Anomalous electric-field-induced damping of ultrasound in superionic crystals

V. L. Skritskiĭ, V. I. Samulenis, and G. B. Tel'nova
V. Kapsukas State University, Vil'nyus

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Anomalous damping and change in the velocity of ultrasonic waves in superionic crystals induced by a constant electric field are observed for the first time experimentally.

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Superionic crystals attract the attention of researchers because they have an anomalously high ionic electrical conductivity[1] and broad practical applications.[2] However, the physical processes accompanying the flow of an electric current in them have not been adequately studied. All of the theoretical and experimental investigations performed up to now indicate the possibility that electric fields affect the electric and acoustical properties of crystals with mixed and electronic-ionic electrical conductivity.[3–6] However, there is no information on the elastic properties of crystals which are in the superionic state produced by the action of an electric field.

In this work, we investigated the effect of a constant electric field on the propagation of ultrasonic waves (USW) in the superionic crystals $RbAg_4I_5$ and Na–β alumina. An anomalously large change in damping induced by the electric field was observed. For the measurements, we used specimens of $RbAg_4I_5$ and Na–β-alumina, cut out of single crystals and prepared in an appropriate manner for ultrasonic measurements. The dimensions of the specimens were $0.4\times0.5\times0.5$ cm and $0.5\times0.6\times0.6$ cm. The measurements were performed by a pulsed USW method in the frequency range 20–60 MHz.

The longitudinal ultrasonic wave propagated along the direction [001] of the $RbAg_4I_5$ crystal and along the conducting surfaces in the Na–β-alumina crystal. The constant electric field was created both along the USW wave vector and along the vector perpendicular to it. Silver electrical contacts were used for $RbAg_4I_5$ and sodium contacts were used for Na–β-alumina. The measurements were performed at room temperature. Typical results of variations in the absorption coefficient and USW velocity as a function of time with application of a constant field are presented in Fig. 1 for the ($\Delta\alpha > 1$ cm^{-1}) specimen. It is evident that when an electric field is applied the coefficient of absorption of USW increases slowly and reaches anomalously high values for a 20-MHz frequency ($\Delta\alpha > 1$ cm^{-1}), while the USW velocity decreases. After the electric field is removed the absorption and velocity of USW assume their initial values with time. Analogous behavior of the velocity and absorption of USW were also obtained when the electric field was oriented perpendicular to the direction of propagation of USW. This indicates that the increase in damping is a volume effect. Similar results were obtained in the Na–β-alumina crystal (Fig. 2), but the relative changes in the velocity and coefficient of absorption in this case are smaller. It should be noted

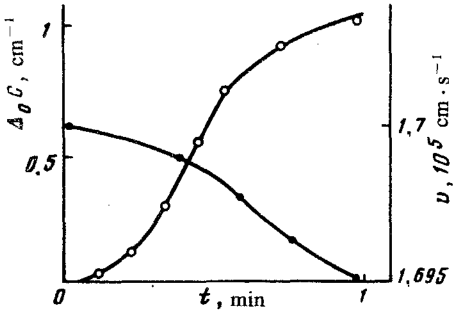

FIG. 1. Change in the absorption coefficient (O) and velocity (●) of USW with time under the action of a constant electric field $E = 5$ V cm^{-1} in a $RbAg_4I_5$ crystal.

that for Na–β-alumina crystals, the action of the constant electric field applied perpendicular to the conducting planes does not lead to a change in velocity and absorption of USW. The strong time dependences of the measured quantities did not permit establishing accurately the frequency dependence $\alpha = f(\omega)_{E=\text{const}}$, but for good reasons it may be assumed that in the frequency range 20–60 MHz the change in the absorption of USW is either independent of frequency or this dependence is very weak. An analogous effect is also observed with propagation of transverse USW in the specimens that we studied with application of a constant electric field.

We observed the effect of a constant electric field on propagation of USW previously for crystals with mixed electronic-ionic conductivity of proustite (Ag_3AsS_3)[6] and miargyrite $(AgSbS_2)$.[5] In the piezoelectric proustite crystals, this influence is explained by an increase in its electrical conductivity and acousticoelectrical interaction. In the nonpiezoelectric miargyrite crystal the effect of the constant electric field can be explained by the superionic phase transition, which induces an electric field.[3] In our case, the crystals $RbAg_4I_5$ and Na–β-alumina do not exhibit a piezoelectric effect, the electronic component of the electrical conductivity is negligibly small, while the crystals at room temperature are already in the superionic state. For this reason, both of the mechanisms indicated above are not applicable. Thus the results obtained by us provide some justification for proposing the existence of a new mechanism for interaction of USW with conductivity ions in superionic crystals, which is responsible for the anomalously large change in absorption and USW velocity induced by an electric field.

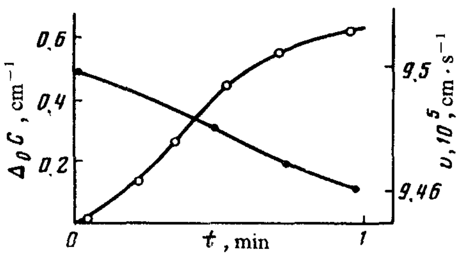

FIG. 2. Change in the absorption coefficient (O) and velocity (●) of USW with time under the action of a constant electric field $E = 5$ V cm^{-1} in a Na–β-alumina crystal.

Apparently, the effect observed is a general effect for all superionic crystals and requires further theoretical and experimental analysis.

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