Investigation of the phase of the electroacoustic echo

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The dependence of the phase of a two-pulse, dynamic, electroacoustic echo on the amplitude, duration of the exciting pulses, and on the interval between them is investigated experimentally.

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In view of the fact that the electroacoustic (polarization) echo (EAE) is of great interest as a new method of investigation of solids and as a promising basis for solving a number of applied problems, investigation of this effect is one of a number of urgent problems in solid state physics. The basic idea, mechanisms of formation, current state

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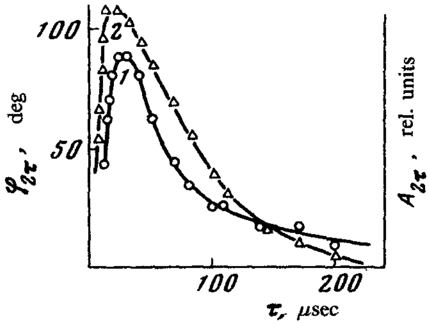

FIG. 1. Dependence of the phase (curve 1) and amplitude (curve 2) of the echo 2τ on the interval between the pulses τ. $\Delta t_{1,2} = 7$ μsec and $E_{1,2} = 100$ V/mm. The phase at the peak on the curve is assumed to be 90°.

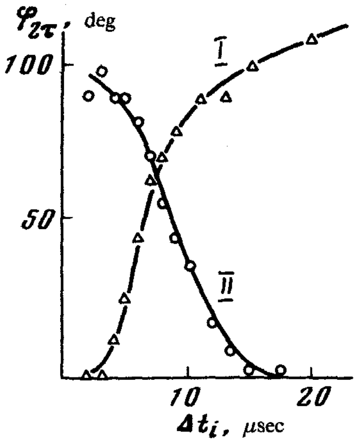

FIG. 2. Dependence of the phase of the echo 2τ on: (I) the duration of the first pulse Δt_1 at $\Delta t_2 = 7$ μsec and (II) on the duration of the second pulse Δt_2 at $\Delta t_1 = 7$ μsec. $\tau = 100$ μsec and $E_{1,2} = 100$ V/mm. At $\Delta t_1 = 2$ μsec and $\Delta t_2 = 7$ μsec the phase is assumed to be zero.

of experimental research of EAE, feasibility of practical utilization, and bibliography are given in sufficient detail in Ref. 1. At present, a large number of experimental data on the amplitude, frequency, and time-dependent properties of EAE has been published. The phase characteristics, however, have been investigated relatively little. The phase of the echo signals was investigated in Refs. 2–4, as a function only of the phases of the exciting pulses. However, determination of the effect of other parameters of the pulses is very important in determining the dominant contribution of a given echo mechanism and for practical utilization of this effect.

The goal of this paper is to investigate the dependence of the phase of a two-pulse dynamic EAE produced at the time 2τ on the amplitudes $E_{1,2}$, duration Δt_1 and Δt_2 of the exciting pulses, and on the interval τ between them, and to specify the mechanism for formation of the EAE on the basis of the obtained area

The measurements were performed using the YaKR ISP-1 pulse coherent spectrometer.[5] The phases of the echo signals and of the exciting pulses were determined from the peak of the amplitude of the signal from the synchrodetector while varying the phase of the reference signal. The phase difference between the first and second pulses in all the experiments was equal to zero. The sample was prepared from a

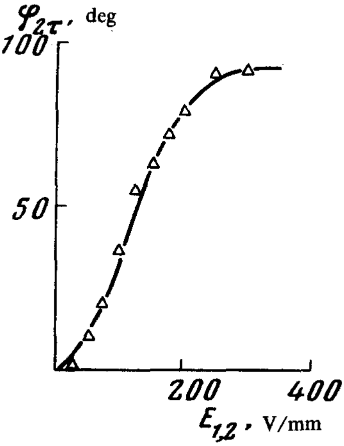

FIG. 3. Dependence of the phase of the echo 2τ on the amplitudes of the exciting pulses at $E_1 = E_2$, $\Delta t_{1,2} = 7$ μsec, and $\tau = 50$ μsec. At $E_{1,2} = 25$ V/mm the phase is assumed to be zero.

crystal powder of a piezo-electric crystal $CsBrO_3$ 1 cm^3 in volume. The results were obtained at room temperature at rf frequency of 9 and 16 MHz.

