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A QUSI-GAPLESS SEMICONDUCTOR AT HIGH PRESSURES – A MODEL OF AMORPHOUS SEMICONDUCTOR

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In [1-3] there was emphasized an analogy between properties of heavily doped and fully completely compensated semiconductor (HDFCS) and amorphous semiconductor stipulated by the presence of random large-scale fluctuational potential in both systems, and was stated the idea about a modeling of amorphous semiconductor by creation of compensating impurities in different ways in a crystal heavly doped semiconductor. In this connection it was developed a HDFCS theory (fig.1) [1].

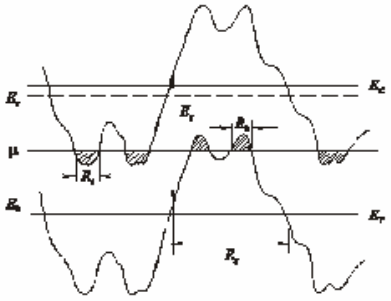

Fig.1. Energy scheme of fully compensated semiconductor. Upper and lower lines are undisturbed bottom of the conduction band and valence band maximum, middle line is Fermi level. Curve line is band boundary, modulated by the electrostatic potention of charged impurities, shading line are the percolation level for electrons and holes. Regions located by the carriers (drops) are shaded. R_e, R_h are the sizes of electron and hole drops.

The quasi-gapless semiconductors (QGS) [4] are suitable objects for modeling of amorphous semiconductors, in particular semiconductors *p*-Ge<Au> [5], *p*-InAs with concentration excess acceptors $(N_A\text{-}N_D)<10^{17}$ cm^{-3} [6], InSb chromium doped [7,8] and InAs [9], narrow-gap semiconductors CdHgTe [10] and $CdSnAs_2$<Cu> [4,11-16].

QGS are crystal semiconductors in which a gapless state forms as a result of the state junction of conduction band and impure band with the contrary sign conductivity and with the occupancy coefficient $0 \le K_{oc} \le 1$ ($K_{oc} = N_A^- / N_A$) [4] (fig.2). QGS are intermediate materials between semimetals and semiconductors, on the one hand and ideal and disordered semiconductors, on the other hand with effectively controlled high pressure, temperature, level of doping and compensation, quantum magnetic field, and other factors of disorder degree. It should be noted that high pressure allows continuously and reversibly adjust a height of potential barriers close to formation of HDFCS state and a degree localization level of carriers in wells of large-scale fluctuational potential and in impure centers changing them from metal conductivity to activational one. Experimental results for transport phenomena in QGS unlike amorphous semiconductors allow to carry out a detail quantitative analysis, in particular, divided the electric conductivity into the concentration product and mobility product in a region of the jump conductivity, and interpret a negative sigh of Hall coefficient and a positive sign of thermoelectric power observed in amorphous semiconductors with small gap of the mobility [4,11,12].

In temperature interval 2÷300 K in the dependence upon hydrostatic pressure up to 1.5 GPa, electric field up to 250 V/cm, and magnetic field up to 20 kOe in a range of concentration change of excess acceptors there are carried out the complex measurements for kinetic coefficients QGS of *p*-type Ge<Au> [5], InAs with a $(N_A\text{-}N_D)<10^{17}$ cm^{-3} [6], InSb<Cr> [7] and $CdSnAs_2$<Cu> [4,11-16] with the occupancy coefficient of the acceptor band $0 \le K_{oc} \le 1$. Characteristics parameters are calculated.

The results are presented on example of *p*-$CdSnAs_2$ with $N_A\text{-}N_D=1.6\cdot10^{15}$ cm^{-3} at T=4.2 K (fig.3-4). In the neighborhood of atmospheric pressure the conduction

band electrons and acceptor band holes are characterized by the metallic conductivity.

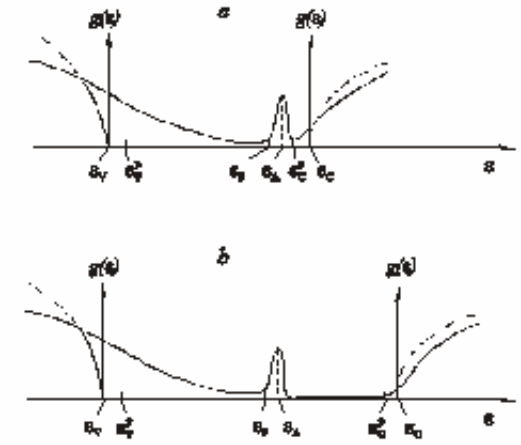

Fig.2. The (schematic) behavior the density of states of quasi-gapless, a heavily doped and compensated semiconductor with a deep acceptor band whose population coefficient K_A is approximately zero, at atmospheric pressure (*a*) and under hydrostatic compression (*b*). Here ε_V and ε_C are the unperturbed energies of the top of the valence band and the bottom of the conduction band, ε_A and ε_F are the energies of the deep acceptor level and the Fermi level, and ε_V^P and ε_C^P are energies of the percolation levels for the holes of the valence band and the electrons of the conduction band. The dot-dash curve describes the behavior of the density of states in a perfect crystal. The shaded areas correspond to populated states.

