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Observation of deep levels associated with dislocations in *n*-type $Hg_{0.3}Cd_{0.7}Te$

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Deep level transient spectroscopy (DLTS) has been used to study the traps associated with dislocations in *n*-type $Hg_{0.3}Cd_{0.7}Te$. Dislocations have been generated by ion implantation at high fluence. Two of the broadened lines ($E1 = E_c - 0.22$ eV and $E3 = E_c - 0.34$ eV), we have observed, show a logarithmic dependence with the filling pulse. They are characteristic of point defect clouds surrounding or generated by the dislocations. An unusual broadened line ($E2 = E_c - 0.27$ eV) has also been observed, its amplitude decreases for filling pulses longer than 50 μs. This can be explained by a configuration change of the defect leading to the appearance of a new DLTS line. In addition, an electron trap ($EP4 = E_c - 0.49$ eV), which seems to behave like an isolated point defect, has also been found.

1. Introduction

Dislocations can be easily introduced into $Hg_{1-x}Cd_xTe$ even at room temperature. They are known to be electrically active and can contribute to the creation of deep levels acting as generation–recombination trapping centres. Recent work on Hg-rich solutions has shown that dislocations intentionally introduced or generated from material growth and array processing, affect the device performances. Johnson *et al.* [1] have studied the temperature dependence of the R_0A_j (resistance at zero bias times junction area) with dislocation density in a narrow band gap HgCdTe. These authors have observed, for high dislocation densities, a slope close to Eg/4 in the g–r region suggesting multiple trap levels. Deep level transient spectroscopy has evidenced only a midgap level in *p*-type $Hg_{0.8}Cd_{0.2}Te$ with a high dislocation density of about 10^6 cm^{-2} [2]. Moreover it has been shown that the formation of dislocations in HgCdTe appears also associated with an increase in donor concentration, about 1 donor/10 nm of dislocation length [3]. However, all of the earlier published works were focused on the effect of dislocations in Hg-rich HgCdTe, i.e. on infrared photovoltaic detectors in the wavelength ranges 3–5 μm ($x \approx 0.3$) and 8–12 μm ($x \approx 0.2$). However, in recent years, more attention has also been devoted to the development of integrated optical circuits with $Hg_{0.3}Cd_{0.7}Te$ ($\lambda = 1.35$ μm) and much less work has been done on them. In this paper the possibility of deep levels associated with dislocations was studied by deep level transient spectroscopy (DLTS) in $Hg_{0.3}Cd_{0.7}Te$.

As-grown $Hg_{0.3}Cd_{0.7}Te$ is so far always *p*-type. If plastic deformation is used to introduce dislocations we observe a conversion from *p*-type to *n*-type [4]. Lack of control over the conductivity transition has driven us to create dislocations by ion implantation at high fluence. Since ion implantation generates n^+-n-p diodes in $Hg_{0.3}Cd_{0.7}Te$, the deep levels associated with dislocations were studied in *n*-type material.

2. Experimental technique

Starting materials were single crystals of $Hg_{0.3}Cd_{0.7}Te$ grown by the Travelling Heater Method (THM) at the SAT (Société Anonyme Télécommunications, Saint-Benoit, France). They were *p*-type (N_A–$N_D \approx 10^{16}$ cm^{-3}) with a grown-in dislocation density of about 10^5 cm^{-2}. A previous work had shown that these samples contained two deep majority carrier traps [5]. Ion implantation was performed with Al ions using a fluence of 5×10^{15} cm^{-2} at 320 keV. Studies of junction formation mechanism in implanted HgCdTe have shown that the ion-implantation-induced junction lies deeper than the range of the implanted species ($R_P \approx 380$ nm) whatever the Cd-composition may be. The junction location should be 3 μm below the surface (extrapolating our results [6]). By transmission electron microscopy (TEM) it had been shown that damage produced at such fluence in $Hg_{0.3}Cd_{0.7}Te$ consists mainly of dislocation line segments with a Burger's vector of $1/2\langle 1\,1\,0\rangle$ [6]. Some dislocation loops had also been observed. These defects extend in depth down to 1 μm at least. Ohmic contacts and Schottky diodes were made both on the implanted surface by evaporating dots of In and Au, respectively. The DLTS measurements were performed with a 21 MHz capacitance bridge together with a lock-in amplifier. From C-V

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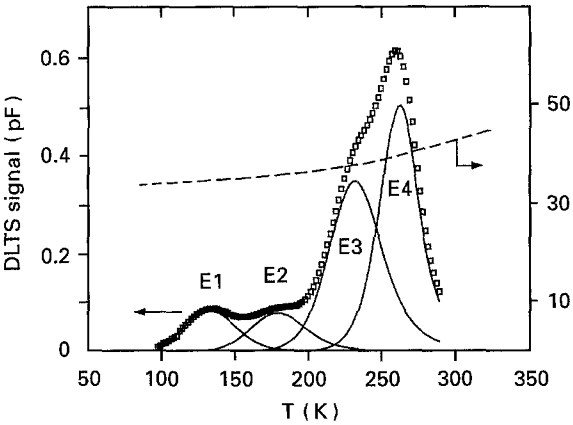

Figure 1 Temperature dependence of the capacitance (dashed line) and DLTS spectrum (squares) recorded at a rate window 80 Hz, a filling pulse duration $t_p = 250$ µs, a reverse bias $V_B = 0.7$ V and a pulse height $V_p = 0.7$ V. Deconvoluted peaks are drawn with a solid line.

