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INFLUENCE OF RATE OF SURFACE RECOMBINATION ON THE EXCITATION THRESHOLD OF AN OSCILLISTOR

V. V. VLADIMIROV and V. F. SHANSKIĬ

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The effect of the rate of surface recombination on the excitation threshold of an oscillistor is investigated. It is shown that at high surface recombination rates the experimental points correspond to excitation of a "volume" oscillistor, whereas at low rates they correspond to a "surface" oscillistor.

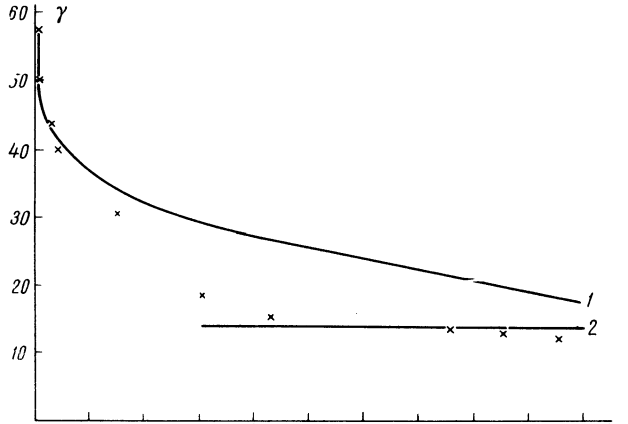
As is well known[1-4], the oscillistor effect consists in the fact that a diffusion helical instability[1)] of the electron-hole plasma is excited under certain conditions in a thin and long semiconducting crystal placed in a strong magnetic field (directed along the large dimension) and parallel to it, and in a constant electric field parallel to it. This becomes manifest in oscillations of the current and of the transverse potential. The development of the instability is determined by the balance of the drift (on the helical perturbations) and transverse diffusion fluxes. Both volume[3] and surface helical[4] waves can be excited in semiconductors. Excitation of volume helical waves occurs only in the presence of a stationary density gradient transverse to the cell. The diffusion flux, which attenuates the helical instability, is proportional to this gradient, the slope of the which is determined, and the case of a large diffusion length by the rate of surface recombination s ($l_D > a$, $l_D = \sqrt{D_a\tau_b}$, τ_b—time of volume recombination of the carriers, a—transverse dimension of the sample, D_a—coefficient of ambipolar diffusion of the carriers). The larger the rate of surface recombination, the steeper the density distribution of the nonequilibrium carrier and the more stringent the criterion for the excitation of volume helical waves. The excitation of surface helical waves is connected with the sharp change in density on the boundary of the sample, and these waves can be excited only in samples with sufficiently pure surfaces ($D_a/a \gg 1$).

The criterion for the excitation of the volume oscillistor in long samples of cylindrical shape, in the region of the intrinsic excitation, is of the form[2)]

$$\gamma = \frac{ea}{c} b_e \left(1 + \frac{1}{b}\right) \frac{HE}{T_c} > \gamma_{\text{cr}}. \tag{1}$$

The quantity γ_{cr} is a function of the parameter $G_s = D_a/as$, which determines the rate of surface recombination. We have introduced above the notation: $b_{e,h}$—carrier mobilities, and $b = b_e/b_h$, T_c—lattice temperature. In the derivation of (1) it was assumed that $l_d > a$, $Hb_{e,h}/c \ll 1$, and $T_e = T_h = T_c$. The figure (curve 1) shows the value of γ_{cr} for different values of the parameter G_s.

The criterion for the excitation of the surface oscillistor coincides with (1) when $\gamma_{\text{cr}} = 14(1 + 1/3\, G_s)^{3/2}$. The gradient of the density in the stationary state was not taken into account in the derivation of this criterion[4] ($G_s \gg 1$). This criterion is practically independent of G_s (straight line 2 in figure) and is somewhat less rigid than the excitation threshold of the volume oscillistor in the region $G_s \gg 1$. Therefore we should expect the experimentally-obtained oscillistor excitation threshold, to be determined in the region $G_s \gg 1$ by the criterion for the excita-



Parameter γ_{cr} vs. G_s. Solid curve–theoretical: curve 1–for volume oscillistor, curve 2–for surface oscillistor. Points–experimental data.

