ANOMALOUS CHANGES IN THE PROPERTIES OF TELLURIUM-DOPED INDIUM ARSENIDE SINGLE CRYSTALS

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The change in the main parameters of indium arsenide with the introduction of tellurium is considered from weak doping to concentrations corresponding to the solubility limit. Analysis of the experimental data shows that the functional dependence on the electron density of the band gap width, the Fermi energy, the magnitude of background absorption, the parameter characteristic of the carrier scattering mechanism has a discontinuity at N = \( (3-5) \times 10^{18} \text{ cm}^{-3} \). The observed phenomena are explained by the redistribution of component atoms of the system between sublattices with the formation of an ordered phase.

1. INTRODUCTION

The properties—composition function of heavily doped diamond-type semiconductors is traditionally considered as continuous within the solubility range. Detailed complex investigations showed that at a definite impurity atom concentration either a discontinuity or a bend appears on the composition dependence of a number of physical parameters indicating the emergence of a qualitatively new state. Anomalous changes in the properties are experimentally observed in elementary semiconductors [1], in \( \text{A}_3\text{B}_5 \) type compounds [2-12], in isovariant solid solutions of the type \( \text{A}_2\text{B}_6-\text{A}_3\text{B}_5 \) [13-18].

The present paper is concerned with the investigation of the changes in the optical parameters of one of the classical \( \text{A}_3\text{B}_5 \) type compounds, namely, indium arsenide, due to doping with tellurium.

2. EXPERIMENTAL METHODS

Indium arsenide single crystals doped with tellurium \( (10^{16}-10^{20} \text{ cm}^{-3}) \) were obtained by the Czochralsky method.* The carrier density and mobility were determined from the electric conductivity and Hall effect at 300 and 77 K. Crystals for optical measurements were prepared by standard methods. Transmission and reflection spectra in the wavelength interval 2-25 μm were measured in UR-20 and Specord IR-75, while for wavelength less than 2 μm in IKS-21 spectrometers, in the temperature interval 100-500 K. Calculations of the absorption coefficient taking multiple reflections into account were carried out on a computer using standard programs. From the spectral dependence of the absorption coefficient measured at various temperatures

*The crystals were grown in GIPO, Kazan'.

Fig. 1. Spectral dependence of the absorption coefficient of tellurium-doped indium arsenide (our data and [25]), \( T = 300^\circ\text{K}, N, \text{cm}^{-3} \): 1) \(9 \cdot 10^{15} \); 2) \(1.1 \cdot 10^{17} \); 3) \(2.0 \cdot 10^{18} \); 4) \(1.35 \cdot 10^{18} \); 5) \(1.77 \cdot 10^{18} \); 6) \(2.14 \cdot 10^{18} \); 7) \(4.0 \cdot 10^{18} \); 8) \(1.10 \cdot 10^{19} \); 9) \(1.44 \cdot 10^{19} \); 10) \(3.9 \cdot 10^{19} \); 11) \(5.0 \cdot 10^{19} \); 12) \(10^{20} \).

Fig. 2. Electron density dependence of the background absorption \(a_b\) of tellurium-doped indium arsenide crystals.

and the reflection spectra, the following parameters were determined: the width of the band gap \(E_g\) [19]; the disorder parameter \(\Delta_0\) as the characteristic of the states formed in the band gap owing to the distortion of crystal field by statistically distributed impurities [14]; the Fermi energy \(\mu\); from the longwave region of the spectrum, the parameter \(n\) characteristic of the scattering mechanism of free carriers in the band [20].

3. EXPERIMENTAL RESULTS

3.1. The Intrinsic Absorption Edge. The wavelength dependence at \(300^\circ\text{K}\) of the absorption coefficient of the crystals investigated is shown in Fig. 1. With increasing electron density the intrinsic absorption edge is regularly displaced, in consequence of the Moss–Burshtein effect, to the side of high energies, simultaneously increasing also the level of the so-called background absorption \(a_b\) characteristic of carrier scattering by dislocations, inclusions, point defects, and other crystal lattice imperfections. However, a number of specimens with electron densities of \(4 \cdot 10^{18} \text{ cm}^{-3}, 1.5 \cdot 10^{19} \text{ cm}^{-3}\) (their absorption coefficients are denoted in Fig. 1 by dots) have such a low background absorption as pure crystals. If the electron density dependence of \(a_b\), i.e., of the value of the absorption at the minimum of the \(\log \alpha = f(\log \lambda)\) curves, is plotted, a discontinuity is found at \(N > 3 \cdot 10^{18} \text{ cm}^{-3}\) (Fig. 2).

The intrinsic absorption edge obtained after deduction of free carrier absorption is described by an exponential function over the whole density range (Fig. 3).

In [3, 12] it is shown that the crystals investigated can be divided in three series according to the temperature dependence of the \(\log \alpha\) (\(\hbar\omega\)) curves.

In weakly doped crystals the optical transitions take place to free states of the conduction band. The energy dependence of \(\log \alpha\) at various temperatures approximates a system of parallel straight lines (Fig. 3a).

At electron densities of \(\sim 10^{18} \text{ cm}^{-3}\) (Fig. 3b), simultaneously with the above-considered absorption mechanism, transitions take place between states whose energy lies in the band gap. The levels of such states arise in consequence of fluctuations in the impurity concentration, their probability decreases as one moves down the band gap according to \(\exp(-E/\Delta_0)\), where \(\Delta_0\) is the fluctuation potential due to statistical distribution of impurities in the crystal lattice, and it does not depend on the temperature [21]. The presence of two absorption mechanisms explains the bend on the \(\log \alpha = f(\hbar\omega)\) curves [12].

At high doping levels the absorption edge describes the distribution of vacant states below the Fermi level and the high-energy part of the system of \(\log \alpha = f(\hbar\omega)\) curves for different temperatures form a so-called "temperature fan" (Fig. 3c)

\[
\alpha(\hbar\omega, T) = \alpha_0 \exp \left[ -\frac{\sigma}{kT} (\hbar\omega_0 - \hbar\omega) \right],
\]