Experimental studies of the amplitude of the ponderomotive acoustic signal (PAS) in NaCl as a function of surface electron-current density and irradiation pulse length are reported. Published experimental data on radiation-induced conductivity in NaCl subjected to strong electron fluxes are used to analyze nonlinear PAS generation under the same irradiation. It is shown that the maximum PAS amplitude is determined by the rapidly varying strong electric field set up in the specimen by the charge in the beam of irradiating electrons and depends on the charge drain due to the radiation-induced conductivity of the NaCl in that field. The satisfactory agreement of the NaCl conductivity calculated with consideration of the PAS amplitude variations with published direct-method data conductivity in strong electric fields indicates that the coefficient $K_c$ of PAS generation is constant in fields with $E$ up to $3 \cdot 10^5$ V/cm. This makes it possible to determine $K_c$ in electric fields $E < 10^5$ V/cm and establish variations in the conductivity of the material from PAS amplitudes under irradiation with nanosecond electron beams.

Experimental studies of radiation-acoustic effects in dielectrics and semiconductors have shown that a ponderomotive elastic-stress pulse is generated along with the thermoelastic acoustic signal [1]. The ponderomotive effect is known to be due to the electric field. The experimental work was distinctive in that the electric field in the specimens was created by the uncompensated nonequilibrium charge formed by electrons absorbed during irradiation. The deformation due to the ponderomotive effect is proportional to the square of the electric field strength [2]. In our experiments, a broad band aperiodic piezo transducer was used to register the pressure $P_c$ that corresponds to this deformation. The signal was then displayed on an oscilloscope in the form of a voltage pulse. We studied the amplitude of the ponderomotive acoustic signal (PAS) as a function of beam current density $i_e$ and irradiation pulse length at a constant surface density of the injected charge, $Q = 4.3 \cdot 10^{-7}$ C/cm$^2$ (Fig. 1). To explain the anomalous behavior of PAS amplitude, we performed an analysis based on published experimental data on radiation-induced conductivity in NaCl irradiated by nanosecond electron beams [3].

For the one-dimensional case, the PAS amplitude can be defined as [2]

$$P_c = K_c E^2,$$

(1)

where $K_c$ is the generation coefficient. As the ground electrode is moved away to a distance of several target thicknesses from the irradiated surface, the field $E$ in the specimen can be written

$$E \approx q/\varepsilon \varepsilon_0,$$

(2)

where $q$ is the surface density of the uncompensated nonequilibrium charge, $\varepsilon$ is the relative permittivity, and $\varepsilon_0$ is the dielectric constant. Specifically for our case, in which the lifetime of nonequilibrium electrons is much shorter than the irradiating pulse, $q$ is given by the expression [4]

$$q = i_e \tau [1 - \exp (-t/\tau)],$$

(3)
Fig. 1. Maximum ponderomotive acoustic signal amplitude as functions: a) in NaCl, of electron-irradiation current density; b) of irradiating-pulse length for NaCl specimens of various thicknesses: 1) 1.6; 2) 0.74; 3) 0.45; 4) 0.3 mm.

where \( t \) is the width of the irradiating pulse at half height, \( \tau = \varepsilon \varepsilon_0 / \Delta \sigma_e \) is the Maxwellian dielectric relaxation time, and \( \Delta \sigma_e \) is the nonequilibrium conductivity of the irradiated crystals. Substituting (2) and (3) into (1), we obtain

\[
\Delta \sigma_e = \left( K_e / P_e \right)^2 \tau \left[ 1 - \exp \left( -t / \tau \right) \right].
\]  

This expression indicates that we must know \( K_e \) and \( \tau \) to derive a relation for conductivity as a function of current density.

To determine \( K_e \), we use the results of [5] and plot the weak-electric-field conductivity \( \Delta \sigma_p \) against \( i_e \) (Fig. 2), using volt-ampere characteristics for NaCl. Here the thickness of the specimens was made 0.2 mm larger than the depth of the extrapolated electron-free path. We assume that the nonequilibrium conductivity found from (4) for low current densities (below 10 A/cm\(^2\)) agrees with the \( \Delta \sigma_p \) found from experiment. The variation of the PAS with \( i_e \) for current densities \( i_e < 30 \) A/cm\(^2\) is represented by the solid line in Fig. 1a. Taking all this into account and using (4), we obtain \( K_e = 1.6 \times 10^{-9} \) N/V\(^2\). The assumption that the conductivities \( \Delta \sigma_p \) and \( \Delta \sigma_e \) are equal at \( i_e < 10\) A/cm\(^2\) is based on the notion that the electric field that appears in the specimen on application of a voltage to the electrodes on its outer surface and the field set up in the same specimen as a result of absorption of the uncompensated equilibrium charge are too small to influence the conductivities. Figure 2 (curve 2) represents \( \Delta \sigma_e \) as a function of \( i_e \) according to (4) and the experimental data (Fig. 1a). We see on comparing the curves in Fig. 2 that they diverge as the electron current density increases (\( i_e > 10 \) A/cm\(^2\)). This may be due to the increase in the nonequilibrium conductivity of the NaCl crystal in the strong electric field. Figure 3 shows \( \Delta \sigma_e / \Delta \sigma_p \) as a function of the electric field set up by the charge in the beam of irradiating electrons. The trend of the curve is consistent with the experimental results of [6], where the averaged ratio of the conductivities in strong electric fields is described by

\[
\sigma / \sigma_0 = \exp \left( 2 \cdot E^2 \right).
\]

Here \( \beta = 10^{-15} \) and \( \alpha = 2.6 \) are empirical coefficients. For the \( \Delta \sigma_e / \Delta \sigma_p \) vs. \( E \) curve calculated from \( P_e \), the coefficients \( \alpha = 2.4 \) and \( \beta = 10^{-13} \). The difference in the values of \( \beta \) can be attributed to different nonequilibrium-electron lifetimes in the NaCl, which are determined by the power of the absorbed dose.

The correctness of the chosen physical model is also supported by an experimental study of PAS amplitude in NaCl as a function of irradiating-pulse length at a constant surface density of the charge striking the target. Specimens of various thicknesses \( d \) were used: 1.6, 0.74, and 0.45 mm (Fig. 1b). If the depth of the extrapolated electron free path in the specimen is less than one-third of its thickness, then \( \tau \gg t \) in (4), so that \( P_e = (K_e / \varepsilon \varepsilon_0)^2 = \text{const} \), as is observed in experiment. The calculated curve of \( P_e \) vs. \( t \) for NaCl with \( d = 0.3 \) mm (Fig. 1b, curve 4) has the same tendency to fall off with increasing irradiating-pulse length as in the case \( d = 0.45 \) mm.

Thus, published experimental data on the radiation-induced conductivity of NaCl crystals irradiated by strong electron fluxes were used to analyze experiments that indicated nonlinearity of PAS generation in NaCl under the same irradiation. It was shown that the maximum PAS amplitude is determined by the rapidly varying strong electric field created in the specimen by the charge in the nanosecond beam of irradiating electrons and depends on charge drainage, which is controlled by the