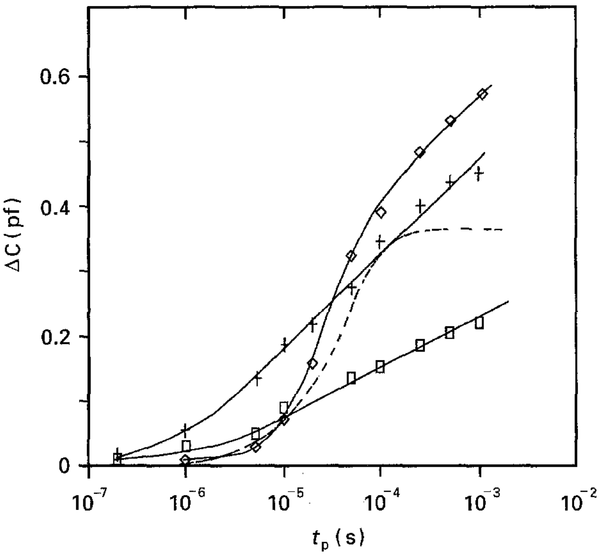

Figure 2 Variation of DLTS amplitude ($f = 80$ Hz, $V_B = 0.7$ V, $V_p = 0.7$ V) with refilling pulse width t_p for traps E1 (□), E3 (+) and E4 (◇). The dashed line E4P is obtained by taking a point defect capture for the line E4, $\Delta C \propto (1 - \exp(-t_p/\tau_c))$ with a value of $\tau_c = (\sigma_n \langle v_n \rangle n)^{-1} = 5 \times 10^{-5}$ s.

measurements N_D–N_A was found to be about 8×10^{14} cm^{-3} in the investigated region.

3. Results and discussion

Fig. 1 shows both a DLTS spectrum obtained with a filling pulse t_p of 250 µs (squares) and the temperature dependence of the capacitance (dashed line). Within the observed temperature range, four different deep centres in the upper half of the band gap have been evidenced from the deconvolution of the DLTS spectra measured for different rate windows. Table I gives the thermal activation energy E, the apparent electron capture cross-section σ_n and the width at half maximum δ for all these traps. Because of the overlapping of the lines all these trap characteristics are obtained from fitting parameters of a simulation procedure. The broadening of the line shapes represented by δ has been ascribed to density inhomogeneities of point defects located in the vicinity of the dislocations [7]. The amplitude of the spectrum strongly increases with increasing rate window suggesting that some electron capture cross-sections are temperature dependent as observed in the starting material, but in contrast to the different traps observed in narrow band gap HgCdTe [2, 8]. Thus, it follows that the values of E_T are apparent activation energies. On the other hand no electric field dependence has been observed.

In Fig. 2 the plot of DLTS signals ΔC versus t_p of lines E1, E3 and E4 is shown. The Gaussian broadened defects E1 and E3 show unusual capture characteristics which appear to follow a relationship of the form $\Delta C \propto \ln t_p$. Logarithmic behaviours have previously been observed in plastically deformed CdTe [9], GaAs [10] and InP [11]; they are characteristic of dislocations or point defect clouds surrounding them. The capture rate is thus modified by a potential barrier of the form $E = \alpha . f_T$ where f_T is the fraction of occupied states and α the coupling constant. The logarithmic dependence of line E1 and E3 is obtained in a t_P range from 10^{-6} to 10^{-3} s suggesting that α is about 0.2 eV [12]. The capture characteristic of defect E4 behaves like a point defect for filling pulses of duration lower than 10^{-4} s (see the dashed line labelled E4P in Fig. 2; the "slow capture" in the Debye tail not being taken into account). For longer filling pulses its amplitude does not saturate as expected for point defects but rises with a logarithmic dependence as already emphasized for lines E1 and E3. The broadened E2 line also shows unusual capture characteristics, see Fig. 3. Indeed ΔC decreases with increasing t_p for $t_p > 50$ µs. This behaviour has recently been observed in deformed p-type CdTe by Hümmelgen and Schröter [13]. These authors have supposed that a change of atomic configuration occurs after capture. However, they did not find the expected new line associated with the defect in its new configuration. According to their reasoning the decrease in amplitude of line E2 should be associated with the appearance of a new line. Therefore, we can reasonably tend to ascribe the logarithmic growth of line E4 observed for long filling pulses to this new line. In this case the E4 peak should be the sum of two contributions: one characteristic of an isolated point defect (EP4: $\delta = 0$ and $\alpha = 0$) with a trap concentration

