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Electrical Characterization of Defects in Schottky Au–CdTe:Ga Diodes

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Deep electron states in gallium doped CdTe have been studied by deep-level transient spectroscopy method. The Schottky Au–CdTe diodes were processed to perform the investigations. Rectifying properties of diodes have been examined by the room temperature current–voltage and capacitance–voltage measurements. Deep-level transient spectroscopy measurements performed in the range of temperatures 77–350 K yield the presence of three electron traps. The thermal activation energies and apparent capture cross-sections have been determined from related Arrhenius plots. The dominant trap of activation energy $E_2 = 0.33$ eV and capture cross-section $\sigma_2 = 3 \times 10^{-15}$ cm^2 has been assigned to the gallium related DX center present in the CdTe material.

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1. Introduction

It is well known that Ga forms in $Cd_{1-x}Mn_xTe$ metastable defects, so-called DX centers, responsible for persistent photoeffects observed in these materials. The properties of the traps related to DX centers in $Cd_{1-x}Mn_xTe$ have been studied intensively (cf. [1] and references therein). According to the calculations carried out in [2] the shallow Ga state should be metastable with respect to the deep state also for Ga doped CdTe. Recently persistent photoeffects have been observed by us for gallium doped CdTe [3, 4] confirming this theory. However there are no reports on the DX-linked trap in this compound. In present paper in order to investigate the DX-related defect in Ga doped CdTe, deep-level transient spectroscopy (DLTS) method has been applied. The Schottky Au–CdTe diodes have been processed. The rectifying properties of the diodes have been examined by the measurements of room temperature current–voltage (I–V) and capacitance–voltage (C–V) characteristics.

According to the thermionic emission model, the I–V characteristics of a metal–semiconductor junction can be analyzed by the following equation [5]:

$$I = I_0 \exp\left(\frac{qV}{nkT}\right)\left[1 - \exp\left(-\frac{qV}{kT}\right)\right]$$
$$\text{with} \quad I_0 = SA^*T^2 \exp\left(-\frac{q\Phi_B}{kT}\right). \quad (1)$$

I_0 is the saturation current, q — the electron charge, n — ideality factor, k — the Boltzmann constant, T — temperature, S — the contact area and Φ_B — Schottky barrier height. A^* is the effective Richardson constant: $A^* \cong \frac{m*}{m_0}\frac{\text{A}}{\text{cm}^2\text{K}^2}$. For CdTe $\frac{m*}{m_0} \cong 0.1$ resulting in $A^* \approx 12\ \frac{\text{A}}{\text{cm}^2\text{K}^2}$. The saturation current can be determined by extrapolating the linear region of the forward $\ln I$ versus V curve to zero voltage, for $V \geq 3kT/q$ and then the Schottky barrier height can be deduced. The ideality factor of the diode can be calculated from the slope of the linear region.

For a metal–n-type semiconductor Schottky diode, C–V measurements yield the donor net concentration N_D and the value of built-in voltage V_{bi}. The relation between capacitance and voltage is given by [6]:

$$\frac{S^2}{C^2} = \frac{2(V_{bi} + V)}{\varepsilon_s \varepsilon_0 q N_D}, \quad (2)$$

where ε_s is the semiconductor permittivity and ε_0 — the permittivity in vacuum. The slope of the S^2/C^2 against V plot reveals N_D whereas V_{bi} can be obtained from the intersection between the S^2/C^2 line and voltage axis. The Schottky barrier height and built-in voltage are interrelated [6]:

$$\Phi_B = V_{bi} + V_n + \frac{kT}{q} \quad (3)$$

with V_n — the distance between the bottom of conduction band and Fermi level given by following equations:

$$V_n = \frac{kT}{q} \ln \frac{N_C}{N_D} \quad \text{with}$$
$$N_C = 4.83 \times 10^{15} T^{3/2} \left(\frac{m*}{m_0}\right)^{3/2} \text{cm}^{-3}. \quad (4)$$

N_C is the effective density of states at the bottom of conduction band. Equations (3) and (4) allow to calculate Φ_B once N_D and V_{bi} are known.