[1)] This instability was first considered by Kadomtsev and Nedospasov [5] as applied to the positive column plasma of a gas discharge.

[2)] This criterion can be derived from a paper by one of the authors [6].

tion of the surface oscillistor, and in the region $G_s \ll 1$ by the criterion for excitation of the volume oscillistor.

An experimental investigation of the excitation threshold of the oscillistor as a function of the rate of surface recombination was made on samples of Ge with in-type conductivity close to the intrinsic conductivity ($\rho \sim 40$ ohm-cm, $n_0/p_0 \sim 2$). The crystal dimensions were $1 \times 1 \times (5-10)$ mm ($a\sqrt{2} = 10^{-1}$ cm). The rate of surface recombination was varied by etching the samples with hydrogen peroxide at different exposures. The non-equilibrium carriers were injected into the sample via contacts (p-i-n system similar to that used by Larrabee and Steele[2]). The rate of surface recombination was calculated by the formula[7]

$$s = \left[D_a\left(\frac{1}{\tau_{\text{eff}}} - \frac{1}{\tau}\right)\right]^{1/2} \tan\left\{\frac{\bar{x}_0}{2}\left[\frac{1}{D_a}\left(\frac{1}{\tau_{\text{eff}}} - \frac{1}{\tau}\right)\right]^{1/2}\right\},$$

where τ_{eff} is the effective carrier lifetime, τ is the volume carrier lifetime, and $\bar{x}_0$ the effective transverse dimension of the samples, equal to $a/\sqrt{2}$ for $G_s \gg 1$ and to a for $G_s \ll 1$. The carrier lifetime τ_{eff} was measured by a microwave procedure[8]. The volume lifetime τ was measured in samples with dimensions $3 \times 3 \times 10$ mm ($a > l_D$) with a small rate of surface recombination. It turned out to be $\tau \approx 2.93 \times 10^{-4}$ sec.

We present below the experimental values of the electric and magnetic field intensities at which the oscillistor is excited, for different values of the parameter G_s:

G_s	10^{-2}	$5 \cdot 10^{-2}$	0,3	0,4	1,5	3,1	4,6	7,6	8,6	9,6
E, V/cm:	58,8	69,2	69,2	69,2	61.0	69.2	50.0	46,0	52.6	69,2
H, Oe :	6580	5070	4480	4050	3580	1930	2240	2030	1740	1290

In the figure, the crosses correspond to $\gamma_{\text{cr}}^{\text{exp}}$ for the presented values of the parameter G_s. As seen from the figure, in the region $G_s \lesssim 1$ the experimental points correspond to the excitation threshold of the volume oscillistor, and in the region $G_s \gtrsim 4$ they correspond to the surface oscillistor, in accordance with the initial premises of the theory. In the region $1 < G_s < 4$, the experimental points lie between curves 1 and 2. To calculate the exact criterion for the excitation of the oscillistor in this region, it is necessary to solve the problem of stability with account of the stationary density gradient and the exact boundary conditions on the surface of the sample, which is an extremely difficult problem.

The results can be used, in our opinion, to determine the rate of surface recombination from the oscillistor excitation threshold. To this end one determines experimentally the threshold value of γ_{cr} (it is assumed that the mobilities of the electrons and the holes are known), and the corresponding value of G_s is determined with the aid of the $\gamma_{\text{cr}}(G_s)$ curve, after which it is easy to calculate the rate of the surface recombination. This method is most effective apparently in the region of not too large values of G_s ($G_s \lesssim 5$), when the oscillistor excitation threshold depends strongly on the rate of surface recombination.

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