R3A-28 Various Approaches for Charge Collection Efficiency Determination via Hecht Relation on CdTe/CdZnTe Detectors

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Introduction and Theory

High resistivity CdTe and CdZnTe semiconductors are very promising materials for room temperature X-ray and gamma-ray detectors with high charge collection efficiency (CCE) and mobility-lifetime ($\mu\tau$) product [1]. The higher CCE and $\mu\tau$ parameters detector has the more usable material it is. One of the most widespread method for determination of $\mu\tau$ parametr is from collected charge-voltage dependency via single carrier Hecht equation [2]:

$$CCE = \frac{\mu\tau V}{L^2}\left(1 - exp\left(\frac{L^2}{\mu\tau V}\right)\right) \quad \textbf{(H)}$$

which can be set by alpha particle collected charge-voltage dependency. But high energy particles generate enormous amount of electron-hole pairs which leads to plasma effect – inner screening of internal field at the location of a particles absorption [3]. Due to this effect modified Hecht equation can be used [4]:

$$CCE = \frac{\mu\tau(V+Vi)}{L^2}\left(1 - exp\left(\frac{L^2}{\mu\tau(V+Vi)}\right)\right) \quad \textbf{(MH).}$$

The other modification can be set due to surface recombination velocity:

$$CCE = \frac{1}{1+\frac{s}{\mu\left(\frac{V}{L}+\varepsilon_S\right)}}\frac{\mu\tau V}{L}\left(1 - exp\left(\frac{L^2}{\mu\tau V}\right)\right) \quad \textbf{(SH),}$$

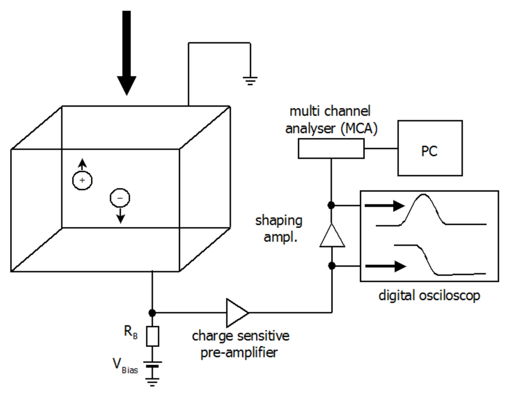
(ε_S – characteristic contribution of band banding to a mean field at the surface)

Experiment

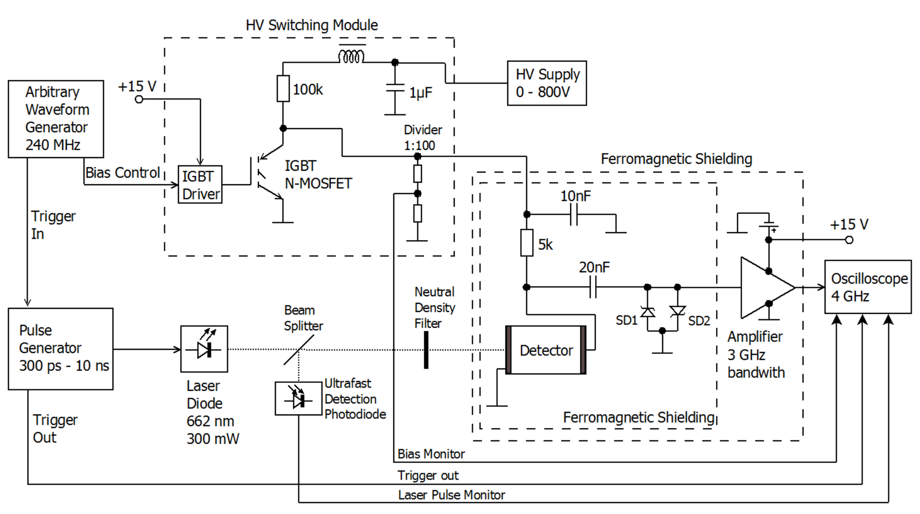
Five methods have been used to set collected charge-voltage dependency:

