Properties of $Cd_{1-x}Zn_xTe$ crystals grown by High Pressure Bridgman (HPB)

A. Drighil, R. Adhiri, C. Sribi, M. Mousstad
L.P.S.C.M., Université Hassan II-Mohammedia faculté des Sciences Ben M'sik Département de Physique Casablanca (MAROC)
K. Cherkaoui, G. Marrakchi and A. Zerrai
L.P.M., INSA Lyon, 20, Av. Albert Einstein, F 69621 Villeurbanne (FRANCE)
M. Zazoui
L.P.M.C., Université Hassan II-Mahammadia Faculté des Sciences et Techniques Mohammadia . Département de Physique Mohammadia (MAROC)

$Cd_{1-x}Zn_xTe$ crystals grown by High Pressure Bridgman are promising for nuclear detection and are already widely used and studied for this application. Phase precipitation is identified for the first time in such HPB grown crystals, more or less pronounced depending on the samples studied. PICTS analyses allow detection of deep levels, which are not revealed by other current spectroscopy techniques generally used, as they enable scanning of a wider region of the energy gap. Four levels have been detected (0.18 eV, 0.32 eV, 0.96 eV, and 1.09 eV).

I. INTRODUCTION

In recent years, most of the investigations have been interested in semiconductor II-VI (CdTe) with a high resistivity ($\rho = 10^7 - 10^{10}$ Ωcm). This high resistivity is caused by intrinsic defects and residual impurities existing in the forbidden band. One of the main constituents of the intrinsic defect in CdTe is the doubly charged Cd Vacancy (V_{Cd}^{2-}) [1]. It is important to determine the apparent thermal activation energy, capture cross section, and the concentration of traps in high resistivity semiconductors CdTe and CdZnTe.

$Cd_{1-x}Zn_xTe$ crystals grown by High Pressure Bridgman method are promising material for such applications. Its uses cover a wide range from medical physics, as a detector for x-rays and γ rays, to optoelectronics, as a substrate material and a superlattice component.

Recent results [2] have shown the possibility of correlation between the observed structure, nuclear detection performances and the presence of deep levels found in the gap of this material. In order to detect and to identify deep level defects many methods are currently used, such as Deep Level Transient Spectroscopy (DLTS) [3], Deep Level Optical Spectroscopy (DLOS) [4], Photoluminescence (PL) [5], and Photo-Induced Current Transient Spectroscopy (PICTS) [6]. Between them the PICTS method is considered a powerful tool for deep level general survey studies.

In this paper, we describe the method of PICTS, and we present a detailed study performed on the deep energy levels present in $Cd_{1-x}Zn_xTe$ crystals grown by High Pressure Bridgman. The PICTS data will be presented showing the deep levels and the capture cross section.

II. PRINCIPLE OF THE PICTS METHOD

A. Theoretical model of the PICTS technique

In order to explain the PICTS method in a high resistivity bulk material, we consider the minimal level diagram as shown in figure 1.

