ALTERNATING ACOUSTOELECTRIC EFFECT IN A PIEZODIELECTRIC-SEMICONDUCTOR LAYERED STRUCTURE

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When acoustic waves propagate in piezosemiconducting crystals, an emf is produced because the carriers are dragged by the sound wave (acoustoelectric effect (AEE)). At low intensities W of the volume [1] and surface Rayleigh waves and Gulyaev-Blyustein waves [2], as well as in layered structures [3], the value of the AEE depends linearly on W, but at large W one observes saturation of the AEE emf [3 - 6].

In an investigation of AEE in layered structures we observed that the dependence of the AEE emf on W can have an entirely different form, and the sign of the AEE may even be reversed at large sound intensities. The experimental setup is shown in Fig. 1. The piezodielectric medium was an acoustic guide of YZ-cut $LiNbO_3$. To excite and receive elastic Rayleigh surface waves (ESW), we used wedge-like pizeosemiconducting converters with a diffusion layer [7], operating in the frequency range 10 - 100 MHz. Such converters made it possible to obtain large values of W, which according to our estimates reached $\sim 10^2$ W/cm^2. The silicon sample was clamped to the acoustic guide with the aid of a device that made it possible to adjust the air gap with accuracy 0.5 μ. The contacting $LiNbO_3$ and Si planes were optically polished and washed with isopropyl alcohol. The p-Si samples measured 0.4 × 6 × 10 mm, and had a dark conductivity $\sigma = 2 \times 10^{-4}$ $ohm^{-1}cm^{-1}$ and a mobility ~ 500 cm^2/V-sec (determined from the value of the field at which the USW gain was zero). The conducting contacts were gold foil made by fusing-in gold foil with Sb additive, and the AEE emf (ε_{ae}) was measured directly with an oscilloscope (R_{in} = 0.5 Meg).

Figure 2a shows a plot of ε_{ae} against the converter voltage $V_{\sim}$. We see that for an unilluminated p-type sample (curve 1) the sign of ε_{ae} corresponds to dragging of holes, and the value of ε_{ae} increases monotonically to saturation with increasing $W \sim V^2$. On the other hand, when the sample is illuminated in the region of the intrinsic absorption (0.4 - 0.5 μ), the sign of ε_{ae} corresponds to electron dragging at small values of W, and to hole dragging at large values (curves 2 and 3). When the illumination is increased, the point where the sign of ε_{ae} is reversed shifts towards larger W. A similar $\varepsilon_{ae}(W)$ dependence was observed when the direction of the ESW was reversed. The ESW absorption coefficient α revealed no singularities and decreased monotonically with increasing W (curve 4). For an n-type sample (curve 5), no change of the sign of ε_{ae} was observed in the same range of variation. We note that these results are not due to any nonlinear effects connected with the propagation of ESW in $LiNbO_3$, for when the voltage on the radiating converter is increased the output signal of the receiving converter varies linearly.

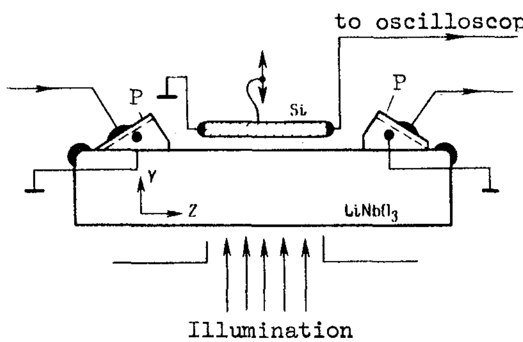
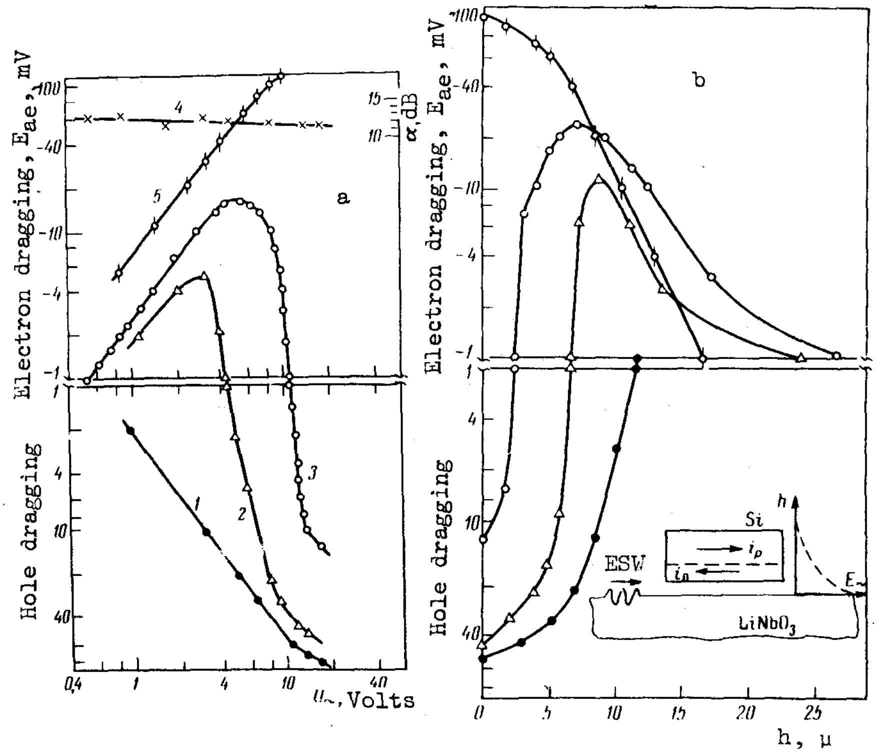


Fig. 1. Experimental setup. P - piezoconverters for elastic surface waves.

