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BINDING ENERGY OF A CARRIER WITH A NEUTRAL IMPURITY ATOM IN GERMANIUM AND IN SILICON

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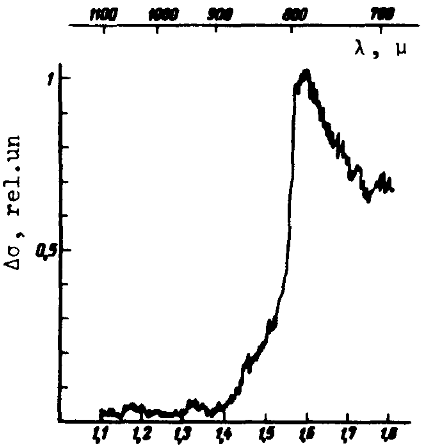
When one more electron joins a neutral donor or an extra hole joins an acceptor, a so-called D^- or A^+ center is produced in the semiconductor. The presence of such centers can apparently determine, under certain conditions, the mechanism of the impurity conductivity [1], the free-carrier scattering [2], the additional lines in the luminescence spectrum [3], and other phenomena. These centers, however, have not been well studied, and even the dimensions of the region of the bound state and the cross section for the capture of the carrier by the neutral atom are known only approximately. No direct measurements of the binding energy ε_i of the electron with the neutral atom (or of the hole with the neutral acceptor) were made. According to the estimate in [4], this energy is ~1/20 of the ionization energy of the neutral impurity atom.

We determined the energy ε_i directly from the long-wave photoconductivity edge at sufficiently low temperatures ($kT \ll \varepsilon_i$). The experiment was performed in the wavelength band 2000 - 250 μ at T = 1.5 - 4.2°K on n- and p-type Ge and Si samples with shallow impurity density 10^{12} - 10^{15} cm^{-3}. The radiation sources were backward-wave tubes in the submillimeter band [5], which made it possible to obtain a power level up to 100 μW at the investigated sample at a monochromaticity $\lambda/\Delta\lambda \simeq 10^5$. The fact that such sources can be tuned over a wide frequency range at so high a power level makes it possible to perform spectral investigations of the photoconductivity due to ionization of centers with low concentration [6].

To study the D^- (or A^+) centers in weakly-doped semiconducting materials, we used either uncompensated samples, where an appreciable fraction of the impurities is in the neutral state at low temperature and the free carriers are produced by the background radiation, or samples with arbitrary compensation of the main impurity but with additional interband illumination neutralizing the ionized impurity centers.



The figure shows, by way of an example, the spectrum of the photoconductivity $\Delta\sigma$ of a germanium sample with arsenic ($N_D = 5 \times 10^{14}$ cm^{-3}, $N_A = 10^{13}$ cm^{-3}) at T = 1.5°K. The long-wave boundary of the photoconductivity is clearly seen: $\Delta\sigma$ at $\lambda \gtrsim 900$ μ is approximately 1/20-th of $\Delta\sigma_{max}$. The table lists the binding energies of the D^- (or A^+) centers for Ge and Si doped with various impurities; ε_i is defined as the energy corresponding to $\sigma_{max}/2$ (see the figure). The table lists also data on the ionization energies of the corresponding impurities (the singlet ground state is indicated) [7 - 10]. ε_i of Si:B could not be measured directly, since the photoconductivity signal $\Delta\sigma$ just begins to grow at the short-wave boundary of the employed spectrometer (5 meV).

	Ge : Sb	Ge : P	Ge : As	Ge : Ga	Si : P	Si : B
$\varepsilon_{D^-(A^+)}$, meV	0.95	1.2	1.55	2.4	2.2	$\gtrsim 5$
$\varepsilon_{D^0(A^0)}$, meV	10.2	12.8	14	11	45.3	46

Evidence indicating that the obtained values of the long-wave boundary of the photoconductivity correspond to the binding energies ε_i of the D^- (or A^+) centers is provided by the following experimental results:

1. In samples with low compensation of the main impurity (<5%), in the absence of interband illumination, the long-wave photoconductivity boundary is clearly observed, whereas in strongly compensated samples it appears only following additional illumination.

2. The obtained values of ε_i depend significantly on the type of impurity and correlate with the depth of the ground state of the corresponding impurity.

3. In samples with impurity density $\lesssim 10^{12}$ cm^{-3}, the long-wave photoconductivity boundary is not observed even at maximum additional illumination.

We note that the value of the photoconductivity at $\varepsilon > \varepsilon_i$ increases with decreasing temperature and with increasing impurity density and additional-illumination level.

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[1] E.A. Davis and W.D. Compton, Phys. Rev. 140, A2183 (1965).
[2] A.Honig, 13th Conf. Phys. Semicond. 1970, Boston, Extended Abstracts FAC-2.
[3] P.I. Dean, I.R. Haynes, and W.F. Flood, Phys. Rev. 161, 711 (1967).
[4] M.A. Lampert, Phys. Rev. Lett. 1, 450 (1958).
[5] M.B. Golant, R.L. Vilenskaya, E.A. Zyulina, Z.F. Kaplun, A.A. Negirev, V.A. Parilov, G.B. Rebrov, and V.S. Savel'ev, Prib. Tekh. Eksp. No. 4, 136 (1965).
[6] E.M. Gershenzon and G.N. Gol'tsman, ZhETF Pis. Red. 14, 98 (1971) [JETP Lett. 14, 63 (1971)].
[7] I.H. Reuzer and P. Fisher, Phys. Rev. 135, A1125 (1964).
[8] R.A. Jones and P. Fisher, J. Phys. Chem. Sol. 26, 1125 (1965).
[9] R.L. Aggarwal and A.K. Ramdas, Phys. Rev. 140, A1246 (1965).
[10] H.I. Hrostowski and R.H. Kaiser, J. Phys. Chem. Sol. 4, 148 (1958).

ESTIMATE OF CHARGE DENSITY ON DISLOCATIONS IN NaCl CRYSTALS

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The most important characteristic of dislocations in ionic crystals is the linear density of the effective (uncompensated) charge distributed along the