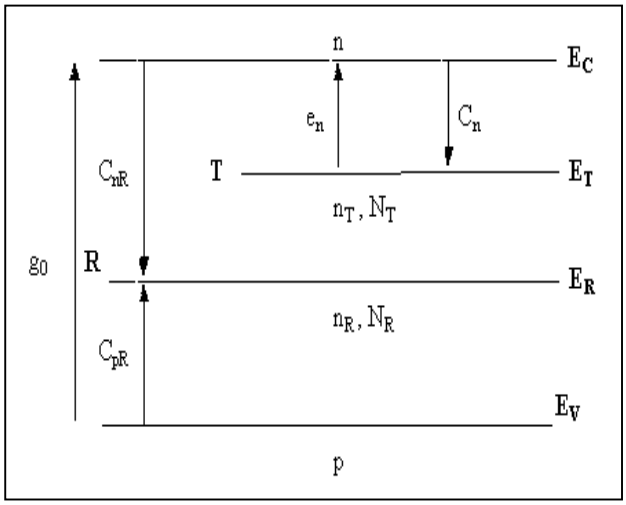

FIG.1. Minimal energy level diagram

g_0 is the generation rate of electron-hole pairs produced by intrinsic photo-excitation; C_n and C_{nR}, the capture coefficients for electrons; e_n, the emission rate of electrons; n_T and n_R, the densities of trapped electrons; N_T and N_R, the densities of the centres; E_T, indicates the energy level of deep electron traps; E_R, the energy level of fast recombination centres; E_C, the energy level of the bottom of conduction band; E_V, the energy level of the top of valence band; C_{pR}, the capture coefficient for holes; and n and p, the densities of free-carriers.

Figure 2 shows a typical shape of the transient. The steep rise (AC) is due to the generation of free photocarriers. Trapping takes place between C and D. The fast current drop (DE) at the end of excitation corresponds to the recombination of the photocarriers. The slow decay of traps occurs over the range (EF) which is the component of interest for PICTS measurements.

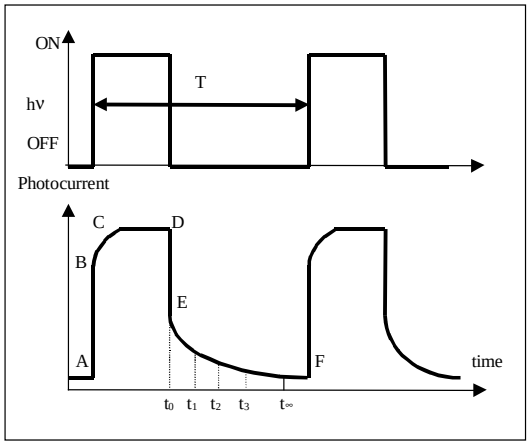

FIG.2. Shape of the photocurrent transient induced by a square light pulse

B. 2-The main equation in PICTS spectroscopy

Under photo-excitation, dynamic equation is well known [7-8]:

$$\frac{dn}{dt} = g_0 + e_n n_T - nC_n(N_T - n_T) - \frac{n}{\tau_n} \qquad (1)$$

$$\frac{dn_T}{dt} = nC_n(N_T - n_T) - e_n n_T \qquad (2)$$

Where $$\frac{1}{\tau_n} = C_{nR}(N_R - n_R) \qquad (3)$$

τ_n is the lifetime of free-electrons,

After interrupting photo-excitation, if we neglect the possibility of recapturing of freed electrons from empty, we obtain the rate equations

$$\frac{dn}{dt} = e_n n_T - \frac{n}{\tau_n} \qquad (4)$$

$$\frac{dn_T}{dt} = -e_n n_T \qquad (5)$$

From equation (4) and (5), we obtain

$$\frac{dn}{dt} + \frac{n}{\tau_n} = n_T(0) e_n \exp(-e_n t) \qquad (6)$$

Where $n_T(0)$ is the initial density of trapped electrons just before the moment when the photo-excitation is turned off. We assume that τ_n is a constant which is fairly short and (n/τ_n) is much larger than (dn/dt). The transient of the free-electrons density is given by:

$$n(t) = n_T(0) e_n \tau_n \exp(-e_n t) \qquad (7)$$

If it is assumed that the photocurrent is associated only with electrons, the transient current after interrupting the photo-excitation, i(t, T) is given by:

$$i(t,T) = qEA\mu_n(T)\tau_n(T)N_T e_n \exp(-e_n t) \qquad (8)$$

Where $\mu_n(T)$ is the electron mobility; q, the charge of an electron; A, the effective cross section area; T, the absolute temperature; E, the applied electric field.

e_n is given by

$$e_n = \sigma_n V_{th,n} N_C \exp\left[-\frac{E_C - E_T}{K_B T}\right] \qquad (9)$$

Where $V_{th,n}$ is the thermal velocity of electron

$$\left(V_{th,n} = \left(\frac{3KT}{m_n^*}\right)^{1/2}\right);$$

Nc is the effective density of states in the conduction band

$$\left(N_C = 2\left(\frac{2\Pi m_n^* KT}{h^2}\right)^{3/2}\right);$$

K_B, Boltzmann's constant.