The dynamic process of capture and emission of electrons by majority deep traps in a Schottky metal–n-type semiconductor can be described in terms of a capture cross-section, σ_n, and emission rate, e_n. The electron emission rates are related to capture cross section by detailed balance equation [7]:

$$e_n = \sigma_n \nu_{\text{th}} N_{\text{C}} \exp\left(-\frac{E_{\text{T}}}{kT}\right), \tag{5}$$

where v_{th} is a thermal velocity of electrons and E_{T} is the apparent activation energy for transient emission. In the case of the DLS-82E system used in the DLTS experiment, the signal peak takes place at a temperature where lock-in frequency is related to emission rate by equation $e_n = 2.17f$. From Arrhenius plot i.e. the plot of experimentally obtained emission rates divided by the square of the temperature corresponding to the signal peak (e_n/T^2) versus reciprocal temperature ($1/T$) apparent activation energy E_{T} and capture cross-section σ_n of a trap can be determined. If the concentration N_{T} of the traps is much less than the donor concentration N_D, it can be found using relationship [7]:

$$N_{\text{T}} = 2N_{\text{D}}\frac{\Delta C}{C}, \tag{6}$$

where $\Delta C/C$ is the relative change in capacitance corresponding to the signal peak amplitude.

2. Experiment

The samples of gallium doped CdTe were processed by the Bridgman method. The Schottky barriers were prepared by vacuum evaporation of gold 1 mm^2 layer on front side of the CdTe slices chemically etched in a 2% Br_2 in methanol solution. Indium soldered to the backside of the slices served as an ohmic contact. *I–V* measurements were performed with the constant current Keithley source, *C–V* measurements — with Boonton 7200 capacitance bridge. DLTS measurements were done by DLS-82E System, SEMITRAP, Hungary.

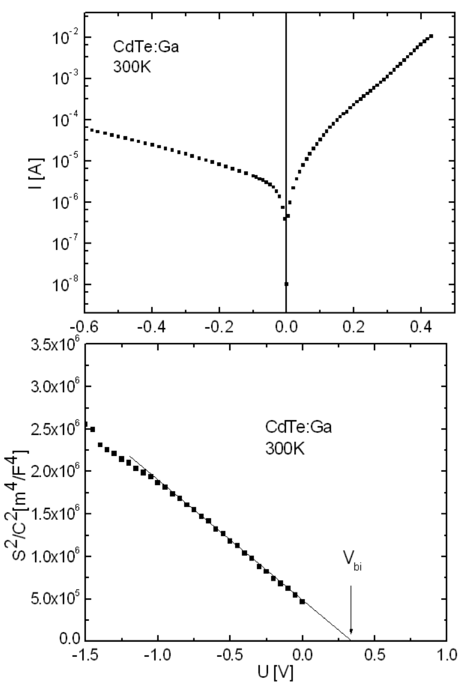

Fig. 1. Room temperature (a) *I–V* and (b) *C–V* characteristics.

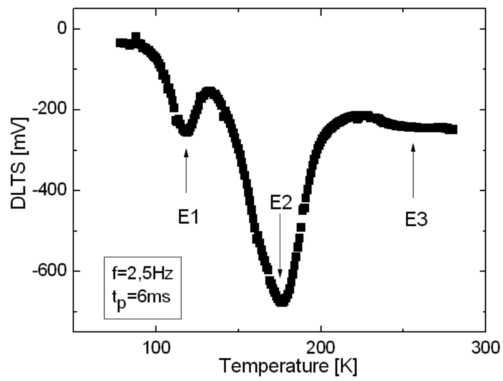

Fig. 2. Typical saturated DLTS spectra.

Figure 1a shows a sample room temperature *I–V* curve. The ideality factor and Schottky barrier height determined by Eqs. (1) and (2) were found to be equal to $n = 2$ and $\Phi_{\text{B}} = 0.33$ V.

In Fig. 1b the room temperature $\frac{S^2}{C^2}$–V characteristics is given. A good linearity of the characteristics up to -1 V allowed to apply Eq. (3) and Eq. (4) to determine $V_{\text{bi}} = 0.33$ V, $N_{\text{D}} = 4.6 \times 10^{16}$ cm^{-3}, $V_n = -0.05$ V and $\Phi_{\text{B}} = 0.38$ eV.

