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THE METAL DIELECTRIC PHASE TRANSITIONS UNDER THE PRESSURE

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It is cleared up that in weakly doped narrow gap semiconductors of *n*-type III-V and II-IV-V_2 with increasing of a pressure a critical concentration of donors arises, i.e. a tendency to localization of electrons on donors is observed. The hybridization of resonant impure states with states of the band continuum stipulates a decreasing of a critical concentration of impure atoms when a state radius of charge carriers in the impure center is changed continuously. There is used an extended criterion of the metal-dielectric phase transition in heavily doped semiconductors and experimental data in *n*-InSb for a description of Anderson localization in the intermediate range of doping.

1. INTRODUCTION

A paper is devoted to discussion of some aspects of the metal – dielectric phase transitions in semiconductors, caused by a reconstruction of the band structure with the help of external isotropic influence which doesn't change the symmetry of crystal, hydrostatic pressure.

2. RESULTS AND DISCUSSION

As one knows the electron dielectric-metal phase transition occurs in a real weakly doped semiconductor with increasing a density (concentration) N_i of disorderly placed electric active impure centers - Mott transitions. It is experimentally defined that the critical concentration N_C for different wide-gap semiconductors can be estimated with good precision from an expression

$$N_{iC} \cdot a_B^{*3} \approx 0.02\,,\ a_B^* = \frac{\hbar^2 \chi}{m^* e^2}\,,$$

where a_B^* is effective Bohr radius of hydrogen-like atoms of the impurity, m^* is electronic effective mass in semiconductor, χ is dielectric constant. In the narrow gap semiconductors, as it will be noted further, the critical concentration is lesser.

The hydrostatic pressure (P) promotes the metallization of semiconductors as a result of shortening a distance between the impurity centers and correspondingly increasing of N_i, – this is volume concentration effect [1]. However the increase of N_i doesn't exceed 2% on 1 GPa. The state radius of charge carrier in the impurity center (a) essentially changes with increase of the pressure (P). So in diamond-like direct-band, narrow gap with Kane dispersion law, semiconductors of *n*-type III-V InSb, InAs and II-IV-V_2 $CdSnAs_2$, $CdGeAs_2$, with account of experimentally obtained baric dependence χ [2] (Fig.1)

$$a_B^* = a_{B0}^* \left[\left(1 + \left(d\varepsilon_g/dP\right) P / E_{g0}\right) \cdot \left(1 + \Theta P / E_{g0}\right) \right]^{-1} \quad (1)$$

Θ=0.025 eV/GPa, the index "0" corresponds to the atmospheric pressure, ε_g is band-gap.

In mentioned above semiconductors $d\varepsilon_g/dP \approx 100$ meV/GPa.

According to (1) in *n*-InSb, for example with increase of pressure up to 1 GPa a_B^* decreases in 1.9 times and N_c increases in 7 times.

There is observed a tendency to localization of electrons.

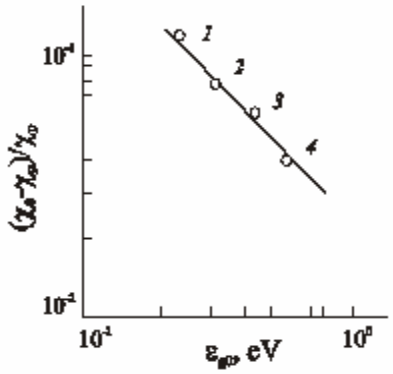

Fig.1. Energy-gap dependence of the relative static dielectric constant χ InSb (*1*), $CdSnAs_2$ (*2*), InAs (*3*) and CdGeAs*2* (*4*) [2]. χ_p – the value χ under pressure of 1 GPa, ε_g – energy gap, index "Zero" relates the parameter to the atmosphere pressure.

A reverse metal-dielectric transformation (Anderson localization) takes place in heavily doped semiconductors under the influence of compensation when $N_a \rightarrow N_d$ and the electrons are localized in wells of large-scale fluctuational potential (N_a and N_d are concentrations of acceptors and donors correspondingly)[1].

The extended criterion of Anderson localization is given in our work [3]

$$n_c = \beta \cdot N^{2/3} \cdot a^{-1}, \quad (2)$$

$$\beta = 2 \cdot (3\pi)^{-3/4} \cdot \delta_c^3, \quad (3)$$

$$\delta_c^{-1} = 1 + 0.86 \cdot \left(N_d^{1/3} \cdot a\right)^{-1/12}, \quad (4)$$

where n_c is a critical concentration of electrons, $N=N_a+N_d$, $\delta_c = \varepsilon_F / \gamma_c = \varepsilon_p / \gamma_c$, ε_p is Fermi energy, γ is a typical amplitude value of random potential, ε_p is percolation level.

