Transport properties of CdTe/CdZnTe Detectors Characterized by Laser-induced Transient Current Technique

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INTRODUCTION

CdTe/(CdZn)Te single crystals: Materials for the preparation of high performance room temperature X-ray and gamma-ray detectors (optimal energy band-gap, high density and good transport properties).
Growth method: Vertical Gradient Freeze Method

Samples: CdZnTe:In
Planar configuration with "ohmic" (Au/Au) contacts, thickness = 1.2mm.

The goal of this work: Detail investigation of the transport properties of CdZnTe detectors using laser-induced Transient current technique (L-TCT) with laser diode (wavelength 660nm, penetration depth ~360nm, pulse width 3ns, frequency 100Hz, output energy 0.4 nJ) .

Evaluated transport properties: Carrier drift mobility, Space charge density, Internal electric field, Charge collection efficiency [1], Mobility-lifetime product, Carrier lifetime, Surface recombination velocity.

Problem: The effect of internal space charge, non-ohmic contacts and surface recombination [2,3] have to be taken into account for exact determination of transport properties evaluated using L-TCT.

Laser-induced Transient Current Technique (L-TCT)

Theory

[2] Š.Uxa et al, IEEE TNS 59(5), 2402, 2012

$$E(x) = E_0 - ax$$

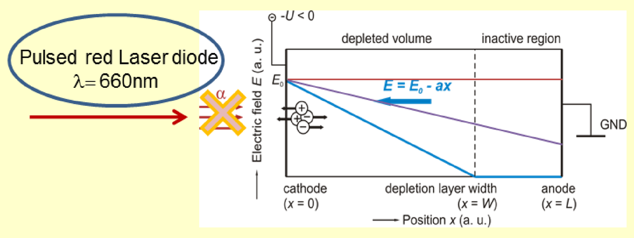
$$x(t) = \frac{E_0}{a}\left(1 - e^{-a\mu t}\right)$$

$$i(t) = Q(t)v(t) \propto e^{-ct}, \quad c = \left(a + \frac{1}{\mu\tau}\right)\mu$$

$$U = E_0 L - \frac{1}{2}aL^2$$

$$ct_{tr} = \left(1 + \frac{1}{a\mu\tau}\right)\ln\left(\frac{1+\frac{aL^2}{2U}}{1-\frac{aL^2}{2U}}\right) \qquad \mu = \frac{L^2}{t_{tr}U}$$

$$x(t_{tr}) = \frac{E_0}{a}\left(1 - e^{-a\mu t_{tr}}\right) = L$$



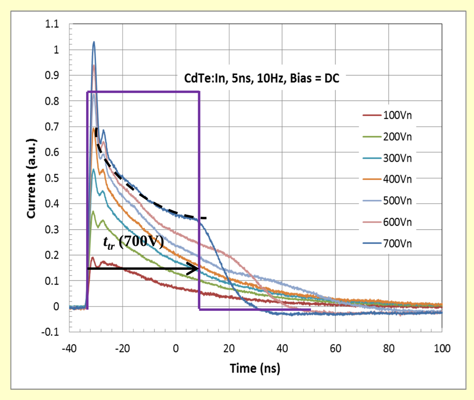
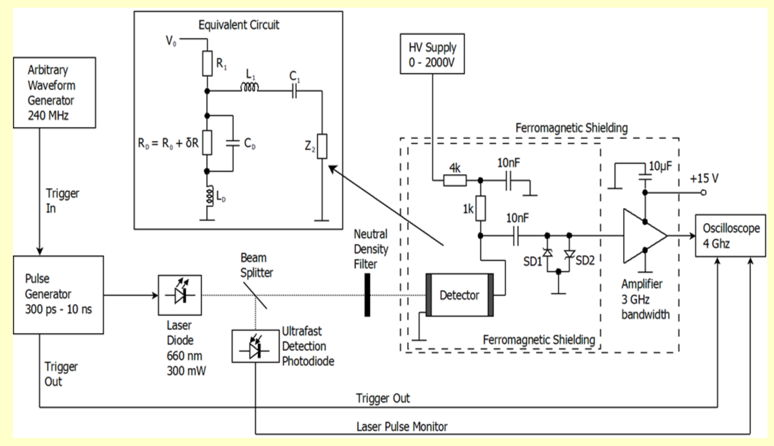