1. **^{241}Am α (5,5 MeV) particle pulse height spectrum analysis (Alpha) [4]**
2. **^{241}Am γ (59,6 keV) and RTG (17,6 keV) pulse height spectrum analysis (Gamma), (RTG)**
3. **Laser (660 nm) pulse height spectrum analysis (L-TChT)**
4. **Laser (660 nm) Transient Current Technique (L-TCT) [3]**

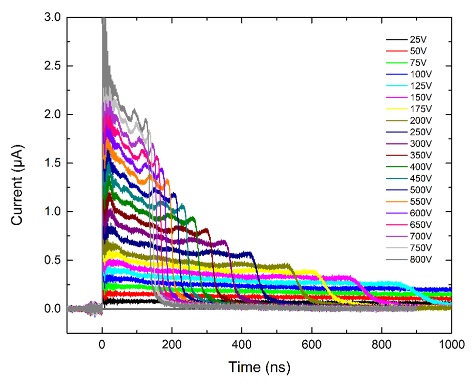
Pulse High Spectrum Analysis



Transient Current Technique (TCT)

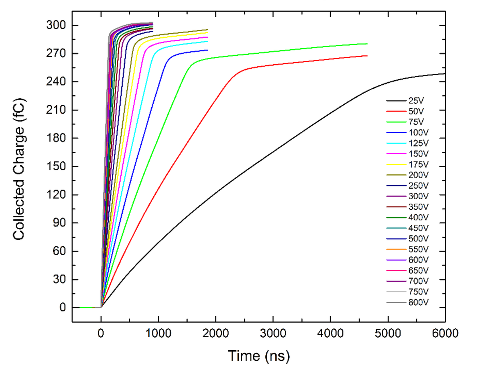


Obtained TCT waveforms



Integration
$Q = \int j(t)\, dt$

