A BISTABLE DEFECT IN InP

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Point defects in n-indium phosphide were studied by deep-level transient spectroscopy (DLTS). A radiation-induced bistable defect is found to form under irradiation of a space-charge region of n-InP Shottky-barrier diodes. The transformations of the defect configuration stimulated by heating, illumination, and current flow are studied.

Radiation-induced metastable defects in n-InP have been studied in [1, 2]. It was shown that the strong electron-lattice interaction results in an additional crystal-lattice distortion in the proximity of the defects with deep levels and generation of metastable states. These defects are believed to be complex. It is shown in [3, 4] for center E10 that the probability of complex formation may depend on the charge state of defects forming the complex. Hence, the formation of new radiation-induced complex defects would be expected in a space-charge region (SCR).

In this work, a new bistable defect is shown to be formed in an SCR of n-InP and we named it a W-defect [4]. We also present our investigation results.

The objects of investigations were semitransparent Shottky-barrier structures produced on an n-InP layer with the free-electron concentration $n = 2 \times 10^{15} \text{ cm}^{-3}$. The layers were grown by vapor-phase epitaxy on highly doped substrates. Irradiation was performed by 1 MeV electrons at room temperature with a current density of $5 \times 10^{-7} \text{ A/cm}^2$. The integral electron flow was $1.1 \times 10^{15} \text{ cm}^{-2}$. The Shottky-barrier diodes were irradiated both with ($U = 10 \text{ V}$) and without ($U = 0$) application of a reverse bias voltage. The measurements were made by DLTS and thermo-stimulated capacity (TSCAP). The change in capacity $\Delta C$ of the reverse-biased diodes upon illumination was also measured. The illumination was performed by white light of a glow lamp. A standard cooling procedure from high temperature at $U = 0$ or $U \neq 0$ was used to obtain the desired configuration (a stable $A$-configuration or a metastable $B$-configuration).

The DLTS spectra of SCRs ($a$) and neutral volume ($b$) of the n-InP Shottky barrier diodes upon electron irradiation are shown in Fig. 1. Figure 1 $b$ shows that cooling both from 250 K (at $U = 0$ and $U \neq 0$) and from 410 K (at $U = 0$ and $U \neq 0$) gives the $E3$ and $EA$ peaks which are due to different configurations of the well-known metastable $M$-center [2]. Cooling of the irradiated SCR from 250 K also gives the $M$-center spectrum (Fig. 1 $a$, curves 2 and 3), while cooling from 410 K at $U \neq 0$ results in the fact that the spectrum of $B$-configuration of an unknown defect is superimposed on the spectrum of $B$-configuration of $M$-center (Fig. 1 $a$, curve 1, full circle, peaks $W1$, $W2$, and $W3$). We named this defect a W-defect. No $A$-configuration of this defect is revealed in the DLTS spectra (the reasons for this fact are given below).

Thermal transformations of the W-defect from $A$ to $B$ and from $B$ to $A$ configurations are reversible. To obtain the DLTS spectra for the case, where all $W$-defects are in the $B$-configuration, the spectra were measured for the specimen heated up to $T = 410$ K and then cooled down to 80 K at $U \neq 0$. To obtain the DLTS spectra for the case, where all $W$-defects are in the $A$-configuration, cooling from $T = 410$ K was performed at $U = 0$.

To obtain the configurational diagram of the W-defect, one should know the relative rates of thermal transformations $A \rightarrow B$ and $B \rightarrow A$. The experiments formally similar to isochronous annealing were performed to determine these rates. The only difference is that in these experiments the defects do not disappear, but transform from one configuration to another.

The results of investigation into the thermal transformations are shown in Fig. 2. Each point in the curves 1–3 corresponding to the transition $B \rightarrow A$ is obtained using the following procedure. The diode was heated up to 410 K, and the
voltage $U$=10 V was applied to the diode (all $W$-defects are transformed to $B$-configurations), then it was cooled down to a certain $T$ at $U$=10 V. Next, the voltage was switched off and the diode was kept at this temperature for $\Delta t = 300$ s (during this time, a portion of defects transforms to $B$-configurations). Further, the diode was quenched down to $T = 80$ K, and the spectrum was recorded on heating from $T = 80$ K. The procedure was repeated at other prescribed temperatures $T$. Each point in the curves 4–6 corresponding to the transformation $A \rightarrow B$ is obtained using a different procedure. The diode was heated up to 410 K (all defects are in $A$-configurations) and then it was cooled down to a certain temperature, the voltage $U$=10 V was applied, and the diode was kept at this temperature for $\Delta t = 300$ s (during this time, a portion of defects transforms to $B$-configurations). Then it was quenched down to $T = 80$ K, and the spectrum was recorded on heating from $T = 80$ K. The voltage $U_b$ specifying the depth of tested region was 4 V (it is less than 10 V to make sure that only the irradiated SCR and the region, where the transformation of the defect configuration occurs, are being tested). The spectrum of $W$-defect was obtained by subtraction of the peaks corresponding to $M$-center. Examination of the thermal transformations gives the following equations for the relative rates $R$:

$$R(A \rightarrow B) = 10^8 \exp\left(-E_1/(kT)\right), \quad [s^{-1}],$$

$$T(A \rightarrow B) = 145 \text{ K},$$

$$R(B \rightarrow A) = 3 \cdot 10^3 \exp\left(-E_2/(kT)\right), \quad [s^{-1}],$$

$$T(B \rightarrow A) = 145 \text{ K},$$

Fig. 1. The DLTS spectra (time window $\tau = 4.5 \cdot 10^{-5}$ s, the bias and filling-pulse voltages are 4 V) of the $n$-InP Shottky-barrier diodes upon electron irradiation ($\Phi = 1.1 \cdot 10^{15}$ cm$^{-2}$, $E = 1$ MeV, and $T = 300$ K); $U = 6.6$ V under irradiation; cooling from 410 K at $U = 10$ V or from 410 K at $U = 0$ and further illumination at $U = 10$ V [the filling-pulse duration $t_p = 10^{-4}$ s (dark symbol) and $t_p = 10^{-6}$ (light symbol)] (1); cooling from 250 K at $U = 0$ (2); cooling from 250 K at $U = 10$ V or from 250 K at $U = 0$ and further illumination (3) (a); $U = 0$ under irradiation; cooling from 250 or 410 K at $U = 10$ V or cooling from these temperatures at $U = 0$ and further illumination (I), cooling from 250 or 410 K at $U = 0$ (2) (b). It makes no difference for the spectra 3 (a) and 1 (b) whether the bias is present or absent during illumination.