COMBINED RESONANCE ON BOUND CARRIERS IN COMPENSATED n-Ge

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Submitted 26 June 1970
ZhETF Pis. Red. 12, No. 5, 201 - 203 (5 September 1970)

Combined resonance in semiconductors is known for free carriers [1] and for certain paramagnetic impurities that produce deep levels in the forbidden band [2, 3]. In the latter case, the effect is due to the absence of an inversion center for the position occupied by the impurity center, and is manifest in the electrodipole character of the excitation of the electron spin resonance (ESR).

We have observed electrodipole excitation of ESR in the 3-cm band on As donors in Ge appreciably compensated by Ga.

In the region of relatively low impurity concentration, where the allowed 4-component spectrum is usually observed [4], compensation leads to the appearance of an intense and broad absorption line at the spin-resonance frequency. Figure 1 shows the form of the absorption signals (spectra 1 and 2) and their first derivative (spectra 3 and 4) for compensated and uncompensated samples 3.2-15K (Nd - Na = 3.2 × 10^{15} cm^{-3}, degree of compensation K = 0.5) and 4.5-15 (Nd - Na = 4.5 × 10^{15} cm^{-3}, K < 0.01). At T = 1.79K, the ratio of the integral intensities of the signals from these samples, which have equal dimensions and are located in the antinode of the microwave magnetic field, is approximately equal to 70.

The electrodipole character of the excitation is confirmed by experiments on the dependence of the signal intensity on the resonance-observation conditions. The additional line has practically the same intensity when \(\vec{H}_1\) (the microwave magnetic field) is either parallel or perpendicular to \(\vec{H}_0\) (the constant field); no resonance is observed in the uncompensated sample in the former case. The signal from a compensated sample, unlike that from a compensated one, increases on moving from the antinode of the microwave magnetic field to the antinode of the microwave electric field (Fig. 2). The comparison was made with a signal from a reference sample, namely single-crystal CuSO_{4}·5H_{2}O located on the end wall of a rectangular H_{162} resonator.

Raising the temperature broadens the additional line and reduces its intensity. At T = 9°K the spectrum of the compensated sample becomes analogous to that of the uncompensated one (Fig. 1, spectra 4 - 6).

An increase of the degree of compensation above 0.5 for samples with a main-impurity concentration \(N_d = (4 - 8) \times 10^{15} \text{ cm}^{-3}\) does not lead to noticeable changes of the picture of the spectrum. For a sample 1.3-16K (Nd - Na = 1.3 × 10^{16} cm^{-3}, K = 0.45) at sufficiently low temperature, there was also observed an intense and broad additional line superimposed on the spectrum of an uncompensated sample with a corresponding concentration difference.

It was impossible to observe resonance in the compensated samples with higher concentration \(N_d \geq 3 \times 10^{16} \text{ cm}^{-3}, K \geq 0.4\), at our disposal, owing to the sharp growth of the electric losses.
Fig. 1. ESR line shape of samples 3.2-15K (spectra 1, 3, 5, 6) and 4.5-15 (spectra 2, 4). \( \mathbf{H}_0 = [100] \), 1, 2 - absorption lines, 3 - 6 - derivatives of absorption lines. Spectra 1 - 4 correspond to \( T = 4.2^\circ \text{K} \), spectrum 5 to 1.7\(^\circ \text{K} \), and spectrum 6 to 9\(^\circ \text{K} \).

Electrostatic excitation of spin resonance of electrons localized on donors.

The important factor here is apparently the loss of the inversion center for the wave function of the electron localized near the \( D^0 - D^+ \) pair (neutral donor - ionized donor), under the influence of the polarizing field of the nearest charged acceptor \( A^- \). The strong anisotropic spin-orbit interaction possessed by the conduction electrons of Ge contributes to the occurrence of the effect.

It must be noted that a change of the structure of the wave function of an electron localized on a donor, under the influence of an acceptor field, was revealed in [5] by the ESR method by the decrease of the hyperfine interaction constant.

We are presently investigating similar effects in samples of Ge doped with P and compensated with Ga.