In fig.2 are presented the dependences of critical concentration of electrons n_c (curves 1,2), coefficients δ_c (curve 3), and β (curves 4,5) on N_d. The curves 1,3,4 are calculated by equation (2-4), curves 2,5 and signes are obtained experimentally.

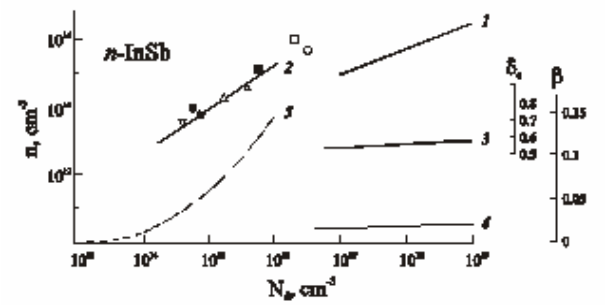

Fig.2. Concentration dependences of critical concentration of electrons n_c (curves 1,2), coefficients δ_c (curve 3), and β (curves 4,5) on N_d. The curves 1,3,4 are calculated by equation (2–4), curves 2,5 and signes are obtained experimentally.

The coefficient β turned out on 1-2 order lesser than given earlier value β=0.42 [4].

According to data on electronic transport the semiconductors $CdSnAs_2$<Cu>, *p*-InAs, InSb<Cr>, Ge<Au,Sb>, where near the bottom of conduction band is situated the deep acceptor band, turned out more convenient objects for the experimental investigation of the metal-dielectric transition under the pressure [5–13]. When the pressure is increased the conduction band moves off from the acceptor band with velocity which is approximately equal to the pressure coefficient of band gap $d\varepsilon_g/dP$. As a result electrons transfer from the conduction band to the acceptor band.

At defined level of doping and compensation at the atmospheric pressure $\varepsilon_F > \varepsilon_p$ both in conduction band and in acceptor band, i.e. electrons and holes are delocalized, a rate of their mobilities is approximate to 1. This is stipulated by the state hybridization of resonant impure acceptor band with delocalized states and an effect of resonant pulling up of the acceptor band hole mobility μ_A to the conduction band electron mobility μ_e [5].

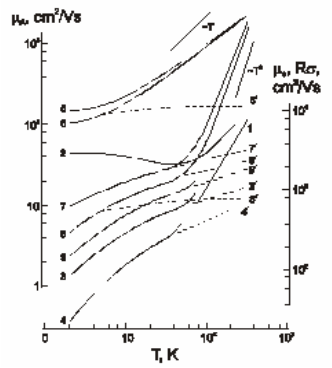

Fig.3. Temperature dependence of various properties. *1*– The Hall mobility $R\sigma$ (H=15 kOe); *2–4*– the electron mobility μ_e; *5–9*– the mobility of acceptor-band holes, μ_A, in sample of *p*-$CdSnAs_2$<Cu>. The pressure P is: 5) 10^{-4} GPa; 1,2,6) 0.02; 3,7) 0.42; 8) 1.14 GPa; 9) $P \rightarrow \infty$. Lines *3'*, *4'*, and *6'–9'* are extrapolations of the Mott law; line *8''* is an extrapolation of the dependence $exp(-\varepsilon_3/kT)$ out of the low-temperature region (2–5 K). The solid lines are experimental.

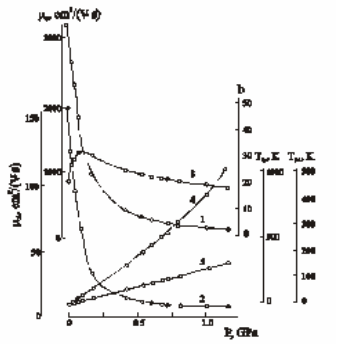

Fig.4. Pressure dependence of the mobility of the conduction electrons, μ_e (*1*), and that of the holes acceptor band, μ_A (*2*), of their ratio $b=\mu_e/\mu_A$ (*3*), of the parameters of the Mott hopping conductivity of electrons, T_{0e} (*4*), and of those of the holes of the acceptor band, T_{0A} (*5*), at 4.2 K in sample 2.

A simultaneous localization of the conduction band electrons in wells of large scale fluctuational potential and the acceptor band holes (resonance-hybridization version of Mott transition) is observed as far as dilution of conduction band and acceptor band states. Fig. 3,4 show mentioned above.