Diagram of the L-TCT setup



Each measured waveform has to be corrected using deconvolution with the device transfer function Details [4]

Evaluated quantities

Transit time t_{tr}, electron/hole drift mobility μ
Space charge density N (value and polarity): $N = \frac{a\epsilon_0\epsilon_r}{e}$

Charge collection efficiency (CCE)

Time-degradation of the charge collection efficiency due to the formation of the internal space charge, which screens applied bias (detector polarization). In case of low fluxes (dark mode) the polarization is due to the free carrier depletion or injection, which results in a variation of deep level occupancy.
The detector polarization depends on the density of deep defects (traps) in the bulk of detector, their energy levels and capture cross sections and on the type of detector metallization.

$$CCE(V) = \frac{1}{L}\frac{\mu}{1+\frac{s}{\mu\cdot\left(\frac{V}{L}+\frac{aL}{2}+ElfS\right)}}\frac{\left(\frac{V}{L}+\frac{a\cdot L}{2}\right)}{\left(a\cdot\mu+\frac{1}{\tau}\right)}\left\{1-exp\left[-\left(a\cdot\mu+\frac{1}{\tau}\right)\cdot\frac{1}{a\cdot\mu}ln\left[\frac{\left(1+\frac{a\cdot L^2}{2\cdot V}\right)}{\left(1-\frac{a\cdot L^2}{2\cdot V}\right)}\right]\right]\right\} \quad if \left|\frac{a\cdot L^2}{2V}\right| < 1$$

$$j(V,t) = \frac{q_0}{L}\frac{\mu}{1+\frac{s}{\mu\cdot\left(\frac{V}{L}+\frac{aL}{2}+ElfS\right)}}\left(\frac{V}{L}+\frac{aL}{2}\right)exp\left[-\left(a\mu+\frac{1}{\tau}\right)t\right]\Phi(t)\Phi(\tau_r(V)-t) \quad if \left|\frac{a\cdot L^2}{2V}\right| < 1$$

$$CCE(V) = 0 \quad if \left|\frac{a\cdot L^2}{2V}\right| < -1$$

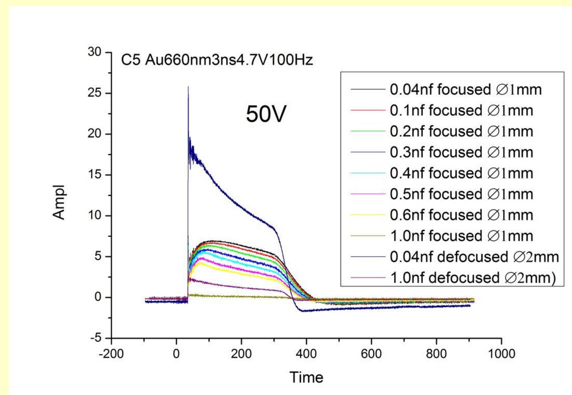
$$j(V,t) = 0 \quad if \left|\frac{a\cdot L^2}{2V}\right| < -1$$

$$CCE(V) = \frac{1}{1+\frac{s}{\mu_e}\frac{1}{\frac{V}{L}+ELfS}}\frac{\mu_e\tau_e V}{L^2}\left[1-exp\left(\frac{L^2}{\mu_e\tau_e V}\right)\right] \quad if\ a = 0$$