TABLE I Trap parameters determined using a fitting procedure

	E1	E2	E3	E4
$E_T = E_c - E_t$ (eV)	0.22	0.27	0.34	0.49
σ_n (cm^2)	1–2 $\times 10^{-14}$	2–5 $\times 10^{-16}$	1–3 $\times 10^{-16}$	1–4 $\times 10^{-14}$
δ (meV)	60 ± 10	50 ± 10	30 ± 10	0

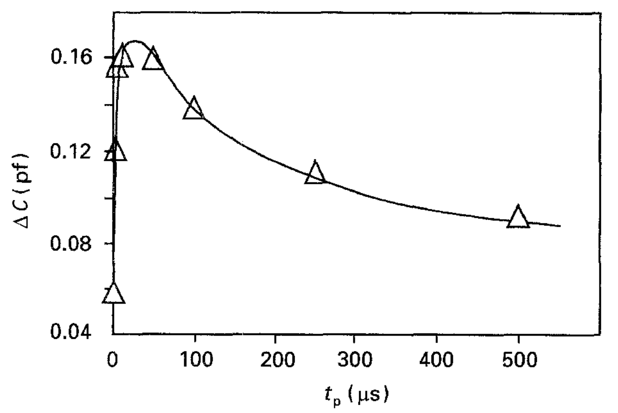

Figure 3 Transient capacitance amplitude of line E2 as function of filling pulse t_p ($f = 80$ Hz, $V_B = 0.7$ V, $V_p = 0.7$ V).

of about $N_T = 10^{13}$ cm^{-3}, the other originating from E2 defect which suffers a configuration change. This latter line ([E4]–([E4P]) thus shows a logarithmic dependence with t_p ($t_p > 10^{-5}$ s). However, its emission parameters could not be evaluated because of the overlapping with lines E3 and E4. Such a defect showing two DLTS lines has also been found by Zoth and Schröter [14] in p-type CdTe after annealing under Te-vapour; its origin being attributed to a complex ($V_{Cd}D^+$). However, it is very difficult at this time to compare their results with ours.

The reason why only a part of the defects E2 can change their configurations cannot be answered now. However, after lithium diffusion in p-CdTe, Riedel [15] observed deviations in the behaviour of the defect first observed by Zoth and Schröter [14]; he only found one characteristic line of one of the two configurations. This line also showed a logarithmic dependence indicating extended defect character. Riedel tentatively proposed that the defects are gettered by dislocations, with only one of the two configurations occurring in the dislocation stress field. Hümmelgen [16] also found deviations in the ratio between the DLTS line amplitudes of the two configurations of the same defect when twin boundaries were present under the Schottky contact used for DLTS measurements.

If we admit that dislocations belong to the glide set, two types of dislocations referred to as A(g) and B(g) are introduced in addition to point defects by the ion implantation process. Moreover they are known to be dissociated into Shockley partials [17]. At present we are not able to distinguish between their electrical activity. However with an appropriate method [18] permitting the characterization of single dislocation types, Hümmelgen *et al.* [13, 19] observed in CdTe a stronger effect of A(g) dislocations on the DLTS signal whatever the conduction type. GaAs aside [10, 20], it seems that the DLTS signals associated with dislocations are more probably due to unavoidable point defect clouds surrounding the dislocations than the dislocations themselves. A model of dissociation in a space-charge region of the complex $(A_sD_i)^\circ$ has been recently proposed to explain the point defects generated in the wake of moving dislocations [21]. Such a complex reaction has also been pointed out in $Hg_{0.3}Cd_{0.7}Te$ containing Se impurities [22]. Thus the broadened lines, E1, E3 and may be E2, could originate from the above mechanism. However, more experiments are necessary to identify them. It only should be noticed that the activation of level E1 agrees well with the generation-recombination centre located at $E_v + 0.75\,E_G$ already observed in both n- and p-type narrow band gap $Hg_{1-x}Cd_xTe$ ($0.2 \leq x \leq 0.4$) [23].

4. Summary

Obviously two traps $E1 = E_c - 0.22$ eV and $E3 = E_c - 0.34$ eV associated with dislocations introduced by ion implantation have been evidenced in n-type $Hg_{0.3}Cd_{0.7}Te$, their associated lines are broadened and their amplitudes show a logarithmic behaviour. This seems to confirm the hypothesis of Johnson *et al.* [1] which suggests multiple trap levels associated with dislocations. A line, at $E2 = E_c - 0.27$ eV, also Gaussian broadened, has been found with unusual capture characteristics. This defect could change its configuration after electron capture leading to the appearance of a new line which also shows a logarithmic behaviour, characteristic of extended defects. Moreover, an isolated point defect located at $EP4 = E_c - 0.49$ eV has been observed.

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