Effect of acoustic noise on the current-voltage characteristic of an n-InSb Corbino disk

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We observed a strong superlinearity of the current-voltage characteristic of an indium-antimonide Corbino disk placed in a magnetic field. The experiments were performed at liquid-nitrogen temperature. The parameter μB ranged from 5 to 15. We obtained, for the first time ever, a number of experimental data that prove that the character of the observed phenomenon is governed by electronic amplification of acoustic noise. It is shown that the presence of reflecting faces on the lateral surface of the disk enhances the effect.

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The amplification of thermal acoustic noise and of acoustic wave fed from the outside into a piezosemiconductor sample having the geometry of a Corbino disk and placed in a magnetic field was theoretically investigated in Refs. 1 and 2. It was shown in Ref. 1 that if the Hall angle is large and the parameter $\mu B \gg 1$ (B is the magnetic induction and μ is the electron mobility), then the current voltage characteristic (CVC) of the sample can become strongly superlinear. The cause of the effect is that the acoustoelectric current produced upon amplification of the noise is directed counter to the noise flux and is deflected in the magnetic field in such a way that the experimentally measured radial current component is increased. In Ref. 2, a theoretical study was made of the singularities of the amplification of the acoustic waves in a disk cut from a piezosemiconducting cubic crystal in such a way that the piezoactive directions for the shear wave lie in the plane of the disk. The order of magnitude of the drift-current density needed for the onset of the amplification was estimated, and the conditions were determined under which cyclic generation of a beam of acoustic wave of finite width sets in. The only experimental study devoted to the CVC in piezosemiconductors with the Corbino-disk geometry is Ref.2, where CdS samples were studied. However, owing to the low mobility of the electrons in CdS, the parameter μB in that study was small. In addition, no direct proof was presented of the acoustoelectronic nature of the kink in the CVC.

We have investigated in the present study the singularities of the amplification of acoustic noise in a disk of diameter $D = 8$ mm, cut from n-InSb with mobility $\mu = 5.6 \times 10^5$ cm^2/V-sec and concentration $n = 1.1 \times 10^{14}$ cm^{-3} (Fig. 1). Ohmic contacts of In with Te were fused-in at the center of the sample (1) and on its lateral surface (2). The measurements were made at liquid-nitrogen temperature. The sample was placed in a magnetic field perpendicular to its plane (see Fig. 1). The magnetic field used in the experiments ($B = 1$–3 kOe) made it possible to attain a parameter $\mu B = 5$–15. Just as in Ref. 2, the sample orientation was chosen such that the mutually perpendicular piezoactive directions [110] and [1$\bar{1}$0] for the shear waves were in the plane of the disk. Flat reflecting faces (3) were produced on the lateral surface of the disk by optical polishing, at angles 45° to the piezoactive directions. The acoustic waves propagating along the piezoactive directions were thus subjected to successive reflection from the lateral faces, and could be amplified by the corresponding projections of the azimuthal and radial components of the drift current over many closed cycles. One could also expect this sample configurations, in which multiple reflections from the faces take place, to enhance the effects connected with amplification of the acoustic noise.[2] To register the electromagnetic signal produced by the piezoeffect when the acoustic noise is generated, a capacitive probe (4) was placed on the plane of one of the reflecting faces and connected to a microwave receiver.

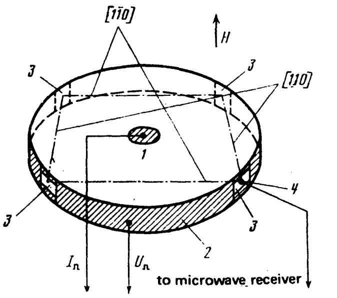

FIG. 1. Sample connection diagram.