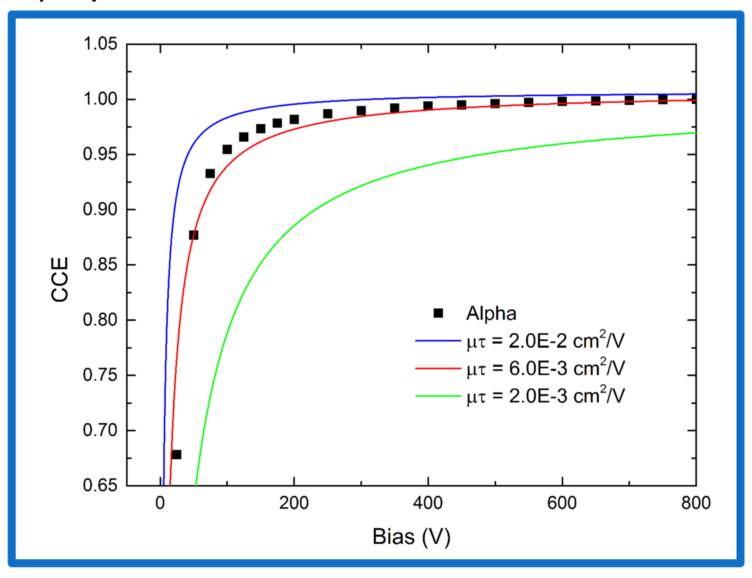
Counted Charges



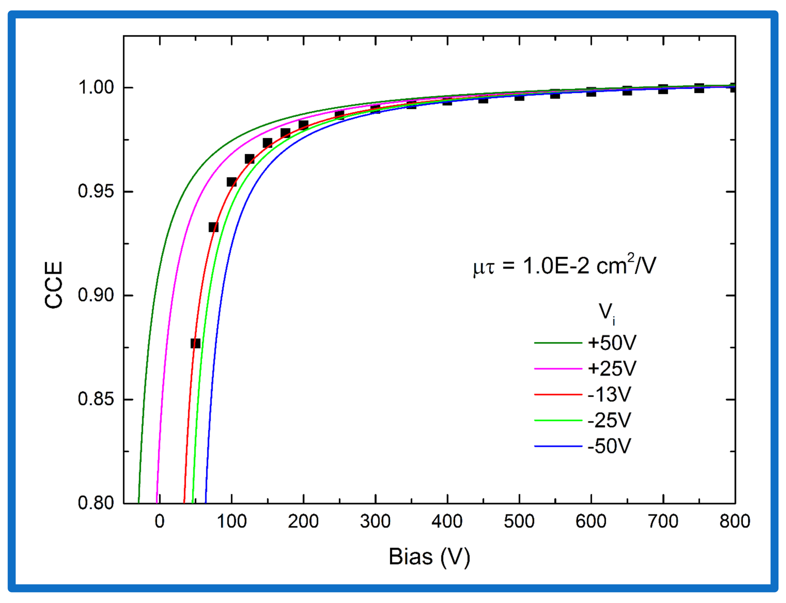
Results and Discussion

Influence of fitting parameters for obtained Alpha particle data of CdZnTe sample (common parameter *L* = 3,15 mm).

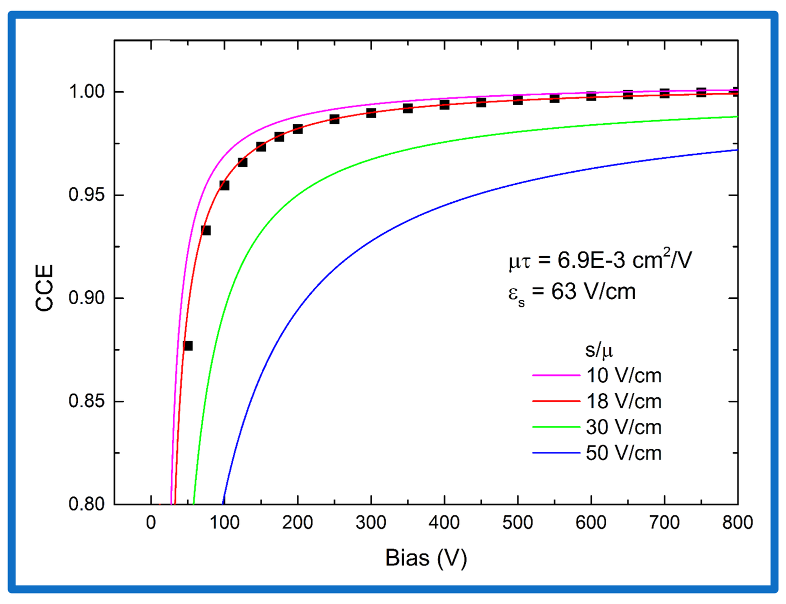
Single carrier Hecht equation (H). Influence of different values of $\mu\tau$ parameter.



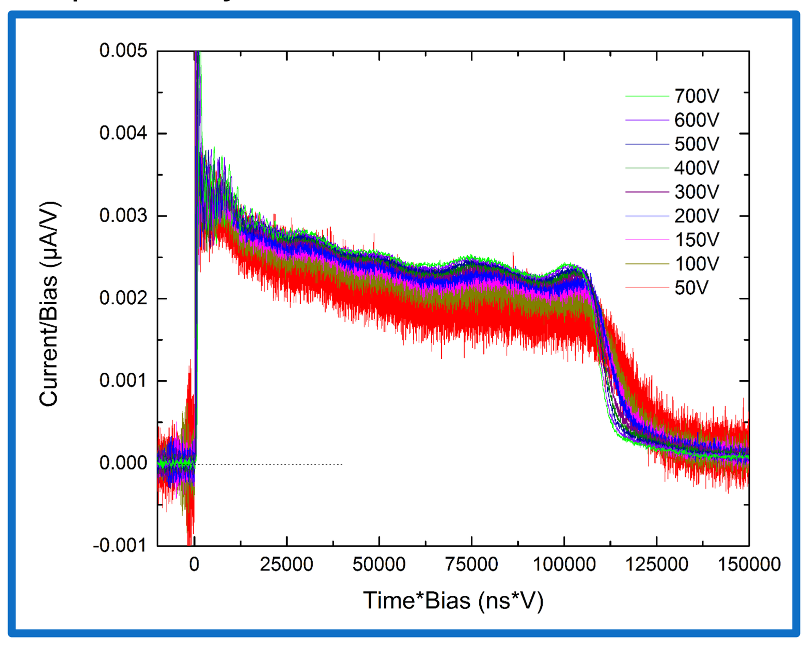
Modified Hecht equation (MH). Influence of different *Vi* produced by polarization field within the device.



