Yu. M. Gal'perin, P. E. Zil'berman, S. N. Ivanov, V. D. Kagan, and G. D. Mansfel'd. A New Type of Acoustoelectric Nonlinearity (Nonlinear Landau Damping of Sound Waves).

Nonlinear effects that accompany the propagation of microwave-frequency sound waves in semiconductors are investigated theoretically and experimentally. At these frequencies, the length $2\pi/q$ of the sound wave proves to be much smaller than the conduction electron free path l for a number of substances ($ql \gg 1$). Under these conditions, only the group of "resonant" electrons that satisfy the laws of energy and momentum conservation on collisions with acoustic quanta interacts with the acoustic wave. The absorption of the sound is determined by the energy balance in such processes and is analogous to the Landau damping of plasma waves. In a sufficiently strong external electric field, absorption of the sound gives way to its amplification. With increasing intensity of the sound, nonlinear effects make their appearance; for example, the gain begins to depend on intensity. At $ql \gg 1$, the mechanism of the nonlinearity differs essentially from the concentration nonlinearity, which is the basic factor at low frequencies. The concentration nonlinearity appears as a result of capture of some of the space charge by potential wells created by the acoustic wave. A measure of this capture is found in the ratio of the depth Φ of the potential wells to the average electron energy $\bar{\epsilon}$. When $ql \gg 1$, the momentum distribution function in the resonant region differs strongly from the equilibrium distribution as a result of a back effect of the acoustic wave on the "resonant" electrons. It is this effect that represents the basic source of the nonlinearity. A calculation indicates that for nonmonochromatic sound with a spectral line width

$$\Delta q \gg \frac{m}{\hbar q \tau_p}$$

(τ_p is the momentum relaxation time of the electrons and m is their effective mass), a nonlinearity of the type in question intervenes when

$$\left(\frac{\Phi}{\bar{\varepsilon}}\right)\frac{\bar{\varepsilon}}{\hbar}\sqrt{\frac{m\tau_p}{\hbar q\,\Delta q}} \sim 1.$$

For monochromatic sound, such a nonlinearity appears at $(\Phi/\bar{\epsilon})(ql)^2 \sim 1$ if $q \ll m/\hbar q\tau_p$, and at $(\Phi/\bar{\epsilon})(\bar{\epsilon}\tau_p/\hbar) \sim 1$ when $q \gg m/\hbar q\tau_p$. Since $(\Phi/\bar{\epsilon})(ql)^2 \sim 1$, and $\bar{\epsilon}\tau_p/\hbar \gg 1$, this nonlinearity intervenes much earlier than concentration nonlinearity.

The electronic amplification of sound of frequency 1–2 GHz was investigated experimentally in n-InSb at T = 77°K (ql = 5–10). The sound was excited and registered with CdS epitaxial transducers. The dependence of the amplification of the sound on its intensity at the input, which varied in the range 10^{-5}–1 W/cm^2, was studied. It was found that the gain decreases progressively with increasing intensity of the sound. The manner in which the effect depends on the frequency of the sound and its intensity is consistent with the theory and permits qualitative and quantitative differentiation of the observed effect from the concentration nonlinearity. The intensity of the sound in the output cross section of the crystal was observed to be independent of the power input into the crystal at large values of the latter. This can be interpreted as establishment of a stationary wave in the crystal.

Translated by R. W. Bowers