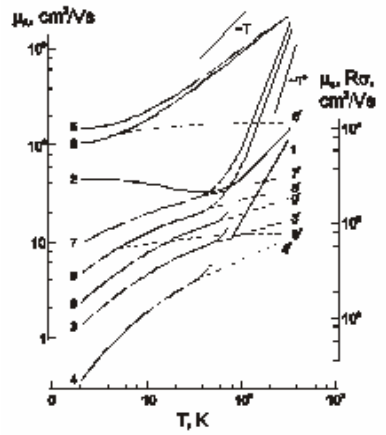

Fig.3. Temperature dependence of various properties. 1- The Hall mobility $R\sigma$ (H=15 kOe); 2-4- the electron mobility μ_e; 5-9- the mobility of acceptor-band holes, μ_A, in sample of *p*-$CdSnAs_2$<Cu>. The pressure *P* is: 5) 10-4 GPa; 1,2,6) 0.02; 3,7) 0.42; 8) 1.14 GPa; 9) $P\rightarrow\infty$. 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.

When pressure increases there is observed a phase transition to the jump conductivity with variable range hopping both of electrons of the conduction band – a localization in well of large-scale fluctuational potential and of holes of the acceptor band a resonance hybridization variant of Mott transition [13,14]. There is observed "resonant" movement of hole mobility of acceptor band μ_A to electron mobility μ_e in the direction of the delocalization (fig.4, curve 3). Effective mobilities $\mu_{e,A}\sim exp\{-(T_{0e,A}/T)^{1/4}\}$ up to T=40÷50 K, the parameters $T_{0e,A}$ increases from zero to $T_{0e}\rightarrow\infty$ with pressure *(P)* and T_{0A} is tended to fixed value when $P\rightarrow\infty$ in correspondence with baric dependence of state densities on Fermi level of conduction band electrons $g_e(\varepsilon_F)\rightarrow 0$ and acceptor band holes $g_A(\varepsilon_F)\rightarrow g_A(\varepsilon_F)_\infty$.

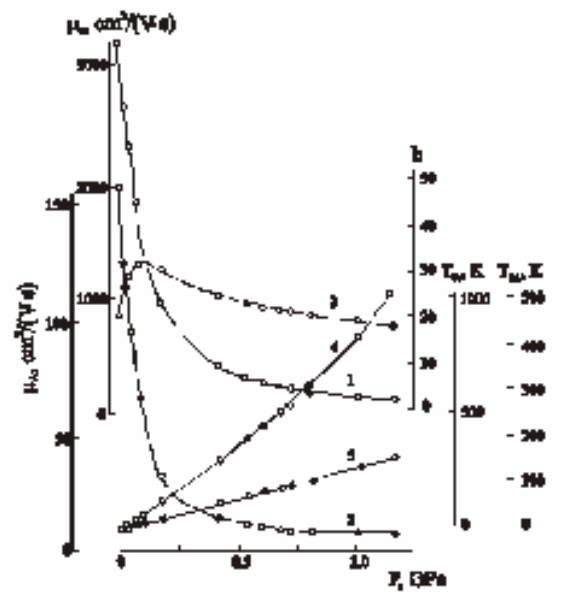

Fig.4. Pressure dependence of the mobility of the conduction electrons, μ_e (1), and that of the holes acceptor band, μ_A (2), of their ratio $b=\mu_e/\mu_A$ (3), of the parameters of the Mott hopping conductivity of electrons, T_{0e} (4), and of those of the holes of the acceptor band, T_{0A} (5), at 4.2 K in sample of *p*-$CdSnAs_2$<Cu>.

On the density tail of conduction band states may be observed two parts approximated by the exponential dependence upon energy. The g_e sharply decreases by 4÷5 orders with increase of distans from the undisturbed edge of the conduction band. The second slope part of $g_e(\varepsilon)$ dependence below the percolation level may be approximated, as it is generally used to make in amorphous semiconductors, by exponential dependence $g_e(\varepsilon)\sim|\varepsilon-\varepsilon_A|^2$, where energy ε_A is (–200) meV, at which $g_e(\varepsilon)\approx 0$ (relatively the undisturbed edge of conduction band) [13,14].

