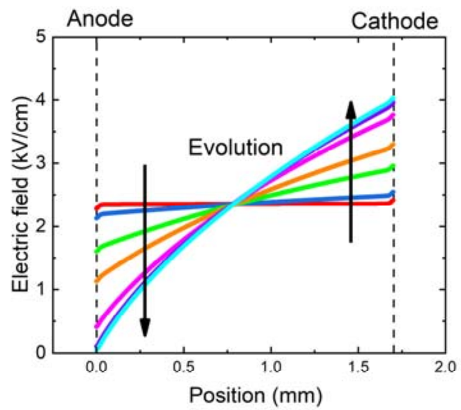
Band diagram



Hole-current waveforms



Electric field profile



Conclusion

- CZTS semiconductor has good electron- and hole-transport properties, and single crystals are suitable for x-ray and gamma-ray detector fabrication
- Transient current technique combined with pulsed bias allow to observe charge transport and space charge dynamics inside detector
- The improvement of the crystal growth technology to suppress the recombination level is recommended

More details in: J. Pipek, M. Betušiak, E. Belas, R. Grill, P. Praus, A. Musiienko, J. Pekarek, U. N. Roy, and R. B. James, **Charge Transport and Space-Charge Formation in Cd1−xZnxTe1−ySey Radiation Detectors**, Phys. Rev. Appl. 15, (2021), doi: 10.1103/physrevapplied.15.054058.

ACKNOWLEDGMENTS

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Thank you for your attention