Observation of a photodielectric effect associated with the excited states of shallow acceptors in germanium

A. V. Petrov, V. I. Bocharnikov, É. É. Godik, and V. P. Sinis
Institute of Radio Engineering and Electronics, USSR Academy of Sciences

(Submitted 26 August 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **32**, No. 7, 479–481 (5 October 1980)

An increase of the dielectric constant of germanium was observed as a result of filling of the excited states of shallow acceptors. The lifetime and polarizability of the first excited state are determined.

PACS numbers: 77.20. + y, 77.30. + d, 72.40. + w

It was shown[1] that the dielectric constant of a semiconductor can be altered significantly as a result of photoexcitation of shallow impurities—the photodielectric effect (PDE). The present paper is devoted to an experimental study of this effect. The excited states of shallow acceptors in germanium were filled in our experiment during the recombination of the photoholes that were excited by a CO_2 laser. The main difficulty of such observation of the effect was the elimination of the influence of photoconductivity. Because of this, the dielectric constant ϵ was measured in the microwave region (at a wavelength $\lambda = 8$ mm). To separately record the imaginary part of the impedance, we used a bridge and a waveguide double T[6]. In addition, to isolate the PDE signal, we took into account the fact that the lifetime τ_b of the first excited state of the acceptors in germanium[2–4] must be much greater than the lifetime τ_p of the photoholes at an adequate concentration of the trapping centers. Therefore, the PDE signal was measured with a rather long delay t_d after the end of the light pulse: $\tau_p < t_d \lesssim \tau_b$. A gate integrator with a time resolution of 10^{-8} sec was used to isolate the

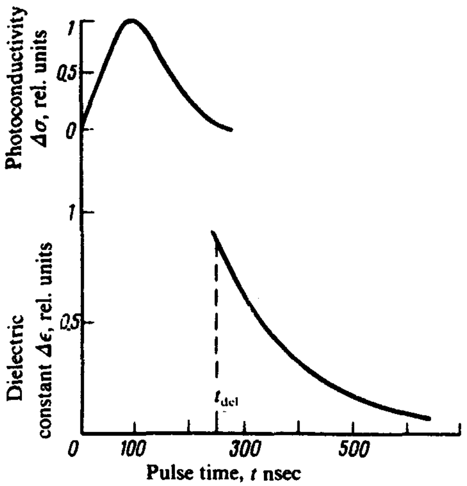

FIG. 1. Oscillogram of the variation of the dielectric constant $\Delta\epsilon$ and the photoconductivity $\Delta\sigma$ obtained as a result of excitation by a CO_2-laser radiation flash.

signal from the noise. The test samples were placed in a waveguide that was immersed in liquid helium. The impurity concentrations were: $N_A = 2\times 10^{15}$ cm^{-3} (Ga) and $N_D = 10^{15}$ cm^{-3} (Sb).

Figure 1 shows oscillograms of the variation of the dielectric constant $\Delta\epsilon$ and the photoconductivity $\Delta\sigma$ as a result of illuminating the sample with a CO_2 laser flash. After completion of the laser flash, which is effectively transmitted by the photoconductivity signal ($\tau_p \sim 10^{-9}$ sec), we observed an increase $\Delta\epsilon$ in the dielectric constant. This signal $\Delta\epsilon$ relaxed in about 150 nsec. As the temperature increased, the PDE signal disappeared sooner than the photoconductivity.

The observed increase of the dielectric constant due to illumination can be attributed to filling of the excited states. The measured relaxation time of the PDE signal in this case is determined by the lifetime of the excited states. The value obtained by us is in good agreement with the results of the experiment[3] and the theory[4] for the first excited state of the acceptors in germanium. We estimated the polarizability of this state from the ratio of the signals, which are proportional to $\Delta\epsilon(U_\epsilon)$ and $\Delta\sigma(U_\sigma)$, on the assumption that the effect is due to the longest-lived excited state:

$$a = \frac{U_\epsilon}{U_\sigma}\,\frac{\tau_p}{\tau_\epsilon}\,\frac{e\mu\,\lambda}{\pi c} \approx 8\cdot 10^{-17}\ \text{cm}^{-3},$$

where μ is the hole mobility and λ is the wavelength of the microwave radiation. The required lifetime τ_p of the free holes was determined from measurements of the phase-frequency characteristic of the photoconductivity. The obtained value of α, which is much greater than the polarizability α_0 of the ground state,[5] is in good agreement with the simple estimate of the polarizability α_{b_1} of the first excited state in the hydrogenlike approximation:

$$a = a_0\left(\frac{E_o}{E_{b_1}}\right)^2 \sim 6\cdot 10^{-17}\ \text{cm}^{-3}.$$

Similar values of the polarizability and lifetime of the excited state of shallow acceptors ($\alpha \sim 10^{-16}$ cm^3 and $\tau_b \gtrsim 100$ nsec) were obtained by using another method based on a measurement of the amplitude and phase of the PDE signal produced as a result of sinusoidal modulation ($f = 4$ MHz) of the radiation of a CW CO_2 laser.

[1]E. E. Godik and A. I. Kuznetsov, Izv. Akad. Nauk SSSR 42, 1206 (1978).
[2]V. F. Gantmakher and V. N. Zverev, Zh. Eksp. Teor. Fiz. 70, 1891 (1976) [Sov. Phys. JETP 43, 985 (1976)].
[3]E. M. Gershenzon, G. N. Gol'tsman, and N. G. Ptitsyna, Pis'ma Zh. Eksp. Teor. Fiz. 25, 574 (1977) [JETP Lett.. 25, 539 (1977)].
[4]S. V. Meshkov and E. I. Rashba, Zh. Eksp. Teor. Fiz. 76, 2206 (1979) [Sov. Phys. JETP 49, 1115 (1979)].
[5]F. D'Altroy and H. Fan, Phys. Rev. 103, 1671 (1956).
[6]A. A. Brant, Issledovanie dielektrikov na sverkhvysokikh chastotakh (Study of Dielectrics at Ultrahigh Frequencies), Fizmatgiz, Moscow, 1963.

Translated by Eugene R. Heath
Edited by S. J. Amoretty