METAL-DIELECTRIC TRANSITIONS IN THE CRYSTALLINE SEMICONDUCTORS INDUCED BY UNIFORM PRESSURE

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Under pressure influence in $CdSnAs_2$ <Cu> the electronic phase transitions from disactivational to hopping conductivity with a variable step both for electrons of the conductivity band and holes of the acceptor resonance band occur.

Transition from metallic fo activation conductivity in the crystalline semiconductors is realised by doping, compensation and quantum magnetic field [1,2]. Metallic or activated type conductivity is observed depending on correlation between the Bohr effective radius dimension and mean impurity distance and promotes metallization of a semiconductor. Nevertheless, in crystalline, especially, narrow-gap, semiconductors, the Bohr effective radius changes considerably stronger. The increase of probability of transition from metallic conductivity to activated one under hydrostatic pressure is higher in strongly doped semiconductors III-V InSb, InAs and II–IV–V $CdSnAs_2$, $CdGeAs_2$ with the conductien band nonparabolically obeing the Kane law. In these materials the energy gap ε_g and the electron effective mass increase, static dielectric constant χ (Fig. 1 [3]) and the Bohr effective radius decrease with pressure:

$$\chi = \chi_0 \left(1 + 0.025/\varepsilon_{g_0}\right)^{-1} \tag{1}$$

$$a_{eB} = a^0_{eB}\left[\left(1 + \beta P/\varepsilon_{g_0}\right)\left(1 + 0.025/\varepsilon_{g_0}\right)\right]^{-1} \tag{2}$$

χ_p — the value of χ under pressure of 1 GPa, $\beta = d\varepsilon_g/dP$, ε_g — eV, P — GPa, index <zero> relates the parameter to the atmosphere pressure.

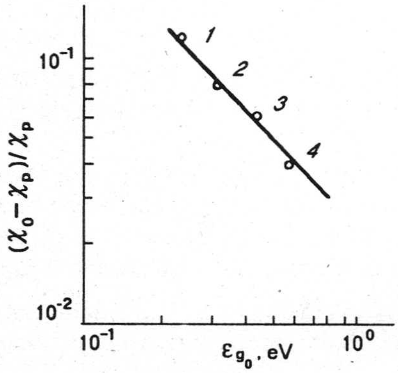

Fig. 1. Energy-gap dependence of the relative static dielectric constant in InSb (*1*), $CdSnAs_2$ (*2*), InAs (*3*), and $CdGeAs_2$ (*4*)

In InSb, the effective Bohr radius, for example, is 1.9 times decreased and the impurity concentration — the volume concentration effect [3] is only 2 % increased by 1 GPa. Thus, in negative InSb the critical concentration of the Mott transition is 7 times increased and the critical magnetic field is 1.9 times decreased; critical electron densities for metal-nonmetal transitions occurring in highly doped compensated semiconductors the Anderson transition [1] — are 1.9 times increased.

So, the baric dependence of the Bohr radius specifies the tendency towards localization. Another opportunity for the investigation of transition from metallic conductivity to the activated one under pressure can be realised in case of the existence of defect level near the Fermi energy. Heavily doped and compensated crystals of $p-CdSnAs_2$ <Cu> [4], are a convenient model material for corresponding research.

The tail of the conduction band of this material has a deep acceptor band. The acceptor band is linked with the valence band in therms of energy. Consequently, with hydrostatic pressure increase, the conduction band moves away from these bands at the same rate equal to baric coefficient of the energy gap (Fig. 2). We came to the conclusion about the formation of the quasi-gapless state. These results have been obtained by us earlier at temperature greater than 776 K [4].

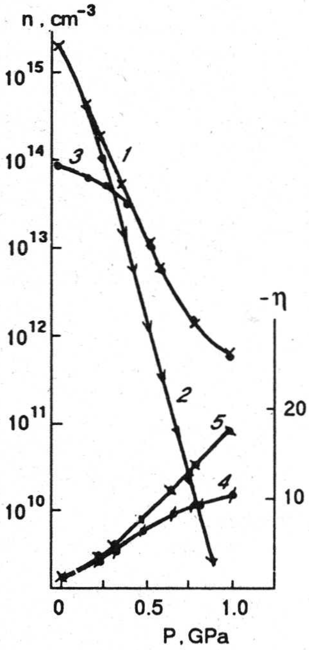

Fig. 2. The baric dependence of the electron density n (1–3) and the relative Fermi energy $\eta = \varepsilon_F/kT$ (4,5) at 77.6 K, sample No 2 (3D 1–1′) [4]. n and η were estimated using the two-band model (1,4) and the equation of the electrical neutrality (2,5) [4], $[n(1)-n(2)]$ — the electron density at the tail of the density of states of the conduction band (3)

We carried out the experiments on heavily doped compensated crystals which were subjected to hydrostatic compression up to $P = 1.5$ GPa at $T = 2-300$ K and in magnetic fields up to $H = 15$ kOe.

