ELECTRICAL PROPERTIES OF GaS: Mn SINGLE CRYSTALS

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ABSTRACT

In resent years, growing interest has been shown to $A^{III}B^{VI}$ – type layer single crystals doped with transition elements [1, 2]. This is due to the fact that the atoms of transition elements produce sensitizing and luminescent centres in the forbidden gap of these single crystals. Inasmuch as the luminescent and photoconductive properties of semiconductors depend on the parameters of recombination centres and traps, an investigation of the recombination and trapping processes taking place in $A^{III}B^{VI}$- type semiconductors doped with transition elements is of undoubted interest.

Keywords: transition elements, crystals, luminescent, photoconductive, recombination.

I. INTRODUCTION

GaS single crystals exhibit the maximum forbidden- gap width (E=2,59 eV) among the $A^{III}B^{VI}$ layer crystals [3]. The recombination and trapping processes in these single crystals have been studied elsewhere [4 – 6]. However, these processes have not been studied in GaS single crystals doped with the transition elements Mn. The present study aimed at determining the parameters of recombination centres and traps in GaS:Mn by the methods of current- voltage characteristics (CVC), thermostimulated conductivity (TSC), and temperature dependences of photocurrent and dark current.

GaS:Mn (1 at.%) single crystals were grown by the Bridgman method and had p- type conductivity. Their resistivity amounted to (5 to 9) $\cdot 10^{10}$ Ω·cm at 293 K. An investigation of EPR spectra has shown that Mn is bivalent in GaSe. The specimens to be used in measurements were produced by spalling large single crystals. The contacts were applied to opposite surfaces perpendicular to the C – axis by fusing- in indium.

II. MAIN PART

Fig.1 gives CVC's of In- GaS: Mn-In structures at 293 K. The following sections are revealed in the CVC's: 1 a linear section, 2 a quadratic trapping section, 3 a sharp-current-growth section, 4 a second quadratic

trapping section, 5 a sharp-current-growth section, 6 a third quadratic trapping section, and 7 a sharp- current growth section. A comparison of the experimental third

quadratic section with the dependence of current on voltage, calculated with the formula for a trapless quadratic section [7] with due regard fore the mobility of current carriers in GaS (25 $cm^2/V\cdot s$) [8] has shown that the estimated section corresponds to currents higher than the experimental one.

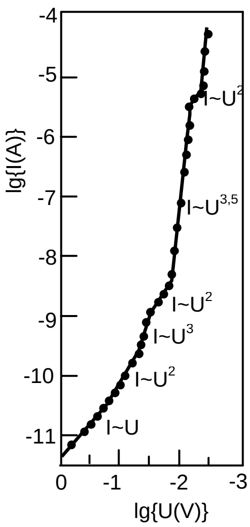

Fig.1. I-U characteristic of GaS: Mn single crystals at 293 K.

The existence of three sharp- current-growth regions indicates that the transfer of current carriers is associated with a monopolar injection corresponding to three discrete levels. The energetic depths, the concentration of traps, and the trapping factors have determined according to Lampert's monopolar injection theory [7] corresponding to several discrete levels and amount to

$E_{t_1} = 0.92\ eV$, $E_{t_2} = 0.86\ eV$, $E_{t_3} = 0.65\ eV$,
$N_{t_1} = 8\times10^{13}\,cm^{-3}$, $N_{t_2} = 2.8\times10^{14}\,cm^{-3}$,
$N_{t_3} = 6.3\times10^{14}\,cm^{-3}$, $\Theta_1 = 2.2\times10^{-9}$, $\Theta_2 = 6.6\times10^{-9}$
and $\Theta_3 = 6.3\times10^{-6}$.

