

Noise spectroscopy of shallow traps in CdTe crystals

P. Schauer

Department of Physics, Faculty of Civil Engineering, Brno University of Technology,
Zizkova 17, Brno, Czech Republic

E-mail: schauer@dp.fce.vutbr.cz

Abstract:

We introduce the noise traps spectroscopy, which is a method of material characterization. This method makes it possible to localize the shallow traps and find out their parameters. It is based on the measurement of the current noise spectral density versus temperature plots for different energies of the sample illuminating monochromatic light. All traps energies can be found in papers of other authors.

SAMPLE DESCRIPTION AND EXPERIMENT SET-UP

For this study a CdTe crystal doped with Cl in an amount ≈ 1800 ppm was selected. Room-temperature parameters of the crystal were as follows: p-type dark conductivity $1.24 \times 10^{-7} \Omega^{-1} \cdot \text{m}^{-1}$, hole mobility $0.0065 \text{ m}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$, electron mobility $0.13 \text{ m}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$, dark hole density $1.8 \times 10^{14} \text{ m}^{-3}$, mobility trapping time product $\mu_e \tau_e^+ = 2 \times 10^{-8} \text{ m}^2 \cdot \text{V}^{-1}$, $\mu_h \tau_h^+ = 7 \times 10^{-9} \text{ m}^2 \cdot \text{V}^{-1}$, sample dark resistance $R_0 = 1.9 \text{ G}\Omega$. The sample was of sandwich configuration with one contact at the bottom (at substrate) and the second one at the upper side of sample. The size of sample: thickness 0.7 mm, cross-section 2 mm^2 . The illumination was provided from the upper side of sample through the semitransparent contact. Both contacts were made by coagulation of gold from AuCl_3 solution.

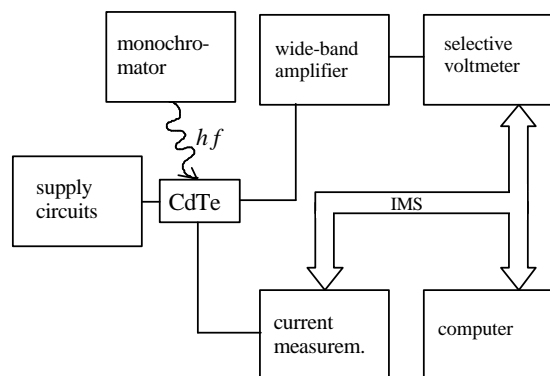


Fig. 1: Block diagram of the setup

In Fig. 1 a block diagram of the apparatus is shown. The used method is described in [1]. The sample circuit, where sample current and noise voltage are measured at one time without any effect on the noise, is in Fig. 2. The CdTe sample was fed from dry cells. The DC current is directly proportional to the

voltage across the resistance R_2 ($R_2 \ll R_L$), which is measured.

Large capacitors C_1 and C_2 (of the order of 1 mF) make an AC bypass, C_3 protects the nano-voltmeters from large DC voltage components. R_V is input resistance of the nano-voltmeter (or preamplifier). The whole setup (with exception for voltmeters) is placed in a steel box which serves to eliminate the electromagnetic smog, which is remarkably high.

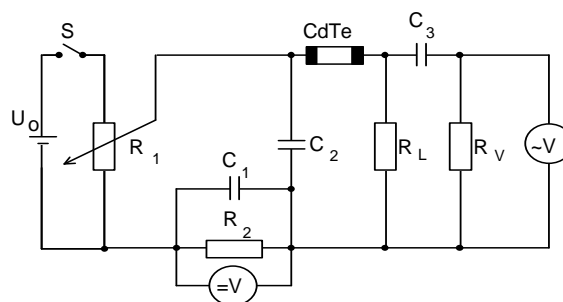


Fig. 2: A circuit measuring sample current and noise at one time

The illumination was provided by the Carl Zeiss mirror mono-chromator with flint glass prism. The light intensity could be adjusted up to $7 \text{ W} \cdot \text{m}^{-2}$. The noise voltage was measured by a sampler and immediately transformed into the corresponding current noise spectral density using FFT. The measured values were recorded and analyzed in a PC.

METHODS OF OTHER AUTHORS

There are several methods for monitoring the energy levels in CdTe crystals. Let us describe briefly some of them. Observation of the activation energy levels in CdTe(Cl) carried out Hoschl in [7] [8] [9]. In determining these levels Hoschl lists four methods: measuring the Hall effect, time of flight method, measuring of the photoconductivity and method of the thermally stimulated currents.

By measuring the temperature dependent Hall effect was determined the level of acceptor activation energy of 0.57 eV. Measurements were performed in a relatively narrow temperature range, since it can not be evaluated at low temperatures when the resistance of samples increased to $10^{12} \Omega$. For un-doped samples was determined activation acceptors energy of 0.15 eV.

Using the method time of flight (TOF) Bell [9] determined several energy levels. As a function of electric field and temperature he measured drift velocity for both electrons and for holes, combined with charge carrier generation by pulsed electron beam. From the reduced mobility Bell has calculated following levels: 0.025 eV and 0.15 eV below the conduction band, 0.15 eV above the valence band. Using the pulsating voltage method, levels 0.05 eV under the conduction band and 0.15 eV and 0.3 eV above the valence band, were obtained.