We give the main results of the experiment. 1) The variation range of the phase of the 2τ echo in all the cases was approximately 90°. 2) A characteristic peak appeared in the τ dependence of the phase of the 2τ echo. A typical curve (curve 1) for the dependence $\phi_{2\tau} = f(\tau)$ is shown in Fig. 1, which also shows the curve for the τ dependence of the amplitude of the echo (curve 2). The correlation between these two dependences is noteworthy. The location of the peak in the investigated range (at $E_1 = E_2$ and $\Delta t_1 = \Delta t_2$) is independent of the amplitudes and duration of the pulses. 3) An increase of the duration of the second pulse Δt_2 (at $\Delta t_1 = \text{const}$) decreases the phase of the echo (curve 2 in Fig. 2). 4) An increase of the duration of the first pulse Δt_1 (at $\Delta t_2 = \text{const}$) increases the peak of the echo (curve 1 in Fig. 2). 5) When the duration of both pulses is increased simultaneously (at $\Delta t_1 = \Delta t_2$) the phase of the echo approaches saturation whose level depends on $E_{1,2}$ and on τ. 6) The phase of the echo increases with increasing amplitude of the exciting pulses (for $E_1 = E_2$ and $\Delta t_1 = \Delta t_2$), and approaches saturation at large $E_{1,2}$ (Fig. 3). The increase depends on the amplitude and duration of the pulses. Deviations from a smooth increase were observed in the region of small values of $E_{1,2}$ and large values of τ. These results can be explained by using a model based on the amplitude shift of the oscillation frequency of the particles. On the basis of the calculations in Refs. 2, 6, and 7, in the approximation of short exciting pulses we can obtain for the phase of the 2τ echo:

$$\phi_{2\tau} = \gamma[A_2^2 - A_1^2(1 - e^{-2\Gamma\tau})](1 - e^{-2\Gamma\tau}), \tag{1}$$

where γ is a constant which depends on the attenuation factor (Γ), on the electromechanical coupling, on the nonlinear frequency shift, etc., and $A_1 = f(E_1, \Delta t_1)$ and $A_2 = f(E_2, \Delta t_2)$ are oscillation amplitudes of the particles excited by the first and second pulses, respectively. This expression was obtained for a uniform distribution of particles according to the natural frequencies and orientations.

At $A_1 = A_2$ Eq. (1) describes qualitatively the result in Fig. 1. As seen in Eq. (1), the location of the maximum on the curve $\phi_{2\tau} = f(\tau)$ is determined by the attenuation factor (Γ) and by the ratio of the amplitudes A_1 and A_2. Fossheim *et al.*[7] investigated the τ dependence of the amplitude of 2τ echo in a ZnO sample using synchronous detection at a temperature of 1.25 K and frequency of 9 GHz. The conclusions drawn from their result on the τ dependence of the phase of the echo coincide with our data.

Expression (1) also describes qualitatively the inverse dependence of the echo's phase on Δt_1 and Δt_2 and the $E_{1,2}$ dependence, if we assume that $A_1 \sim E_1 \Delta t_1$ and $A_2 \sim E_2 \Delta t_2$. The largest deviations of the experimental results from the behavior predicted by Eq. (1) occur when Δt_1, Δt_2, and $E_{1,2}$ are large. These deviations are attributable to the transition of the particle oscillations to the steady-state mode during the action of the pulses, i.e., violation of the proportionality between A_i and $E_i \Delta t_i$ ($i = 1,2$). The region of saturation of the echo's phase at a simultaneous increase of the duration of both pulses apparently also corresponds to this mode.

Thus, we have investigated experimentally for the first time the dependence of the phase of the dynamic EAE on the amplitudes, on the duration of the exciting pulses, and on the interval between them and obtained a qualitative agreement between the results of the experiment and the theory based on the amplitude shift of the oscillation frequency of the particles.[2,6,7]

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