DEEP LEVEL TRANSIENT SPECTROSCOPY MEASUREMENTS OF p-TYPE InP*,**

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DLTS measurements were made on p-type InP crystals, doped with iron and diffused with nickel. Parameters of six hole traps were established. Identification of a $Ni^{3+/2+}$ acceptor level with $E_a = 0.48$ eV and $Fe^{3+/2+}$ acceptor level with $E_a = 0.63$ eV is proposed.

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There is a small information in the literature about transition metal impurities in p-type InP [1]. This work is one of the first presentations of DLTS measurements on this material.

We have investigated an Fe and Zn-doped, LEC-grown, p-type indium phosphide crystal with a room temperature hole concentration around 1×10^{16} cm^{-3}. Part of the crystal was diffused with nickel. Metallic Ni was evaporated on one side of sample, which led after annealing to creation of gradient of impurity concentration.

Presence of iron in examined material was confirmed by optical absorption measurements. A Fe-related photoionization band [2] with superimposed sharp absorption structures [3] was observed. From this measurements an iron impurity concentration can be estimated as at least 1×10^{15} cm^{-3}. Samples diffused with nickel showed distinct increase of absorption between 1 and 2 μm most probably connected with Ni photoionization: $Ni^{3+}(3d^7) + h\nu \rightarrow Ni^{2+}(3d^8) + h$.

Deep Level Transient Spectroscopy (DLTS) was made on as grown and Ni-diffused material giving different results. In as grown material (doped only with Fe) four hole traps were present:

H1: $E_a = 0.18 \pm 0.02$ eV, $\sigma_\infty = 3 \times 10^{-15}$ cm^2,
H2: $E_a = 0.34 \pm 0.03$ eV, $\sigma_\infty = 3 \times 10^{-14}$ cm^2,
H3: $E_a = 0.43 \pm 0.04$ eV, $\sigma_\infty \simeq 10^{-15}$ cm^2,
H4: $E_a = 0.63 \pm 0.06$ eV, $\sigma_\infty \simeq 10^{-15}$ cm^2.

The H1 and H4 traps were dominant (H4 concentration was about 10^{15} cm^{-3}), concentrations of the H2 and H3 traps were about one order of magnitude lower. There wasn't any more detectable trap up to about 500 K. Taking a minimal possible capture cross sections σ_∞ around 10^{-18} cm^2, one can state that there are no more traps with activation energy lower then 1 eV.

On samples diffused with nickel, diode made in different distances from surface of diffusion were examined. Two new traps were found:

HM1: $E_a = 0.33 \pm 0.03$ eV, $\sigma_\infty \simeq 10^{-12}$ cm^2,
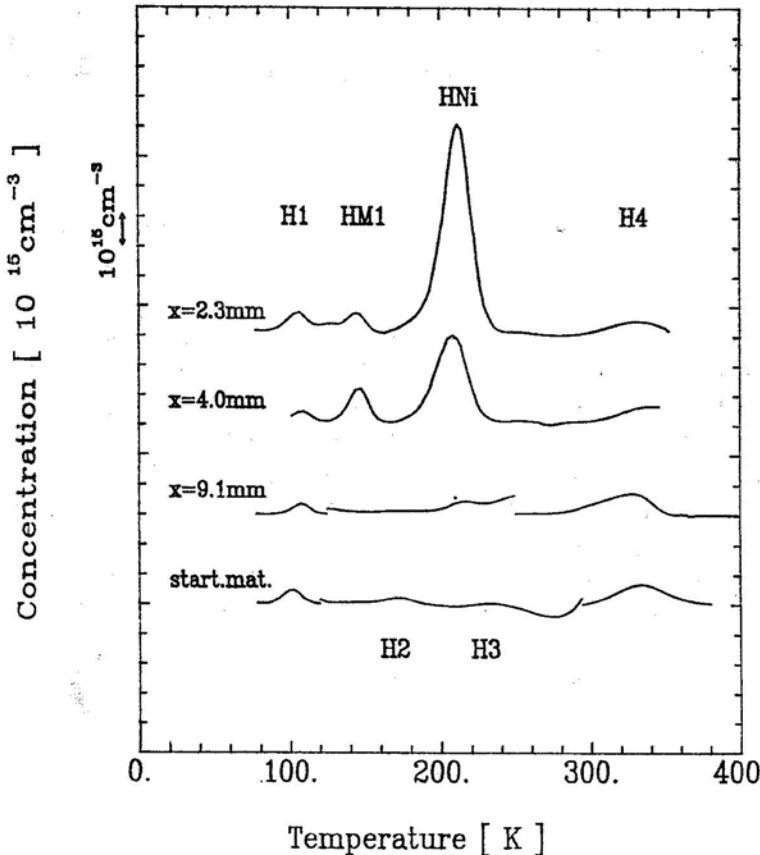HNi: $E_a = 0.48 \pm 0.04$ eV, $\sigma_\infty \simeq 10^{-12}$ cm^2.