Höschl [7] has also measured the activation energies 0.1 eV to 1.6 eV using the photoconductivity spectra at temperatures below 80 K. He measured the impurity photoconductivity with and without the additional lighting. Lighting was used to shift positions of the quasi-Fermi levels in the gap of CdTe. The energy levels determined by method of Bube and Rivkin. The found levels are summarized in Table 1.

Mancini [10] measured photoconductivity for temperatures 230 K to 300 K for the samples CdTe(Cl). From the quadratic temperature dependence of the V-A characteristics Mancini identified energy level 0.45 eV above the valence band. Another level of 0.45 eV above the valence band he determined with less precision.

The last method, by which the literature shows the determination of energy levels in the energy gap of CdTe(Cl), is a method of thermo-stimulated current. Measurements were carried out by Höschl [7] using a standard manner, in the temperature range 100 K to 300 K. Excitations were optical, electrical and combined, at low temperatures and during cooling. The activation energies were determined from the steepness of the ramp peak thermo-stimulated current and temperature at maximum current according to Lean. Höschl found five levels, probably holes traps. Energies values you can find below in the Table 1, reference [7].

There are other methods to determine the activation energy levels in the semiconductor energy gap, such as photoluminescence, electro-absorption, etc., but for the crystals CdTe(Cl) such methods have not been used yet.

Table 1. Energy levels measured by other authors. E_c-E is the energy level below the conductivity band; $E-E_v$ is the energy level above the valence band.

E_c-E eV	$E-E_v$ eV	<i>References</i>		
0,01		[2]		
0,02		[3]		
0,025		[4]	[5]	[6] [7]
0,039		[8]		
0,05		[6]	[7]	[9] [10]
0,052		[10]		
0,06		[11]	[12]	
0,09-0,12		[13]		
0,13-0,14		[2]	[14]	[15]
	0,025	[10]		
	0,028	[19]		
	0,034	[18]	[19]	
	0,05-0,06	[8]	[15]	[18]
	0,072	[10]		
	0,076	[10]		
	0,12	[4]	[5]	
	0,13	[16]		

PRINCIPLE OF PRESENTED METHOD

Our method of scanning the shallow traps energies in the energy gap of CdTe is based on spontaneous slow increasing of the sample temperature, while monochromatic light illuminates the sample. In this process, we measure the noise current density. These measurements we make repeatedly for different wavelengths of light, which illuminates the sample.

As the temperature slowly rises during the measurement, it increases the energy band gap of CdTe as well. At a certain temperature and a wavelength of the illuminating light, ideal conditions are created for the occurrence of significantly higher charge carrier exchange between the energy bands (conduction or valence) and the specific trap. It's when the energy difference between the edge of band and the specific trap is equal to the photon energy of light, which illuminates. This specific trap is the subject of our examinations and calculations.

EXPERIMENTAL RESULTS

The Fig. 3 shows the plots of the current noise spectral density S_I versus temperature T for six different energies of the monochromatic light which was illuminating the CdTe sensor. The photon energies are indicated in the picture. All curves exhibit several peaks or local extreme which are numbered.