Surface Hecht equation (SH). Influence of different surface recombination velocity *s*.

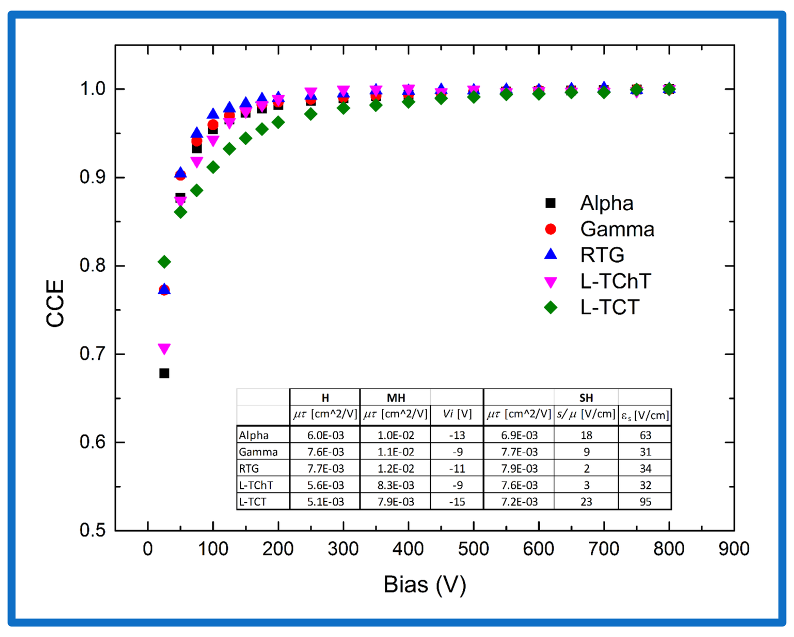


Normalized TCT waveforms of CdZnTe sample. Similar curves indicates a rapid saturation in collected charge-voltage dependency.



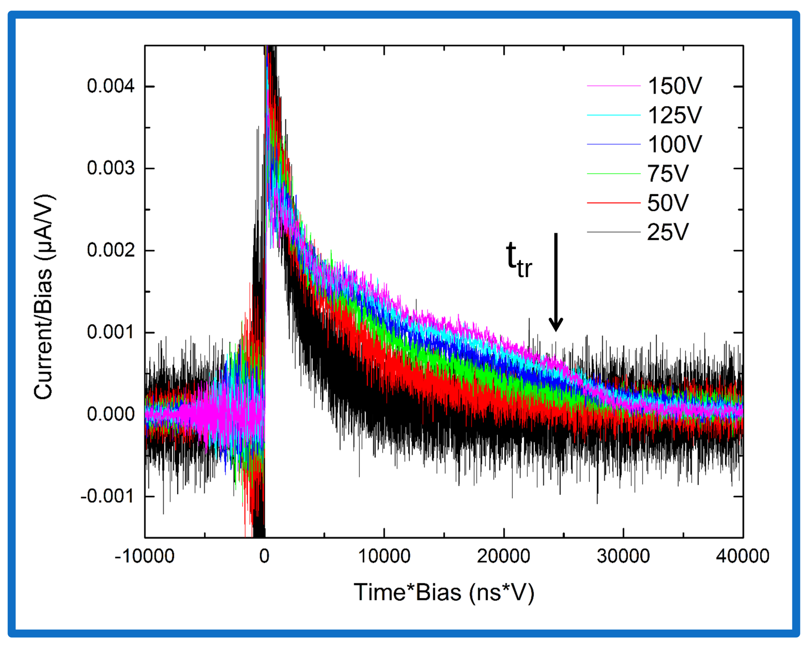
CdZnTe
***L* = 3,15 mm**

Collected charge-voltage dependency of CdZnTe sample. High *Vi* in **(MH)** indicates wrong values of $\mu\tau$. We obtained good match in **(CH)** and **(SH)** for small surface recombination.