At a fixed temperature the Hall coefficient increases with P and H, going from negative values to positive constant quantity; specific resistance tends to constant values. The effective values of characteristic parameters of concentrations (n,p), mobilities (μ_e, μ_A) and other parameters of the conduction-band electrons and acceptor-band holes have been correspondingly were estimated by these data using the two-band model and assuming the characteristic parameters to be independent of the magnetic field (Fig. 3 [4,5]).

The results of the analysis of the experimental data were interpreted by using models and theories presented in monograph [1]. Thus, under pressure the electronic phase transitions from disactivation to jump conductivity with a variable step

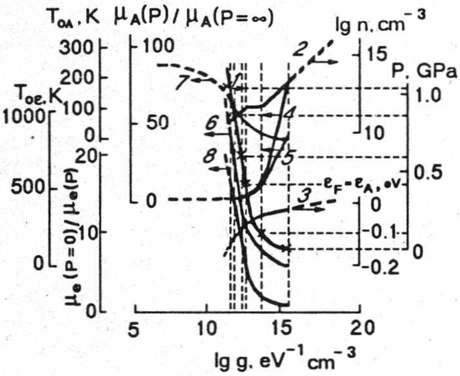

Fig. 3. Conduction-band density of states dependence of various parameters at 4.2 K, sample 14D-1. *1* — the pressure of measurements; *2* — the electron density; *3* — the Fermi energy and the energy of the acceptor level; *4,5* ($T = 2$ K) — the relative mobility of acceptor-band holes; *6,7* — the parameters of the Mott hopping conductivity of electrons (T_{oe}) and of the acceptor-band holes T_{OA} [5]; *8* — the relative electron mobility. The solid lines is the experiment; the dashed lines is the extrapolation

for both the electrons of the conduction band (localization at fluctuational wells of the impurity potential) — the semiclassical version of the Anderson transition, and the holes of the acceptor — the resonance-hybridization version of the Mott transition-occur [5]. The holes are delocalized by a superposition of localized impurity band on the band continuum and their hybridization and the delocalization proceeds until a limiting impurity concentration is reached. In the course of this transition, the mobility of the impurity band carriers is "pulled" towards the mobility of the band carriers [5]. At this point it is useful to make a comparison with the resonant scattering [2]. The resonant <pulling> is responsible for the decrease in the ratio μ_e/μ_A with P decrease near the transition and the high values of the carrier mobility of the resonant impurity band. The limiting case ($\mu_e/\mu_A = 1$) is observed in narrow-gap heavily doped semiconductors like n-InSb, in which the Mott transition occurs until a limiting impurity concentration is reached.

The criterion of transition from the metallic type of conductivity to the activational one occuring in strongly doped semiconductors under the influence of compensation is specified.

It is shown by the experimental results that in strongly doped compensated semiconductor p–CdSnAs$_2$ <Cu> the ionic complexes — specific correlation-reduces the critical concentration by five orders.

The Fermi level is rigidly pinned in the acceptor band, which acts as an electron reservoir. Therefore at high pressure a modification of the model of a completely compensated strongly doped semiconductor in the semiconductor at the impurity zone is realised. In accordance with the theory [1] we have $|\varepsilon_F| \sim n^{-1/3}$ and $\varepsilon^0_{AB} = 30$ meV. This quantity is equal to the value determined at temperature higher than 77.6 K [4].

When pressure tends to infinity, the valence-acceptor band system is adequate to the model of a weakly doped strongly compensated semiconductor [1].

Thus, the uniform pressure scanns the Fermi level under the percolation level for quantity which is 1 to 2 orders of magnitude larger than that reacherd by compensation and magnetic field, and p–CdSnAs$_2$ <Cu> like semiconductors may serve as effectively controlled high-pressure model of an amorphous semiconductor.

The perspective objects for similar investigations are Ge<Sb, Au>, InSb <Cr>, InAs [6] and gapless semiconductors [2].

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