PECULAIRITIES OF IMPURITY INFLUIENCE IN WEAKLY DEGENERATED SYSTEMS

Bodiul Pavel, Peev Leonid
Technical University of Moldova

Impurity influence on kinetic effects in semimetals has some specific peculiarities. As a matter of fact, due to weak overlapping of the conduction and valence bands the impurity states in semimetals differ from the states in semiconductors. If a perturbation caused by the impurity atom is localized in the case of metals the impurity "level" gets into the band of quasi-energetic spectrum of the ideal crystals, as a result near the "level" spikes of the density of states appear, what may be interpreted as availability of certain virtual resonance level ε_0. The states corresponding to these energies have a tendency to the space localization of wave function near the impurity atom. In the case of semiconductor the impurity level usually gets into the band of forbidden states and it is discrete, so that the states corresponding to it have the wave functions localized near the impurity atom. In classical metals small concentrations of the impurity cause in the first place an additional scattering of the charge carriers, not practically changing their concentration, whereas in semiconductors, in a certain temperature range they are main "providers" of free carriers, and change of relaxation processes caused by them is of less importance. In semimetals both factors are comparable in value, what naturally requires another approach to investigation of these materials. Besides, here some more delicate effects may be shown. Weak overlapping of bands in semimetals without fail leads to the fact that the impurity "level" gets into the band of quasi-continuous states, in contrast to metals it must be "localized" near the energy extremes, to be precise - near peculiarities of the density of states. This state itself must determine more complex behaviour of impurities in these crystals. As to bismuth, the problem becomes more complicated due to strong anisotropy of the energy spectrum, especially to availability near the Fermi level of several energy extremes located in different points of k-space and therefore being nonequivalent in symmetry properties. In these conditions the impurity atom electron may occupy any of several states, each of them being described mainly by the Bloch functions corresponding to only one group of the extremes being close to the Fermi level and equivalent in symmetry properties. If such a possibility is realized in bismuth, then it is natural that kinetics of the carriers at doping becomes more complex, because an additional specific scattering mechanism appears. Thus, thorough investigation of transport phenomena in doped bismuth is of principal importance also for specification of our ideas on the impurity states, especially in anisotropic media. Probably this is the

aspect where we should search for solution of the problem of nonintegrality of efficiency of heterovalent impurity atoms in bismuth.

It is experimentally found that small additions to bismuth of elements of the IV and VI groups lead to such change in concentration of free charge carriers that it is less than one electron per atom and considerably depends on nature of the latter. Composition of ternary alloys of bismuth with elements of the IV and VI groups with the electric properties close to those of pure bismuth was successful at the liquid nitrogen temperature. It turned out that tellurium addition leads to an increase of concentration of free electrons by 0,7 el-n/atom, selenium addition - by 0,18 el-n/atom. Tin decreases this concentration by 0,18 el-n/atom, lead - by 0,06 el-n/atom [1]. The value characterizing change of concentration of free carriers by one impurity atom is called "efficiency coefficient", or the same - efficiency of the impurity $\eta_d(a)$ of the donor or acceptor types. In this case the excess concentration of free carriers

$n-p=\Delta n=\eta_d \bullet C_d$ (C_d is the concentration of donors). It should be emphasized that the efficiency of the impurity $\eta_d(a)$ considerably depends on temperature T and concentration of the impurity C_d.

Expression for $\eta_d(a)$ takes especially simple form in the limit of low temperatures and small impurity concentrations [2]: $\eta_d(C_d;T) = 2\pi arctg\beta - \frac{2\pi}{3\beta}(1+\beta^2)^4 \cdot \frac{1}{\gamma^2}$

where $\beta = \frac{E_d}{\Gamma_d}$, $\gamma = \frac{\Gamma_d}{T}$, $E_d = E_d^0 - \varepsilon_F$ is the impurity level energy of the relative Fermi level, Γ_d is its width determined by the interaction of intermixing by the crystal field. It is seen from Fig.1 that the temperature growth leads to the decrease of the efficiency coefficient η_d.