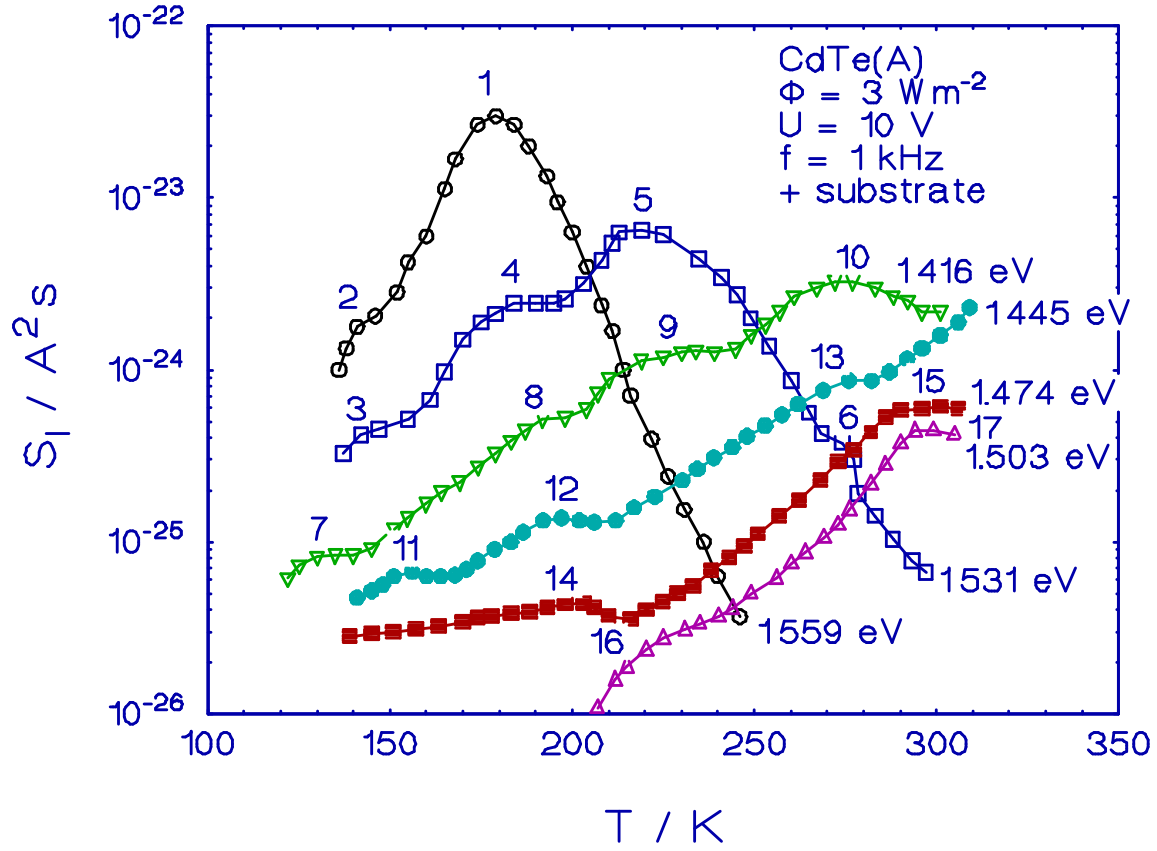


Fig. 3: Current noise spectral density versus temperature plots for various photon energies of the sample illuminating monochromatic light

INTERPRETATION OF MEASUREMENT

On the basis of the dependences in Fig. 3, we carried out an analysis of energy levels behaving as traps. The temperatures T_m , which correspond to the extremes, are given in the Tab. 2. The same table provides also values of the temperature dependent energy band gap $E_g(T_m)$ at the maximum noise temperature T_m . These gaps were calculated from equation given by Strauss [20], for our parameters with constants 1.622 eV and $0.00035 \text{ eV.K}^{-1}$, it means

$$E_g(T) = 1.622 \text{ eV} - 0.00035 \text{ eV.K}^{-1} T, \quad (1)$$

where T is the temperature in Kelvin represented by T_m in our case. Energy levels of the traps were calculated from the difference.

$$\Delta E(T) = E_g(T) - E_p, \quad (2)$$

where $E_g(T)$ is the gap energy calculated by Eq. 1 and E_p is the photon energy of the illuminating monochromatic light.

Let us admit that noise is due to the carrier transitions between the valence band and some levels in the gap near the conductivity band, or, inversely between the conductivity band and some levels near the valence band. Then the energy ΔE would have the meaning of donor or acceptor activation energies except the "levels" corresponding to 0.014 eV denoted with an asterisk, which are due to noise maxima the latter being due to the maximum sensor current. The other noise maxima correspond to each other very well. No maximum appeared which would not have been measured at another photon energy, neither is any maximum missing in the other curve, which in its turn was determined at a given photon energy provided it belongs to the temperature range. As shown in the conclusion, all traps energies can be found in papers of the other authors.

Another important result consists in the calculation of the band gap from No 2 and No 6 maxima at temperatures of 178 K and 257 K respective. This

method can be used to direct calculation of the band gap E_g without allowance to absorption and recombination the latter affecting the calculated band gap when evaluating the photoconductivity measurements.

Table 2. The photon energy E_p and temperature T_m correspond to the curves and their extremes in Fig. 3, energy gap E_g is calculated for temperature T_m in accordance with Eq. 1 and energy level of the ΔE is calculated according to Eq. 2

E_p /eV	Max. No	T_m /K	$E_g(T_m)$ /eV	ΔE /eV
1.559	1	140	1.573	0.014*
	2	178	1.560	-
1.531	3	150	1.570	0.039
	4	185	1.557	0.026
	5	220	1.545	0.014*
	6	275	1.526	-
1.503	7	130	1.577	0.074
	8	195	1.554	0.051
	9	230	1.542	0.039
	10	275	1.526	0.023
1.474	11	150	1.570	0.096
	12	200	1.552	0.078
	13	280	1.524	0.050
1.445	14	205	1.550	0.101
	15	295	1.519	0.074
1.416	16	220	1.545	0.129
	17	292	1.527	0.104

CONCLUSION

Taking into consideration the accuracy of our measurements, we round the results from Tab. 2 with the step 0.005 eV. Then we assign to the energy levels that we found, the references from Tab. 1. Results are bellow:

Table 3. The traps energies we measured and the same energies measured by other authors

E /eV	References
0.025 eV	[4], [5], [6], [7], [10],
0.040 eV	[8],
0.050 eV	[6], [7], [8], [9], [10], [15], [18]
0.075 eV	[10],
0.095 eV	[13],
0.100 eV	[13],
0.105 eV	[13],
0.130 eV	[2], [14], [15], [16].

For each value are given citations by other authors, who found the same levels. Our method therefore shows truly identifies of shallow traps.

This work describes the detection of the shallow traps in CdTe sensors. We define the new testing method, based on the noise-temperature measurement during illumination of the sample.

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