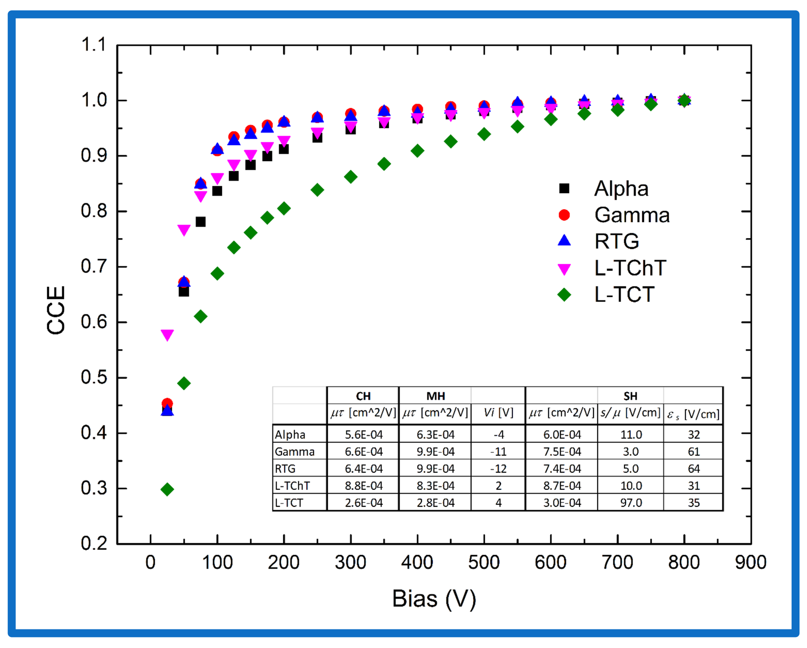
	H	MH			SH	
	$\mu\tau$ [cm^2/V]	$\mu\tau$ [cm^2/V]	*Vi* [V]	$\mu\tau$ [cm^2/V]	s/μ [V/cm]	ε_s [V/cm]
Alpha	6.0E-03	1.0E-02	-13	6.9E-03	18	63
Gamma	7.6E-03	1.1E-02	-9	7.7E-03	9	31
RTG	7.7E-03	1.2E-02	-11	7.9E-03	2	34
L-TChT	5.6E-03	8.3E-03	-9	7.6E-03	3	32
L-TCT	5.1E-03	7.9E-03	-15	7.2E-03	23	95

Normalized TCT waveforms of CdTe:In sample. Low voltages show the absence of transit time, thus we have inactive layer under the anode = low values in collected charge-voltage dependency for those biases.



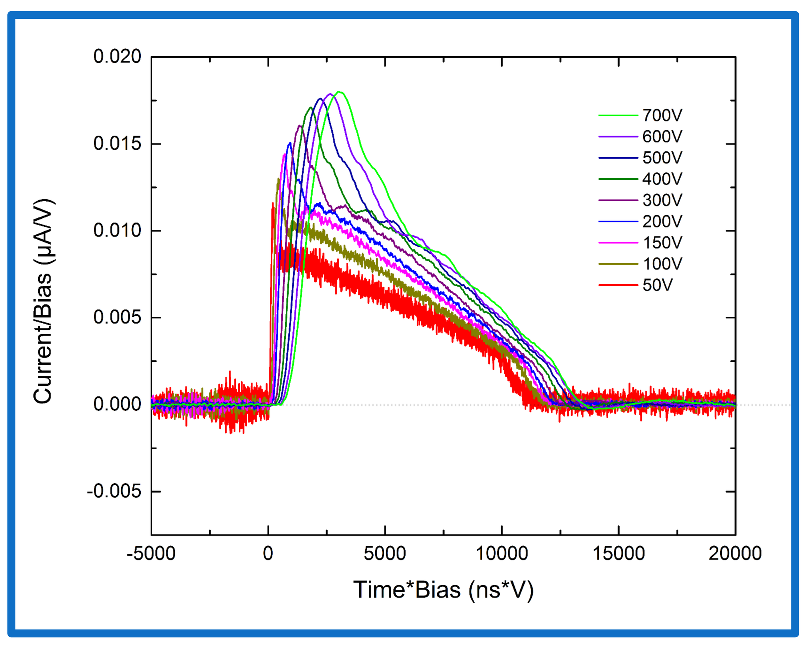
CdTe:In
***L* = 1,65 mm**

Collected charge-voltage dependency of CdTe:In sample. Low obtained values are distored by inactive layer.