DLTS measurements were performed within the 77–350 K range of temperature and for different lock--in frequencies (in the range of 2.5 Hz–2.5 kHz). During the DLTS measurements the reverse bias was set at 1.5 V and periodically pulsed to 0 V for trap filling. Saturated capacitance transients were obtained with a pulse width of 6 ms. A sample DLTS temperature scan measured at 2.5 Hz lock-in frequency is presented in Fig. 2.

Three peaks labeled as E_1, E_2 and E_3, related to majority electron traps can be noted. The concentration of the defects related to the dominant trap E_2 determined from Eq. (6) equals to $N_{\text{T2}} \approx 4 \times 10^{15}$ cm^{-3}. DLTS

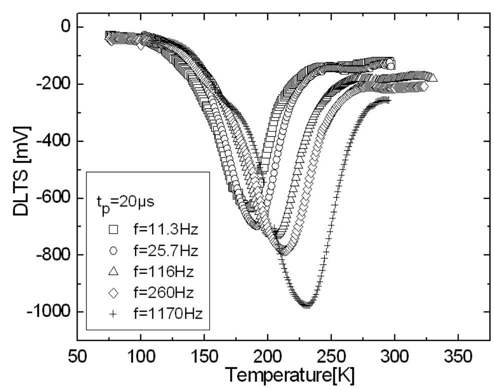

Fig. 3. DLTS spectra for different lock-in frequency. Reverse bias 1.5 V, filling pulse height 1.5 V and its width $t_{\text{p}} = 20$ μs.

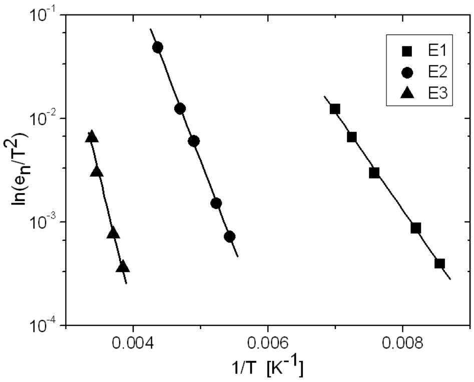

Fig. 4. Arrhenius plots for the traps E_1, E_2 and E_3.

spectra taken for different lock-in frequency are collected in Fig. 3. The Arrhenius data for the three levels are presented in Fig. 4. Apparent activation energies and capture cross-sections determined from the slope and intercept of a linear least squares fit to each set of data are summarized in Table. In Ref. [1] it has been shown that DX related DLTS signal predominates and its amplitude increases with increasing lock-in frequency, indicating thermally activated capture cross-section. Such a property exhibits the trap E_2. It is assumed that this trap is connected with gallium related DX centers in the studied CdTe.

TABLE

Apparent activation energy, capture cross--section and trap concentration.

Trap	E_T [eV]	σ [cm^2]	N_T [cm^{-3}]
E_1	0.19	10^{-16}	$\approx 10^{15}$
E_2	0.33	3×10^{-15}	4×10^{15}
E_3	0.53	1.3×10^{-14}	$\approx 10^{15}$

3. Conclusions

Fundamental electrical parameters of the Schottky Au–CdTe diodes have been determined. Their rectifying properties have been examined by the room temperature I–V and C–V measurements. The ideality factor was found to be equal close to 2 and donor net concentration $N_\mathrm{D} = 4.6 \times 10^{16}$ cm^{-3}, the value of built-in voltage $V_\mathrm{bi} = 0.33$ V and the barrier height $\Phi_\mathrm{b} \approx 0.38$ eV. DLTS measurements have been performed within the range of temperatures 77–350 K. Three electron traps have been observed in the DLTS spectra. Apparent activation energies and capture cross-sections determined from related Arrhenius plots are following: $E_1 = 0.19$ eV, $\sigma_1 = 10^{-16}$ cm^2, $E_2 = 0.33$ eV, $\sigma_2 = 3 \times 10^{-15}$ cm^2, $E_3 = 0.53$ eV and $\sigma_3 = 1.3 \times 10^{-14}$ cm^2. The trap E_2 is the predominant one. Its concentration equals to $N_\mathrm{T2} \approx 4 \times 10^{15}$ cm^{-3} and it exceeds the concentrations of the other traps. This trap has been assigned to the gallium related DX center present in the CdTe material.

Acknowledgments

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