Therefore, the rate of emission becomes

$$e_n = K_n T^2 \sigma_n \exp\left[-\frac{E_C - E_T}{K_B T}\right] \qquad (10)$$

$$K_n = \frac{V_{th,n} N_c}{T^2}$$

Since many sets of $e_{n,m}$ $(=1/\tau_m)$ and T_m are given by calculation and PICTS measurement, we can obtain the trap activation energy (Ec - Et) and the capture cross section (σ_n) from the plot of log $(\tau_m T_m)$ versus T_m^{-1}

III. PROCESSING OF THE TRANSITORY

We evaluated various data processing methods from a more theoretical point of view that will provide information on deep levels involved in the photocurrent decay. In practice the double-gate technique has proved to be the most reliable for the determination of trap parameters [9]. The processing consists in measuring the current at the times t_1 and t_2 (Fig.2) in the emission limited regime, and in plotting the difference $\delta i(t) = i(t_1) - i(t_2)$ as a function of the temperature T.

Under condition of high excitation, which corresponds to the saturation of the traps, the transient current $\delta i(t)$ for electron trap emission is given by:

$$\Delta i_{12}(t) = qAE\mu_n\tau_n \frac{n_t(o)}{\tau_t}\left[\exp\left(-\frac{t_1}{\tau_t}\right) - \exp\left(-\frac{t_2}{\tau_t}\right)\right] \qquad (11)$$

It is clear that the function goes through a maximum at a temperature T_m. At this temperature, τ_m can be related analytically to t_1 and t_2, by searching the maximum of the double gate function:

$$f(t,T) = \exp\left(-\frac{t}{\tau_t}\right) - \exp\left(-\frac{t_2}{\tau_t}\right) \qquad (12)$$

yielding the solution

$$\frac{t_2 - t_1}{\tau_m} = Log\left(\frac{t_2 - \tau_m}{t_1 - \tau_m}\right) \qquad (13)$$

The interesting point is, that for different values of (t_1, t_2), different T_m will be produced. The Arrhenius plot of $\log(\tau_m T_m)$ versus T_m^{-1} will thus yield the trap parameters.

IV. PICTS RESULTS AND DISCUSSION

The electrical characterisation of the deep levels in $Cd_{0.9}Zn_{0.1}Te$ revealed the existence of four major traps. The PICTS spectra are reported in figure 3. The photocurrent peaks revealing the trap presence appear at about the same temperature.

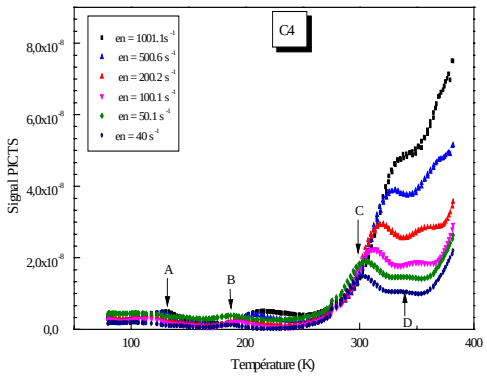

FIG. 3. The PICTS spectra for the sample $Cd_{1-x}Zn_xTe$ (x=0.1)

Figure 4, shows the Arrhenius plot of the levels labelled A, B, C, and D in figure 3.

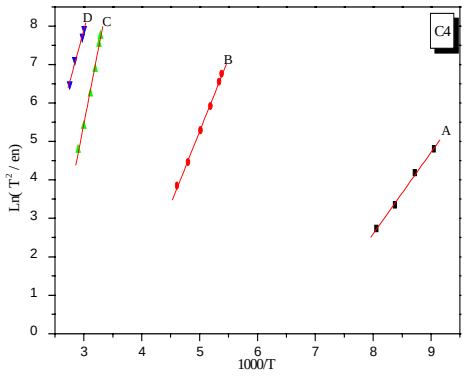

FIG. 4.. The Arrhenius plot

The measured activation energy Ea and the carrier capture cross section σ_n are reported in table 1.