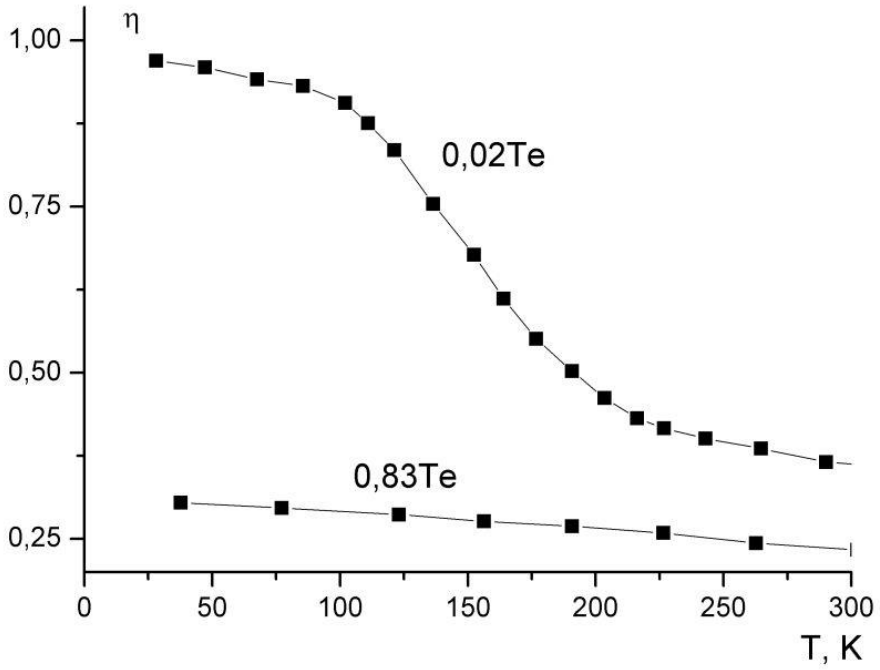

Fig.1 Temperature dependence of the efficiency coefficient.

This behaviour of $\eta_d(T)$ may be explained physically, because as the temperature T grows, there increases the probability of the free electron overthrow from the bands on the localized level having the energy higher than the system Fermi level. Such a character of η_d behaviour remains, when the doping degree increases. When C_d impurity concentration is increased the Fermi level shifts closer to the impurity level E_d^0, this results in the increase of probability of overthrow of free band carriers on the impurity levels, thus value of η_d decreases.

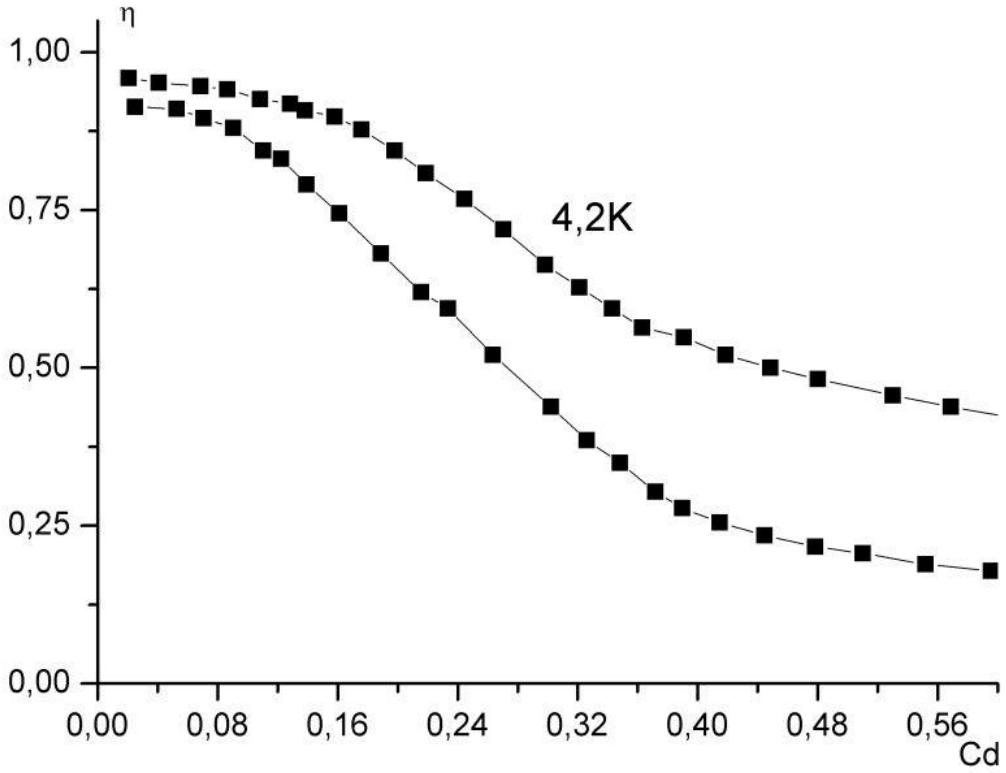

Fig.2 Concentration dependence of the efficiency coefficient at 4,2k.

By the concentration dependence of η_d value at a fixed temperature the analytical expression for it allows estimation of energy of the impurity states in the case when the impurity atom is completely ionized and when the Jahn-Teller distortion of the cell with impurity is absent.

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