Fig. 1. DLTS spectra for InP:Ni recorded in different distances from surface of diffusion (x) and in starting material (InP:Fe)
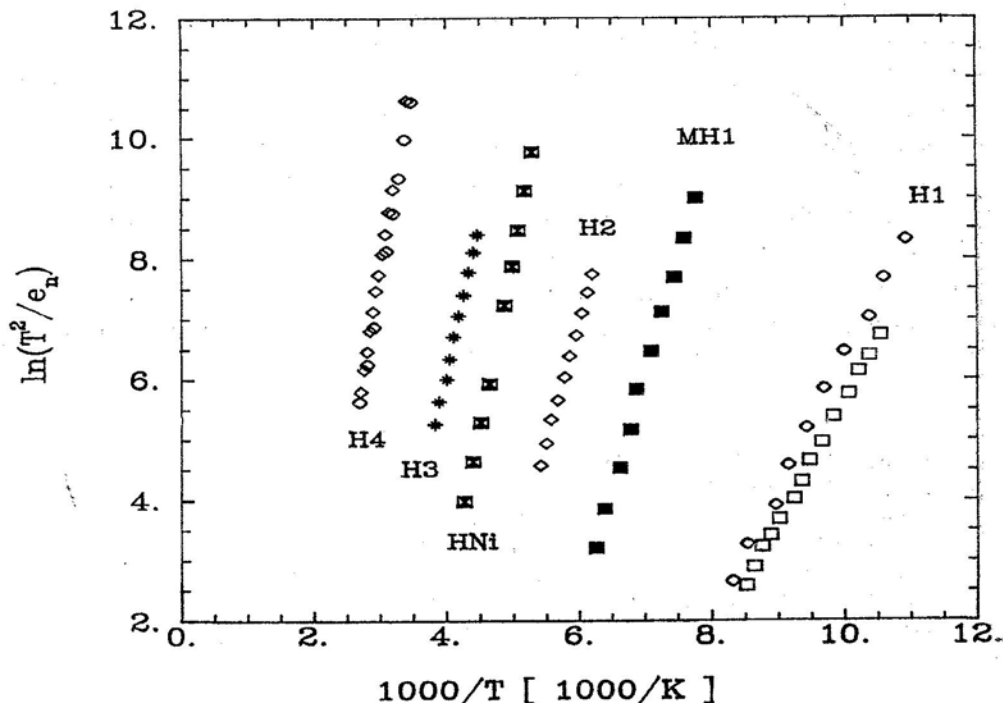
Fig. 2. Arrhenius plot for investigated traps in p-InP, points for traps H1 and H4 originate from both: as grown and Ni-diffused materials

Concentration of HM1 defects was in the same order of magnitude as H1 and H4 and was changing after annealing at 400 K. Concentration of HNi traps was much higher then that of the others and reached 7×10^{15} cm^{-3} at 2 mm from surface of diffusion. Moreover, it decreased strongly with distance from surface of diffusion and at the opposite end was at the detection limit 5×10^{11} cm^{-3}. Some DLTS spectra are presented on Fig. 1. Arrhenius plots for observed traps are shown in Fig. 2.

From optical photoionization measurements, we know that iron impurity charge state is $Fe^{3+}(3d^5)$. It means that we should observe DLTS trap connected with $Fe^{3+/2+}$. Up to now there was no DLTS identification of this level in p-type InP, however in PICT (Photo-Induced Current Transient) measurements on SI InP [4] an hole emission activation energy was found as 0.69 eV. The same energy for the iron acceptor level position in the room temperature obtained by Funk et al. [5] from the photoconductivity measurements. These results suggest that our H4 trap is the $Fe^{3+/2+}$ level, however its energy is slightly lower than expected. This identification is supported by fact that there are no more hole traps with higher activation energy.

The HNi trap ($E_a = 0.48$ eV) exists only in Ni diffused InP and its concentration is correlated with gradient of Ni impurity (see Fig. 1). Moreover, its vacuum-related binding energy (VRBE) equal -5.2 eV [6] is in good agreement with the VRBE of $Ni^{3+/2+}$ level in

GaAs (-5.28 eV) and in GaP (-5.4 eV) [1, 6]. All this facts strongly suggest that this hole trap corresponds to the $Ni^{3+/2+}$ acceptor level in InP.

The HM1 hole trap ($E_a = 0.33$ eV) showing metastable character is probably the same trap as HS hole trap ($E_a = 0.36$ eV) found by A. Sibille and A. Mircea [7].

According to some authors, a 0.18 eV level is also related to the iron impurity. Interpretations of this trap as a donor Fe^{4+}/Fe^{3+} level or a Fe-related complex defect were put forward [1]. Our observation of a Fe^{3+} related photoionization in the same crystal rules out the first possibility.

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