Figure 2(a) shows the waveform of the current pulse through the sample, and Fig. 2(b) shows an oscillogram of the noise registered by the microwave receiver. It is seen that at high voltages a positive step appears on the current pulse, and the noise is noted on this step. The instant of start registration of the intense acoustic noise coincides with the appearance of the step on the current pulse. We note that after the sample current is turned off, a noise of decreasing amplitude is still registered for some time. Figure 3 shows the CVC of the sample, plotted for the initial part of the pulse (1)

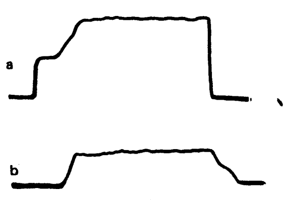

FIG. 2. a) Oscillogram of current flowing through the sample. b) Oscillogram of microwave signal generated in the sample.

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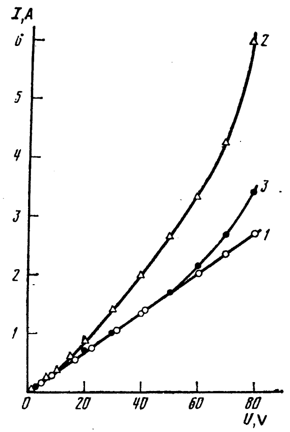

FIG. 3. Current-voltage characteristics of sample.

and for the steady state at the end of the pulse (2). It is seen that curve 2 is superlinear.

Favoring the acoustoelectric origin of the observed effect are the following facts:

1. The time delay at which the CVC break appears. For the acoustoelectric current due to the amplified noise to become noticeable against the background of the drift current, the total gain of the noise should be large, ~70 dB. Reaching such a gain calls for a definite time of the order of several microseconds.[4] In our experiments this time depended on the field applied to the sample. For weak fields, when the electronic amplification is relatively small, the delay was large. It was easy to observe in the experiments delays on the order of dozens of microseconds. With increasing voltage, when the electronic amplification increased, the delay decreased. With further increase of the voltage on the sample, the delay time of the appearance of the CVC break turned out to be ~4 μsec, beyond which it became independent of the voltage. This may be due to the onset of nonlinear effects upon amplification of the acoustic noise.

2. The appearance of an electromagnetic signal precisely at the instant of the appearance of the step on the current pulse. At a specified limited sensitivity of the recording apparatus, the electromagnetic signal due to the amplified noise becomes noticeable precisely at the instant when the noise intensity is abruptly increased as a result of the amplification.

3. The microwave receiver recorded two sharp signal maxima at frequencies ~1400 and 700 MHz. The first value is close to the frequency of the maximum gain of the acoustic waves ($f_{max} = 1490$ MHz at $n = 1.1 \times 10^{14}$ cm^{-3}), and the second corresponds to a subharmonic of the fundamental frequency. Generation of acoustic waves in piezosemiconductors at the maximum-gain frequency and the subharmonic was frequently observed earlier and explained.[6-8]

4. The presence of an electromagnetic signal of decreasing amplitude when the field is turned off is apparently due to the fact that the amplitude of the amplified acoustic noise in the crystal cannot be decreased instantaneously.

5. Finally, evidence in favor of the acoustoelectric origin of the effect is provided by the good agreement between the measured drift current needed to obtain sufficient electronic amplification of the acoustic waves and the theory[2] developed for amplification in the Corbino-disk geometry.

To verify experimentally the degree of the influence of the reflecting polished faces on the observed phenomena, we artificially roughened the surfaces of the faces after obtaining the data described above. The step on the current pulse became smaller and appeared at much higher voltages. The corresponding CVC is represented by curve 3 of Fig. 3. In the presence of specularly reflecting faces, the amplified acoustic noise before and after the reflections propagated along the piezoactive directions or at relatively small angles to them, under conditions favoring the amplification. Therefore even at a small gain, i.e., at low voltages on the sample, the noise intensity can become so large that the associated electroacoustic current exerts a substantial influence on the CVC. When there is no polished surface, the reflections are at random angles, and the greater part of the energy of the amplified acoustic flux is diffusely scattered. As a result, the effective distance over which the noise is amplified has a limit $\sim D2^{1/2}$ and larger voltages are needed to obtain a sufficient gain. Apparently, it is this which explains the difference between the CVC.

We have thus observed in this study an appreciable superlinearity of the CVC of a Corbino disk cut from n-InSb, and presented a number of experimental data indicating that the origin of the observed effect is the amplification of the acoustic noise.

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