In a number of experiments, the intensity of the ESW in the $LiNbO_3$ was maintained constant, and the intensity of the field in the silicon was varied by varying the gap between them. In the p-Si samples we also

Fig. 2. Acoustoelectric voltage vs. the voltage on the wedge-like converter (a) and the gap h between the piezodielectric and the semiconductor (b). Frequency 65 MHz. 1, 2, 3 - p-Si, $\sigma \times 10^4$ $ohm^{-1}cm^{-1}$ = 5 (curve 1), 10 (2), 20 (3); 5 - n-Si, $\sigma = 20 \times 10^{-4}$ $ohm^{-1}cm^{-1}$; 4 - USW absorption coefficient, p-Si, $\sigma = 20 \times 10^{-4}$ $ohm^{-1}cm^{-1}$.



observed a reversal of the sign of the AEE when the gap was decreased, i.e., when the electric field inside the silicon was increased (Fig. 2b). On the other hand, in the n-type samples the sign of the AEE remained the same.

The observed unusual behavior of the AEE can be explained by assuming that an n-type inversion layer is produced on the surface of the p-type samples when they are illuminated. Such a layer can result from the preferred capture of photo-holes by local levels (both on the surface and in the interior). When an acoustic wave passes through a piezoelectric, the piezoelectric field of the ESW penetrates into the semiconductor [8] and drags carriers of opposite sign in the same direction. The resultant AEE current is the difference between the hole and electronic components corresponding to the dragging of carriers in the volume of the semiconductor and in the inversion layer. If the ESW intensity is low, and the inversion layer is sufficiently broad, then the total acoustoelectric current will correspond to electron dragging. When W increases, the electric field at each point of the semiconductor increases and an ever-increasing part of the volume of the semiconductor contributes to the acoustoelectric current (i.e., the hole component of the current increases). On the other hand, when W is increased saturation of the acoustoelectric current in the inversion layer is still possible, owing to the total bunching of the carriers in it. Both these effects lead to a deviation from the linear dependence of ε_{ae} on W and to a decrease of the total current. Equality of the currents in the volume and in the inversion layer corresponds to a zero value of the resultant current, and further increase of W leads to predominance of the hole component of the current. The shift of the point at which the sign of ε_{ae} is reversed into the region of larger W with increasing illumination may be due to the broadening of the inversion layer upon illumination. Obviously, in this same case of predominant capture of photo-holes in n-Si samples we should obtain not inversion layers, but enriched surface layers of the n-type, which do not reverse the sign of the AEE.

The presented scheme is oversimplified, for actually both the conductivity of the semiconductor [9] and the electric characteristics of the inversion layer are altered when the intensity of the ESW is increased.

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FERRIMAGNETISM OF THE GARNET $Mn_3Cr_2Ge_3O_{12}$

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Measurements of the magnetic properties of garnets containing magnetic ions only in the c- and a-sublattices were first carried out by Bozorth and Geller [1, 2]. It was established there that the c-a exchange interactions cause ferrimagnetism to occur in the garnets $\{Gd^{3+}\}[Mn_2^{2+}](GaGe_2)O_{12}$ and $\{Gd_2^{3+}Ca\}[Mn_2^{2+}](Ge_3)O_{12}$ (with Curie points θ close to 8 and 6°K, respectively), whereas no spontaneous magnetic moment was observed in the garnets $\{Mn_3^{2+}\}[Fe_2^{3+}](Ge_3)O_{12}$, $\{Gd_3^{3+}\}[Co_2^{2+}](GaGe_2)O_{12}$, and $\{Gd_3^{3+}\}[Ni_2^{2+}](GaGe_2)O_{12}$ down to 1.5°K.

In the present study we have established the presence of ferrimagnetism in the garnet $\{Mn_3^{2+}\}[Cr_2^{3+}](Ge_3)O_{12}$, the Curie point of which is 3.68 ± 0.03°K. To obtain information on the values of the intrasublattice exchange interactions of the ions Mn^{2+} and Cr^{3+}, we measured also the magnetic properties of the "single-sublattice" garnets $\{Mn_3^{2+}\}[Ga_2](Ge_3)O_{12}$ and, earlier $\{Ca_3\}[Cr_2^{3+}](Ge_3)O_{12}$ [3].

The investigated polycrystalline samples were synthesized by a ceramic technology with double annealing in air at T = 1160°C; the phase composition was monitored by x-ray diffraction.

We present below the unit-cell parameters of the garnets investigated by us:

$$Mn_3Cr_2Ge_3O_{12},\ a_0 = 12.028 \pm 0.004\ \text{Å},$$
$$Mn_3Ga_2Ge_3O_{12},\ a_0 = 12.016 \pm 0.004\ \text{Å},$$
$$Ca_3Cr_2Ge_3O_{12},\ a_0 = 12.260 \pm 0.002\ \text{Å}.$$