Fig. 2 depicts a TSC curve in which three peaks have been revealed, namely at 169, 205, and 267 K. An analysis of the TSP curve has shown the presence of bimolecular recombination with fast retrapping. The trap depths have been determined with the use of formulas relating to fast trapping levels independent of the type of retrapping [9–15] and amount on the average to 0,17; 0,26 and 0,52 eV. The trapping cross-section S_t, the concentration of original filled traps n_{t_0}, and the concentration of traps N_t, have been calculated with the following formulas [10]:

$$s_t = \frac{\beta E_t}{kT_m^2 N_c V}\exp\left(\frac{E_t}{kT_m}\right), \qquad (1)$$

$$n_{t_0} = \frac{j_m kT_m^2}{e\mu\tau F E_t}\exp\left(-\frac{E_t}{kT_m}\right), \qquad (2)$$

$$N_t = \frac{N_c kT_m}{E_t \beta\tau}\exp\left(-\frac{E_t}{kT_m}\right), \qquad (3)$$

and amount to
$S_{t_1} = 1.1\times10^{-17}\,cm^2$, $S_{t_2} = 9\times10^{-18}\,cm^2$,
$S_{t_3} = 1.1\times10^{-18}\,cm^2$,
$n_{t_{01}} = 10^{11}\,cm^{-3}$, $n_{t_{02}} = 1.7\times10^{11}\,cm^{-3}$,
$n_{t_{03}} = 4.2\times10^{10}\,cm^{-3}$, $N_{t_1} = 2.5\times10^{15}\,cm^{-3}$,
$N_{t_2} = 2.7\times10^{14}\,cm^{-3}$ and
$N_{t_3} = 4.2\times10^{13}\,cm^{-3}$, respectively.

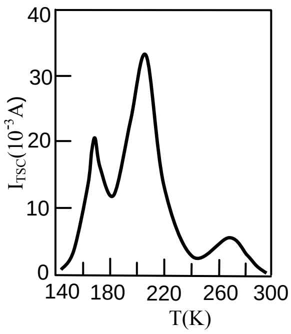

Fig.2. Thermostimulated current of GaS: Mn single crystals

Fig.3 shows the dependences of photocurrent and dark current on reciprocal temperature. It is seen that in the temperature region 83 to 195 K the photocurrent is weakly dependent on temperature. Starting with 195 K, The photocurrent grows sharply and passes through a maximum at 270 K. From the slopes of the temperature dependences of photocurrent, the activation energies amounting to 0,17 and 0,26 eV have been determined. The increase of photocurrent with growing temperature (195 to 270 K) is associated with the traps. As seen from the TSC curve, an effective hole-emptying of traps takes place in this temperature region.

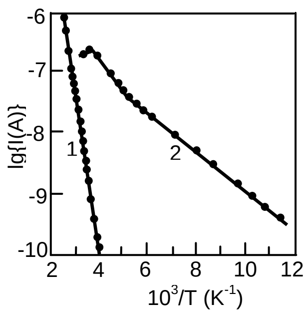

Fig.3. Temperature dependence of the dark (1) and photocurrents (2) of GaS: Mn single crystals

The dependence of dark current on reciprocal temperature (Fig. 3, curve 1) gives a straight line, from whose slope an activation energy of 0,52 eV has been found.

The activation energies determined from the temperature dependence of photocurrent are in good agreement with those found from the TSC. It should be noted that an exposure to light of the close-to contact area of the specimen, corresponding to a negative electrode, increase the intrinsic photoconductivity. The coincidence of the trap levels, determined while studying injection current and the infrared quenching of photoconductivity (0,86 eV), as well as the sharp increase in photoconductivity on exposing the close-to- contact area to light, with the electrodes having negative polarity, allow one to conclude that minority carriers are injected into levels below the bottom of the conduction band.

III. CONCLUSION

Thus, the following acceptor and donor levels are present in the forbidden gap of GaS: Mn single crystals: E_V +0,17 eV, E_V +0,26 eV, E_V +0,52 eV and E_C -0,65 eV, E_C -0,86 eV, E_C -0,92 Ev. When calculating the parameters of recombination centres and traps the lifetime τ, the mobility μ, the density of states in the valence band N_V were assumed to be 25 cm^2/Vs [8], 10^{-3} s [16], $2{,}5\times10^{19}\,cm^{-3}$ [8]. In this way the parameters of the traps were determined with an error of 6 to12 %. Electronic levels with energies of 0,02 and 0,5 eV have been determined by the authors of an earlier report [4] in undoped p- GaS single crystals.

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