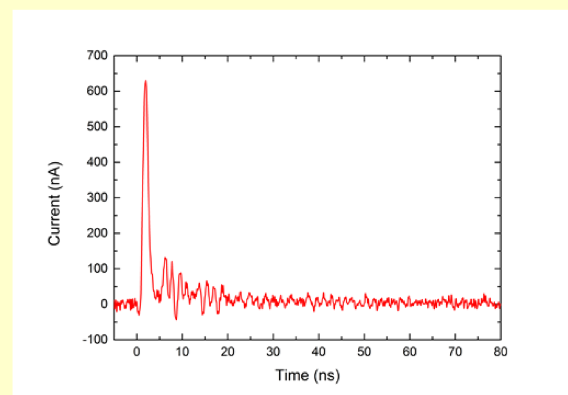
$$CCE(V) = \frac{1}{L}\frac{\mu}{1+\frac{s}{\mu\cdot\left(\frac{V}{W(V)}+\frac{a\cdot W(V)}{2}+ElfS\right)}}\frac{\left(\frac{V}{W(V)}+\frac{a\cdot W(V)}{2}\right)}{\left(a\cdot\mu+\frac{1}{\tau}\right)} \quad otherwise$$

$$j(V,t) = \frac{q_0}{L}\frac{\mu}{1+\frac{s}{\mu\cdot\left(\frac{V}{W(V)}+\frac{aW(V)}{2}+ElfS\right)}}\left(\frac{V}{W(U)L}+\frac{aW(V)}{2}\right)exp\left[-\left(a\mu+\frac{1}{\tau}\right)t\right]\Phi(t) \quad otherwise$$

Screening effect



Photoeffect



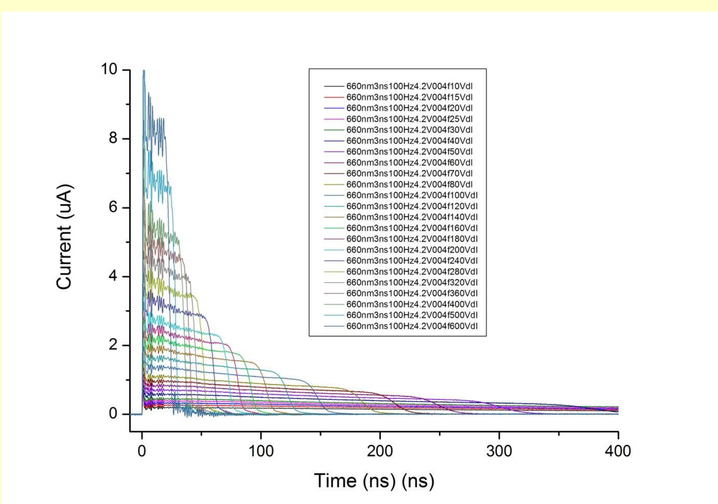
Screening effect: Delayed formation of current waveforms due to the screening of generated carriers

Photoeffect: Photopeak at zero bias, non-ohmic contacts

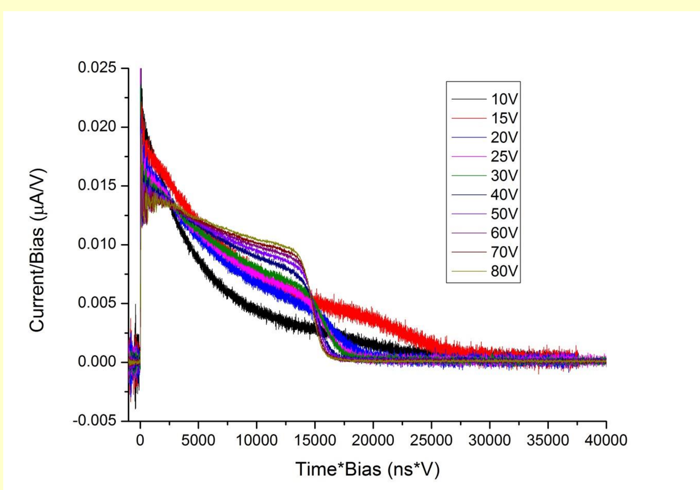
Elimination of the screening effect – low light intensity and defocusing of the laser beam
Limiting factors for detail 2D mapping of the surface of detector

