Acoustoelectric "aftereffect" in the interaction of surface acoustic waves within a piezoelectric-semiconductor layered structure

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As shown by Chaban[1–3], nonlinear interaction of acoustic waves in piezo-semiconductors in the presence of a slowly relaxing inhomogeneity of the electric properties can lead to an acoustoelectric "aftereffect," which makes it possible to record an acoustic signal and restore it after some time—acoustic "memory." In interactions between sound and an electric field, different variants of this phenomenon were observed in volume waves[4] and in surface acoustic waves (SAW).[5,6] It is of great interest, however, to investigate this phenomenon in pure form in the case of interaction between sound and solid.

In nonlinear interaction of transverse SAW, it follows from the energy and quasimomentum conservation laws

$$\omega_1 \pm \omega_2 = \omega_3; \qquad \mathbf{k}_1 \pm \mathbf{k}_2 = \mathbf{k}_3 \tag{1}$$

that when the frequencies and velocities of the interacting waves are equal, a process with

$$\omega_3 = 0; \qquad \mathbf{k}_3 = 2\mathbf{k} \tag{2}$$

is possible, in which a dc component of the resultant signal is produced with a spatial period $\lambda/2$. In the case of interaction of opposing waves in a piezoelectric-semiconductor layered structure, such a signal will be the transverse acoustic emf[7], which leads to a redistribution of the space charge on the impurity levels of the semiconductor. The signal recorded in this case on the impurity states will be proportional to the acoustic convolution of the pulses of the opposing SAW. This signal is preserved until diffusion and thermal processes wash out the space charge. The recorded signal can be read either with a surface wave or with an electric signal at the frequency 2ω. In the former case, in the case of interaction between the SAW and the space charge

$$0 + 2\omega = 2\omega; \qquad 2\mathbf{k} - 2\mathbf{k} = 0 \tag{3}$$

an electric signal of frequency 2ω is produced in the semiconducting crystal (Fig. 1). In the latter case, an electric signal of frequency 2ω applied to the semiconductor excites forward and backward surface waves in the piezoelectric upon interaction with the space charge.

The described interactions, i.e., the "recording" of the signal produced by interaction of sound with sound and two variants of reading the signal, were verified by us experimentally in a piezoelectric-semiconductor layered struc-

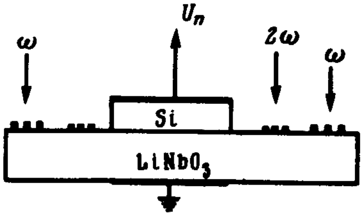

FIG. 1.

ıre shown schematically in Fig. 1. We used for the recording opposing SAW : frequency 29 MHz. The semiconductor sample (Si or CdS) was placed in the ɜntral part of an $LiNbO_3$ sound conductor. The reading SAW pulse was excited ⁄ a second converter at 58 MHz or else was applied to the semiconductor

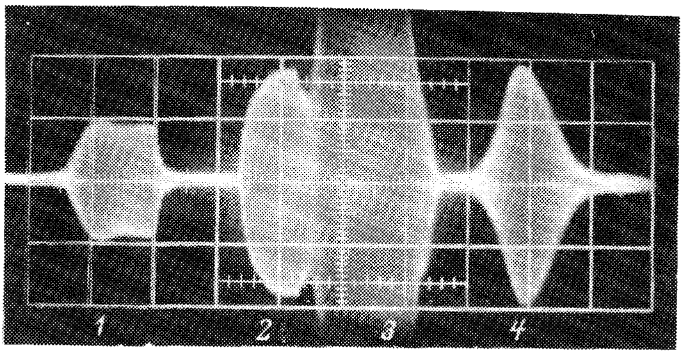

FIG. 2.

ılate. An oscillogram of one of the processes is shown in Fig. 2. Here **1** is he electric signal at frequency $\omega = 29$ MHz—the "recording" signal, **3** is the ıignal of the acoustic convolution from the opposing SAW ($\omega_3 = 2\omega$; $k_3 = 0$), de-ayed by the time of propagation of the SAW from the converters ω to the center ıf the semiconductor. **2** is the reading-signal pulse at the frequency of 58 MHz. :—acoustic "memory" pulse delayed by a time τ_d relative to the convolution ıignal. The change in the instant when the reading pulse **2** is applied changes

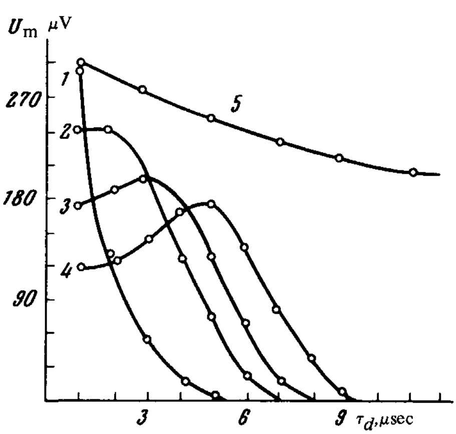

FIG. 3.

the delay of the "memory" pulse 4, but when τ_d is increased the amplitude of the "memory" pulse decreases. In the case of Si, the "memory" pulse decreases to the noise level within 5—10 μsec, and in the case of CdS this time increases to 10 μsec. No memory pulse was observed in some of the Si samples (dislocation-free silicon). Annealing the samples increases the time τ_d to 50 μsec. The same takes place if the sample is cooled with dry ice to − 55 °C. Figure 3 shows plots of the "memory" signal amplitude against the delay time τ_d for p-type silicon ($\rho \sim 10^3$ Ω-cm). Curve 1 was obtained at an input-signal amplitude of 5 V on each converter and a reading-pulse amplitude 7 V. The "memory" pulse amplitude, at the minimum delay $\tau_d \sim 1$ μsec, amounted in this case to 300 μV and an exponential dependence of the "memory" pulse amplitude on τ_d was observed. Increasing the amplitude of the input signals to 10 V (curves 2—4) leads to saturation of the amplitude of the "memory" pulse on the initial sections (small τ_d). Illumination of the crystal Si strongly decreases the memory time and the saturation level is shifted at the same time. Cooling the crystal to − 55 °C increases greatly the "memory" time (curve 5). Similar relations were obtained for n-type Ge plates with a somewhat larger memory time.

Analogous effects are observed also at CdS crystals, but in this case the memory signal level is smaller by a factor 3—4 under the same conditions, but the memory time increases to 10 msec, and the saturation of the memory signal is almost unnoticeable. Illumination of the crystal decreases the memory by 3—4 orders.

The observed effects are very well explained by the dispersion diagrams of wave interaction. It appears that these effects are a good tool for the investigation of surface states and for measuring the relaxation times in semiconductors In addition, these effects are of interest also for reduction of signal information, since it is possible to produce a dynamic memory for functional devices.

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