The values of characteristic parameters are calculated on the measurements of temperature, field and baric dependences of specific electric conductivity and Hall coefficient [5–9].

Phase diagrams (fig.5) summarize the results above mentioned for a process of electron metal-dielectric phase transition in real semiconductors in a change range of the impurity concentration from weak doping to heavy one. The experimental data generalized in [14] for Ge about dependency critical values of the compensation coeffi-

[1] Here and further for a definition are considered the *n*-type semiconductors.

cient upon a concentration donors and acceptors in intermediate doping region have been taken into account.

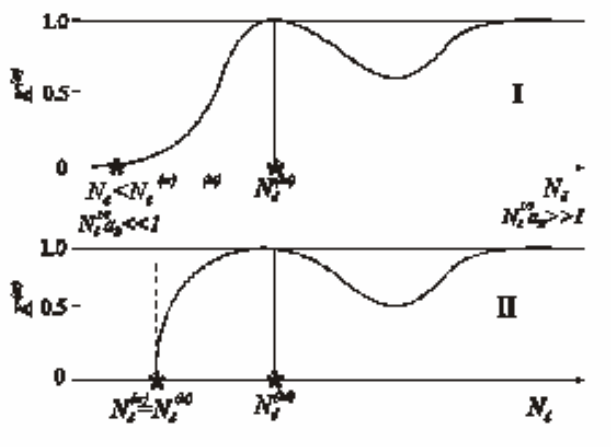

Fig.5. Dependencies for the critical value of compensation coefficient upon concentration of hydrogen-like donors in narrow-gap (I) and wide-gap (II) semiconductors. N_{hd} is donor (acceptor) concentration at which the impure band merges with conduction band (valence band).

3. CONCLUSION

In inference let's note that we proceed from the following conception on the dielectric-metal phase transition according which this transition is connected with splitting of impure states in the impure band - a classical expansion of a level as a result of disordered situation of impure centers and with a merging of this band with the conduction band.

In narrow-gap semiconductors with shallow (hydrogen-like) donors a prevailed role plays an effect of state hybridization, i.e. resonance hybridization version of Mott transition. The dielectric-metal phase transition in wide-gap semiconductors (Ge, GaAs et al.) with shallow impure centers in some cases is realized before merging of the impure band with own band in consequence of classical and quantum expansion of the energy level.

4. ACKNOWLEDGMENT

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[1]. M.I.Daunov, A.B.Magomedov, A.E.Ramazanova, Fiz. Tekh. Poluprov., **19**, 936 (1985).
[2]. M.I.Daunov, A.B.Magomedov, A.E.Ramazanova, Izv. vuzov. Fizika, **8**, 98 (1986).
[3]. M.I.Daunov, I.K.Kamilov, V.A.Elizarov, Fiz. Tverd. Tela, **37**, 2276 (1995).
[4]. I.M.Tsidilkovski, Transition metall-dielectric in magnetic field. Ekaterinburg, 287 p. (2000).
[5]. I.K.Kamilov, M.I.Daunov, V.A.Elizarov, A.B.Magomedov, Pis'ma Zh. Eksp. Teor. Fiz., **54**, 589 (1991).
[6]. I.K.Kamilov, M.I.Daunov, V.A.Elizarov, A.B.Magomedov, JETP, **77** (1), 92 (1993).
[7]. I.K.Kamilov, M.I.Daunov, A.B.Magomedov, JETP, **84** (2), 309 (1997).
[8]. M.I.Daunov, I.K.Kamilov, V.A.Elizarov, Physics-Doklady, **42**, N12, 657 (1997).
[9]. M.I.Daunov, I.K.Kamilov, A.B.Magomedov, Phys. Stat. Sol. (b), **211**, 553 (1999).
[10]. M.I.Daunov, I.K.Kamilov, A.B.Magomedov, A.Sh.Kirakosyan, Semiconductors, **33**, 59 (1999).
[11]. V.V.Popov, M.L.Shubnikov, S.S.Shalit, V.V.Kosarev, Semiconductors, **11**, 1914 (1977).
[12]. M.I.Daunov, I.K.Kamilov, S.F.Gabibov, Semiconductors, **35**, 59 (2001).
[13]. M.I.Daunov, I.K.Kamilov, S.F.Gabibov, R.Kh.Akchurin, Phys. Stat. Sol. (b) **223**, 529 (2001).
[14]. N.A.Poklonskii, S.A.Virko, A.G.Zabrodskii, Fiz. Tverd. Tela, **46**(6), 1071 (2004).