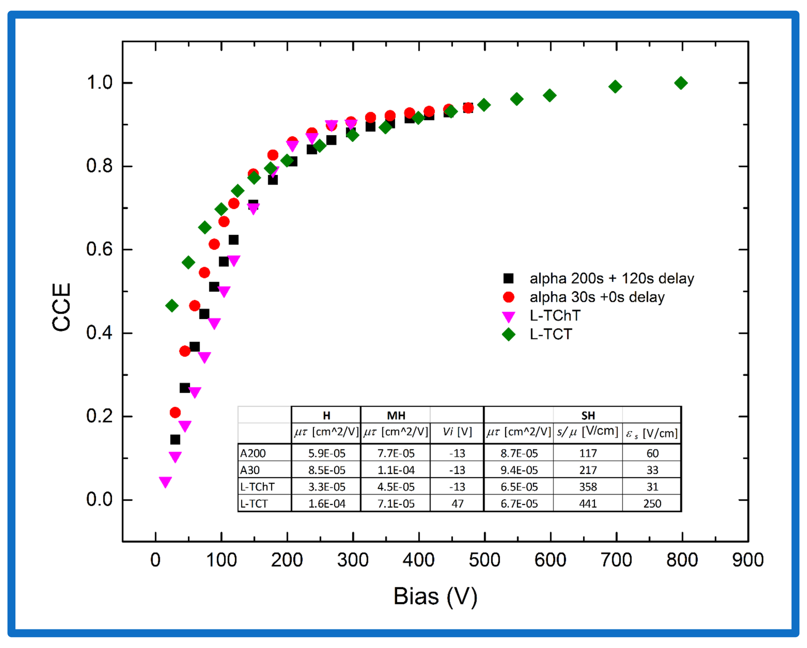
	CH	MH			SH	
	$\mu\tau$ [cm^2/V]	$\mu\tau$ [cm^2/V]	*Vi* [V]	$\mu\tau$ [cm^2/V]	s/μ [V/cm]	ε_s [V/cm]
Alpha	5.6E-04	6.3E-04	-4	6.0E-04	11.0	32
Gamma	6.6E-04	9.9E-04	-11	7.5E-04	3.0	61
RTG	6.4E-04	9.9E-04	-12	7.4E-04	5.0	64
L-TChT	8.8E-04	8.3E-04	2	8.7E-04	10.0	31
L-TCT	2.6E-04	2.8E-04	4	3.0E-04	97.0	35

Normalized TCT waveforms of CdTe:Cl sample. The increasing character correspond to a large surface recombination.



CdTe:Cl
***L* = 1 mm**

Collected charge-voltage dependency of CdTe:Cl sample. Due to a similar resistance of the sample as the value of R_B, it is not possible to measure spectral analysis to higher voltages.



	H	MH			SH	
	$\mu\tau$ [cm^2/V]	$\mu\tau$ [cm^2/V]	*Vi* [V]	$\mu\tau$ [cm^2/V]	s/μ [V/cm]	ε_s [V/cm]
A200	5.9E-05	7.7E-05	-13	8.7E-05	117	60
A30	8.5E-05	1.1E-04	-13	9.4E-05	217	33
L-TChT	3.3E-05	4.5E-05	-13	6.5E-05	358	31
L-TCT	1.6E-04	7.1E-05	47	6.7E-05	441	250

Conclusion

- **Modified surface recombination Hecht equation (SH) gives good values of $\mu\tau$ parameter, if we counted the influence of characteristic contribution of band banding to a mean field at the surface – ε_s.**
- **It is always good to complete spectral analysis with TCT measurements, because the samples with inactiv layer under the low voltages distors the obtained values of $\mu\tau$ parameter due to this effect.**
- **Normalized TCT waveforms show the influence of surface recombination.**
- **Simple modification of Hecht equation (MH) is not sufficient and the high values of *Vi* do not correspond the real state.**

References

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