Since the question about partial sign for acceptor band Hall coefficient R_A [10] is discursive it should be emphasized that $R_A>0$ independently upon an occupancy degree of the acceptor band and a character of conductivity, and partial thermoelectric power $\alpha_A>0$, when $K_{oc}>0.5$ and $\alpha_A<0$, when $K_{oc}<0.5$ [4,11,12].

$$\alpha=\frac{k_B}{e}\ln\frac{\beta K_{OC}}{1-K_{OC}},$$

where k_B is Boltzman constant, e is absolute walue of electron charge, β is a parameter of spin quenching.

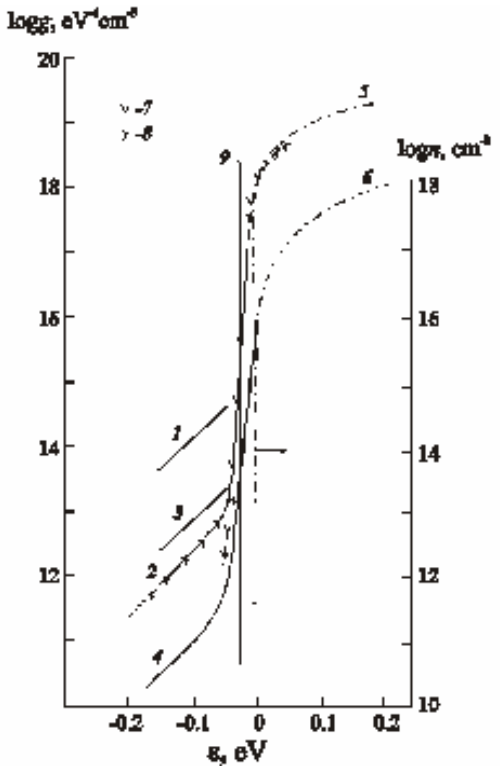

Fig.5. Energy dependence of various properties. 1,2 - Density of states of the conduction band; 3,4 - the electron density [at 4.2 K; sample 15D-2 (1 and 3) and sample 14D-1 (2 and 4) of p-$CdSnAs_2$<Cu>]. The origin of the energy scale corresponds to the unperturbed edge of the conduction band. Solid lines: Experimental. Dot-dashed lines: Density of states (5) and electron density (6) of ideal $CdSnAs_2$. Dashed line and points (7): Semiclassical theory of linear screening for γ=14.8 meV. Dashed line and points (8): The approximation $g_e=2.55\cdot10^{12}\cdot\chi\cdot exp(-x^2)$, where $\chi=|\varepsilon|/\gamma$ and γ=145.3 meV. (9): Density of states of the acceptor band.

An influence of the hydrostatic pressure up to 1.5 GPa at T=300 K upon p-$CdSnAs_2$<Cu> permits to change an occupancy degree of narrow acceptor band. A conduction band bottom removes from the acceptor band at a speed 120 meV/GPa with hydrostatic compression and the occupancy coefficient of acceptor band in studied crystals p-$CdSnAs_2$<Cu> increases approximately from 0.3 to 0.8 with increasing of the hydrostatic pressure up to 1.5 GPa. Fig.6 shows baric dependences for thermoelectric power of the acceptor band for studied samples p-$CdSnAs_2$<Cu> at room temperature. It is may be seen that thermoelectric power sign inverts from negative to positive in correspondence with the theory.

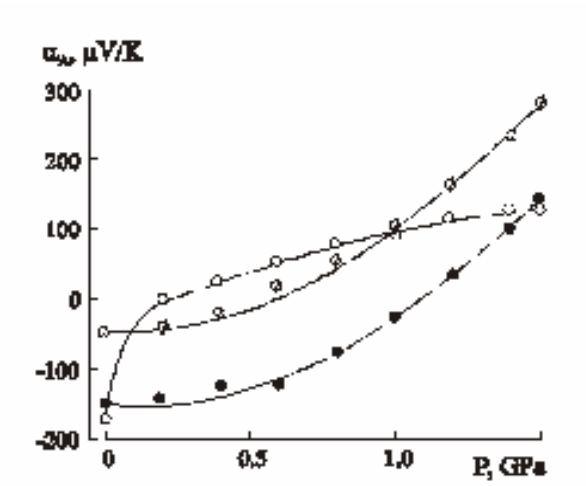

Fig.6. Dependence of the thermo-e.m.f. on the narrow band population at a constant temperature 300 K and at the all-round pressure on a model object.

ACKNOWLEDGMENT

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