Sample reference	Ea (eV)	σ_n (cm^2)	Levels
C4 $Cd_{0.9}Zn_{0.1}Te$	0.18	$4.96x10^{-15}$	A
	0.32	$2.43x10^{-15}$	B
	0.96	$1.48x10^{-12}$	C
	1.09	$7.9x10^{-13}$	D

Tacble 1. Activation energies and capture cross section of the levels found by PICTS measurements

The analysis of PICTS results has allowed us to detect four energy levels, noted: A(0,18 eV), B(0,32 eV), C(0,96 eV) and D(1,09 eV). We compared this result with recent works [10-11].

Level A: This first level detected by the PICTS measure at 0.18 eV, on crystal $Cd_{1-x}Zn_xTe$ is similar at a level found in the literature [12].

Several works have shown the existence at low temperature of this variable energy level in range [0.12eV and 0.2eV] [13,14].A similar level, has been detected at 0.2 eV in CdTe samples grown by THM (Traveling Heater Method), this level is not present in $Cd_{0.8}Zn_{0.2}Te$ (grown by HPB) [10], authors attribute the presence of this defect to the growth process, and attributed this level to the hole trap located at Ev + 0.2 eV.

Level B : The detection of this level in our sample and its absence in CdTe, could lead us to believe that this defect is linked to the Zinc. But the observation of this level in CdTe sample doped vanadium and its absence in CdZnTe crystal doped vanadium, removes all hypothesis including the introduction of Zinc and Vanadium [15].

This defect has been attributed in the past to copper (Cu), gold (Au) and carbon (C) can create levels in this area of energy[14].

A similar level is reported in the work [10] in CdTe:Cl (grown by THM), and is not present in $Cd_{0.8}Zn_{0.2}Te$ (grown by HPB), authors are agreement with the hypothesis that the defect is attributed involves a Te_{Cd} complex possibly introduced during the growth process [16], but it seems that a distinct Zn-related level has been found in $Cd_{0.9}Zn_{0.1}Te$ in recent literature [11].

Level C **:** The level at 0.96 eV is reported in the literature studied by the PICTS technique [11]. However, other levels are common to CdZnTe, CdTe:V and CdZnTe:V at 0.7 eV and 0.9 eV [15]. For sure all these deep levels are involved in the compensation process, but the role of Zinc is still to be defined.

Level D: This level detected by the PICTS technique has been found in the CdTe and $Cd_{1-x}Zn_xTe$. It is attributed largely to an intrinsic defect V_{Te}, this level is linked to a donor trap [17]. A similar level is detected in all samples (CdTe, CdTe:Cl, $Cd_{0.8}Zn_{0.2}Te$) [10] by the PICTS technique and CL spectra at 1.1 eV and ($Cd_{0.9}Zn_{0.1}Te$) [11]. This defect is supposed to behave as an electron trap [18].

V. CONCLUSION

Currently, Photo Induced Current Transient Spectroscopy (PICTS) is the only appropriate technique for a relatively complete characterisation of deep levels in high resistivity bulk material (semi-insulators).

This technique (PICTS) has allowed us to undertake a systematic and complete study, and thus to notice both deep levels and less levels in $Cd_{1-x}Zn_xTe$.

These defects can be classified in four levels A, B, C, and D. These results are in agreement with other authors works. By comparing our results to those reported in other literature, we have succeeded in identifying the origin of these defects.

We suppose that the presence of levels A and B in our sample $Cd_{0.9}Zn_{0.1}Te$ (HPB) and its absence in $Cd_{0.8}Zn_{0.2}Te$ (HPB) is linked to the composition of Zinc.

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