RESULTS

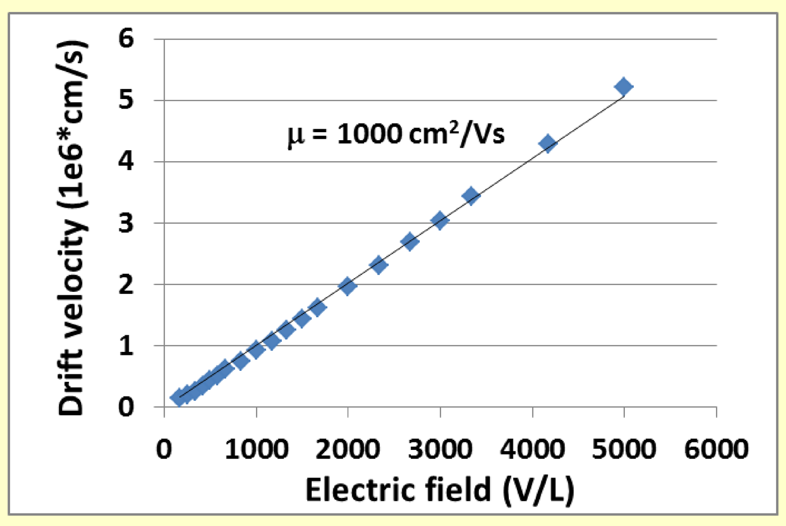
Current transients



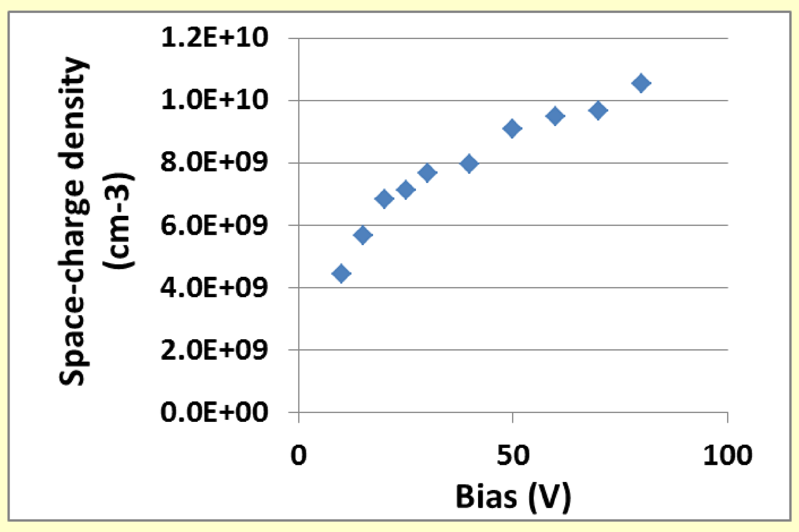
Current transients – low bias



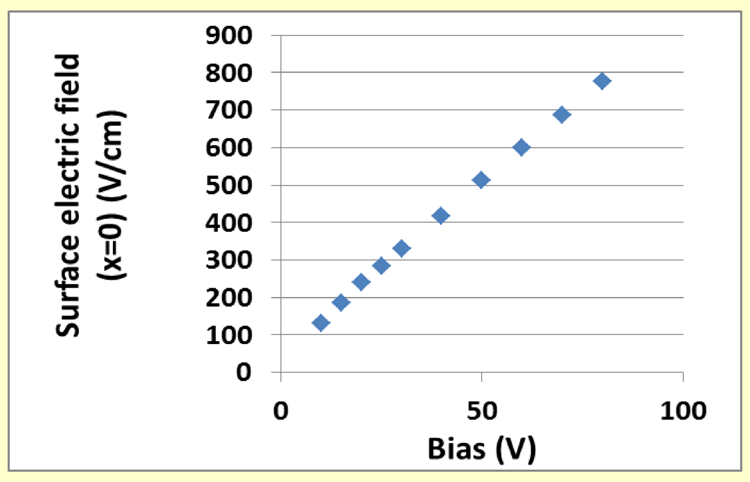
Drift velocity



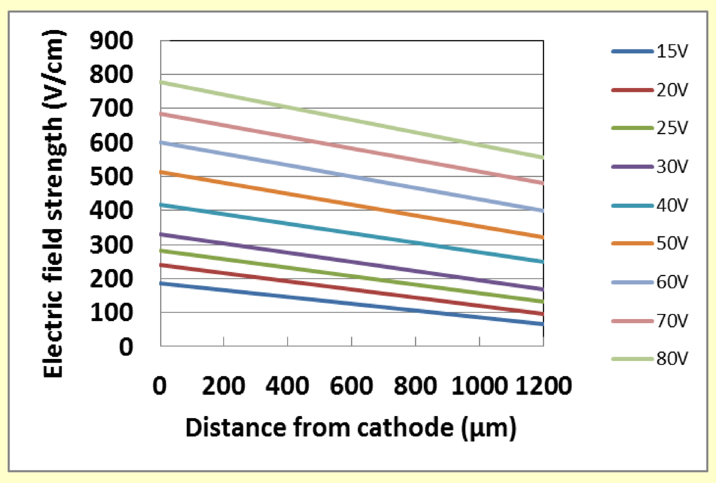
Space-charge density



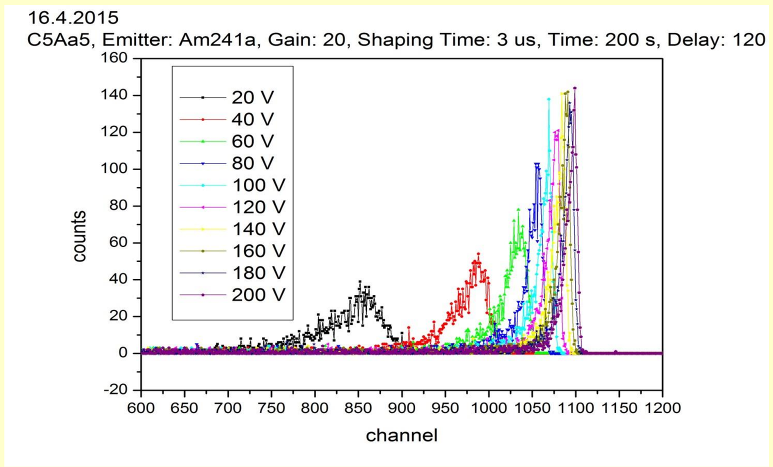
Surface electric field



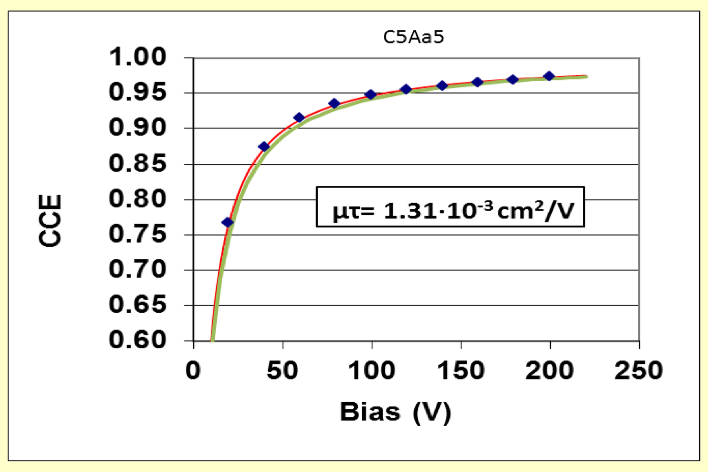
Electric field strength



Pulse height spectra



Hecht equation – Standard and modified fit procedure



CONCLUSION

Transport properties of CdTe/CdZnTe detectors can be easily determined using L-TCT. Modified equation for CCE and current density have to be used in case of existence of the internal space-charge and surface electric field. Characterization of the detectors by standard Hecht equation gives us only a rough information about the spectroscopic quality of the detector. L-TCT enables us investigate detector properties in more details.

References

[1] Š.Uxa, R.Grill, E.Belas, J.Apl.Phys. 114, 094511, 2013.
[2] Š.Uxa, E.Belas, R.Grill, P.Praus, R.B.James, IEEE Trans. Nucl. Sci. 59(5), 2402, 2012.
[3] K. Suzuki, T. Sawada, and K. Imai, IEEE Trans. Nucl. Sci., vol. 58, pp. 1958–1963, 2011.
[4] P.Praus, E.Belas, J. Bok, R.Grill, J. Pekárek, to be published.

Acknowledgement

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