ON THE PASSAGE OF ULTRASONIC PULSES THROUGH A WAVEGUIDE WITH A SPECIMEN CONTAINING CHARGED DEFECTS

A. V. Volkova

We discovered a slight increase in the velocity of ultrasonic waves $C$ and other parameters associated with $C$. We studied materials with charged defects and show that the physical quantity under consideration usually denoted by $C$ may, in some cases, become so high that it loses its physical meaning. It is demonstrated that the discovered effects are similar to the variations of heat conductivity of liquid helium. We also discuss mechanisms of the anomalous behavior of the investigated quantity.

As is known, an increase in the velocity $C_u$ of elastic ultrasonic waves is observed in small specimens with defects for certain values of physicochemical parameters of materials (see, e.g., [1, 2]). The indicated increase in the velocity $C_u$ is traditionally regarded as anomalous because this quantity begins to decrease as soon as the specified values of the parameters are exceeded. In [1, 2], the interpretation of the anomalous behavior of $C_u$ is based on the assumption that the energy of ultrasonic pulses is transferred according to the phonon mechanism and that the role of charge carriers in traps in the process of energy transfer is insignificant [2, 3].

In the present work, we study materials of the same type which undoubtedly contain charged defects and discuss the possibility of deviations from the phonon mechanism of transferring the energy of ultrasonic pulses.

Fig. 1. Block diagram of the installation: (1) G-5-4B generator of sounding pulses (duration of a pulse $< 0.1 \mu$sec), (2) TsTS-19 piezoelectric gauge (with a frequency of $\approx 1$ MHz), (3) reference liquid (distilled water), (4) duralumin buffer rods, (5) specimen, (6) S1-15 oscillograph.

To solve this problem, we used the method of electron-acoustic spectroscopy. The required hardware does not differ from that used in the well-known ultrasonic method for the comparison of the phases of signals (Fig. 1) [4].

We measured the thickness of a specimen $h$ and the time $\tau$ for which a signal passes through the specimen. The values of $\tau$ were determined indirectly. First, we measured the length $l_0$ of the path of ultrasonic pulses in the reference line under the condition that the phases of the first half waves of signals received from the measuring line


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containing buffer rods without specimens between them must coincide with the phases of signals received from the reference line. If we know the velocity of ultrasonic pulses $C_l$ in the reference liquid which fills the reference line, then we can determine the time of delay $\tau_0$ of ultrasonic pulses in buffer rods. Indeed, $\tau_0 = l_0/C_l$.

Similarly, we also equate the phases of the first half waves of signals received from the measuring and reference lines in the case where the specimen is located between the buffer rods. For the sake of brevity, a waveguide formed by the buffer rods and a specimen between them is called a compound waveguide.

We measured the length $l$ of the path in the reference line under the condition that the phases of signals received from the reference line and the compound waveguide coincide. The delay time of signals in the compound waveguide was determined by using the formula $\tau_1 = l/C_l$. The time of transfer of energy of ultrasonic pulses through the specimen was found as $\tau = \tau_1 - \tau_0$. The quantities $h$ and $\tau$ were used to find $C$, namely, $C = h/\tau$.

Thin layers of the material with $h < \lambda$ (where $\lambda$ is the wavelength of ultrasonic waves) were not studied by comparing the phases of signals [4] in the process of transfer of the energy of ultrasonic pulses through their thickness $h$. The investigation performed in [5-6] enabled us to conclude that the essence of the method of comparison of the phases of signal changes when compound waveguides contain specimens with $h < \lambda$, because the energy of ultrasonic pulses is not, in general, transferred through the compound waveguide by elastic ultrasonic waves. The value of $C$ does not coincide with the velocity $C_u$ and, in this case, is defined as the effective velocity of waves. Extensive research performed in [5, 6, 9] revealed good agreement between the data on the properties of the material obtained by measuring the quantity $C$ and by the other (independent) methods.

The method based on measurements of $C$ is called the method of electron-acoustic spectroscopy. The physical mechanism of the transfer of energy of ultrasonic pulses through the compound waveguide which contains a specimen with $h < \lambda$ is not studied in detail. However, it was established that charge carriers in traps participate in the process of transfer of the energy of ultrasonic pulses which leads to the appearance of the difference between the values of $C$ and $C_u$ in the method of electron-acoustic spectroscopy. High sensitivity of this method to changes in the quantum states of charge carriers in the material enables us to solve the problem posed above. It is clear that the values of $C$ and $C_u$ coincide only in the case of realization of the phonon mechanism of energy transfer. In all other cases, these quantities take different values.

It is known [11] that elastic longitudinal waves are excited in the specimen with $h > \lambda$ contained in a compound waveguide. Therefore, to compare the values of $C$ with the values of $C_u$ for a given material in the same experimental installation under identical conditions, we measured the effective velocity of waves in specimens both with $h > \lambda$ and $h < \lambda$. For specimens with $h > \lambda$, the measurement error was about 0.1%, whereas for specimens with $h < \lambda$, it was as high as ~1%.

To change quantum states of charge carriers, the specimens were heated to 100°C at a rate of ~2°K/min. We investigated dielectric materials, such as monocrystals of NaCl, well studied by electric and optical methods [12] and, hence, quite suitable as reference specimens and polyurethane based on polyethylene glycol adipate with a molecular mass of 2,000 and 4,4'-diphenylmethanediisocyanate. 1,4-butandiol was used as a lengthener of the molecular chain. The ratio between the polyether component and the lengthener was 1:4.

Monolithic polyurethane specimens with $h \equiv 6$ mm were formed by mixing source components at $T = 80$°C and holding their mixture at 140°C for 4 h. Polyurethane films were obtained from a 20% solution of monolithic specimens with $h \equiv 6$ mm in dimethylformamide by free casting of the solution onto a support made of silicate glass. Solvent was removed by drying first in air at 25°C for 3 h and then in a vacuum at 75°C for the same period of time.

Charged defects in NaCl and polyurethane specimens were formed by subjecting these specimens to the action of $\gamma$-radiation emitted by a source with Co$^{60}$ isotopes. The concentration of defects in NaCl specimens was about $10^{17}$ cm$^{-3}$. Depending on the dose of radiation, we observed the appearance of defects of different types.

Some polyurethane specimens were exposed to neutron-photon radiation in the channel of the nuclear reactor at the Moscow Institute of Physical Engineering. Charge carriers were present even in source polyurethane films prior to irradiation. As is typical of all films made of polymeric dielectrics, they appear in the process of preparation [13]. It is known that the molecular mobility of polyurethane increases at relaxation temperatures $T_r = 70-80$°C [14].