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THE MEASUREMENT OF HYPERSONIC ATTENUATION IN $LiNbO_3$

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The paper deals with the measurement of the absorption coefficient temperature dependence within the range of the temperature of liquid nitrogen and room temperature at 2620 MHz. Comparisons with the results of other authors and the discussion follow.

I. INTRODUCTION

Considering the range of possibilities of hypersonic methods with respect to the investigations of solids, a device for the generation and detection of hypersound was installed at our department [1]. The first application of these methods was the investigation of the temperature dependence of the absorption coefficient in the single crystal of $LiNbO_3$. Although absorption investigations have been made, there are still only a few published articles on temperature dependence of the absorption coefficient. As single crystals of $LiNbO_3$ are known because of different kinds and contents of crystal lattice perturbances affecting the absorption, the importance of these measurements consists also in the possibility of assessing the quality of single-crystals.

II. EXPERIMENTAL PROCEDURE AND RESULTS

Measurements have been made by the conventional pulse-echo method for the generation and the detection of hypersound shown in the block diagram in Fig. 1.

The single-domain lithium niobate sample under study — prepared in ČSSR by the firm Monokrystaly Turnov — was a rod 12 mm long with a diameter of 3 mm. The two ends of the rod were parallel within 4 sec of the arc and polished to within 500 Å. The crystallographic C-axis ran parallel to the longitudinal axis of the rod. For the generation and detection of hyper-

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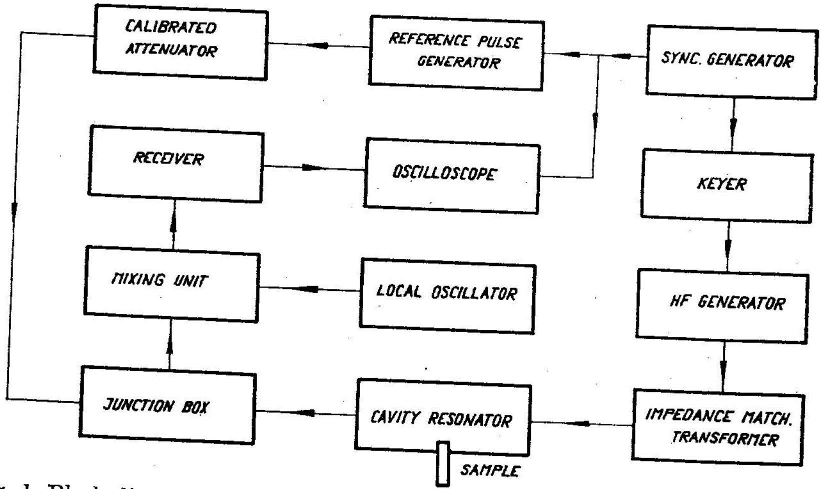

Fig. 1. Block diagram of the experimental arrangement for the measurement of hypersonic attenuation.

sound there were employed the piezoelectric properties of the sample, the face of which was inserted in a region of a microwave field of high electric intensity in a re-entrant cavity through its drilled central peg shaped like a truncated cone [1]. From the generator a high-frequency 2620 MHz pulse of 1.5 μs duration (about 0.5 W) was fed into the cavity, where on the sample surface a hypersonic longitudinal wave was generated. After its reflection from the opposite end of the rod, the wave returned to the original sample surface and there by the inverse effect a small fraction of the hypersonic energy was reconverted into an electromagnetic wave of the same frequency and by means of the coupling loop brought out through the receiving tract onto the oscilloscope. On the oscilloscope there appeared as the first the driving pulse and there followed a series of pulses corresponding to the double (the first echo), to the quadruple (the second echo) etc. travelling of the hypersonic wave through the sample (Fig. 2). Distances of individual echoes were read by the calibrating time base. From the echoes time delay readings it was possible to compute the hypersonic wave velocity. From the measured quantities for the velocity there was obtained the value $v = 2l/t = 7.5 \times 10^5$ cm/sec (l is the sample length and t is the time interval between two neighbouring echoes). Frank A. Olson [2] gives for the longitudinal hypersonic wave velocity in $LiNbO_3$ the value 7.4×10^5 cm/sec and Wen and Mayo [3] give 7.2×10^5 cm/sec.

For the attenuation measurements there was employed the reference pulse generator, tuned on the frequency of the HF generator, with the calibrating attenuator on its output. Measurements were made by the comparison method

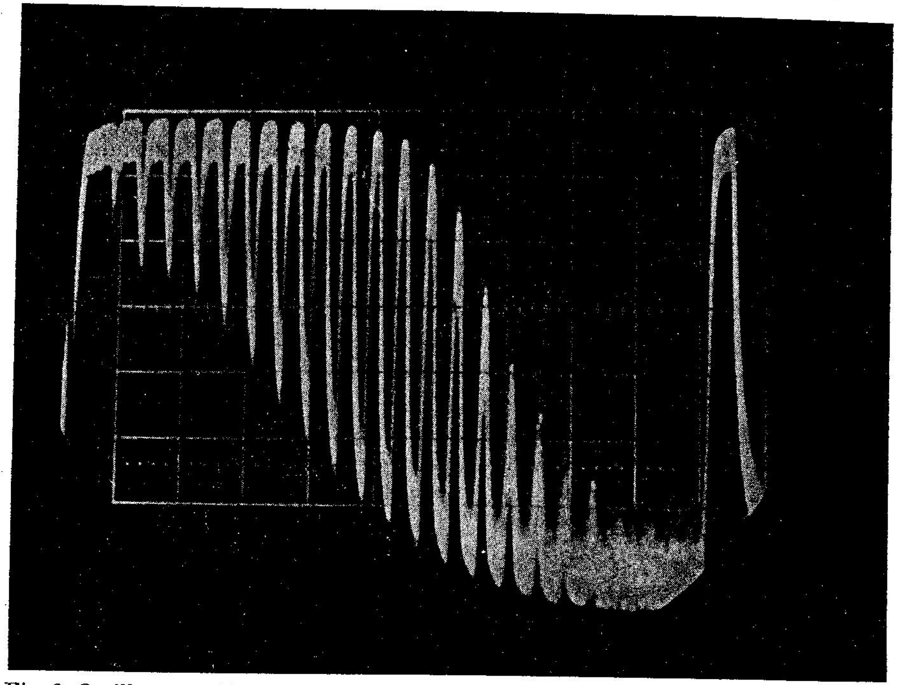

Fig. 2. Oscillogram of hypersonic pulses in $LiNbO_3$ at 2620 MHz and 77 °K. The isolated pulse of the right-hand side is the reference pulse.

in the following way: the calibrating attenuator was set on a particular value so that the level of the reference pulse (the isolated pulse on the right-hand side of Fig. 2) was the same as, e. g., that of the first echo. Afterwards the reference pulse was compared with a further echo by adjusting its value by the calibrating attenuator to the level of this echo and the attenuation was read on the scale. The difference of both readings gave the attenuation in dB for the hypersonic wave, which traversed the distance corresponding to the measured echoes in the sample. The measurements of the attenuation from the echo-amplitudes by which the receiver was saturated were possible after lowering the receiver gain. The receiving part of the equipment (Fig. 1) was tested by the reference pulse generator; at the signal noise–ratio 1 : 1 the registered signal represented at the output of the reference pulse generator the pulse power 3×10^{-10} W.

To reach various temperatures, the temperature gradient above the boiling liquid nitrogen in the thermostat placed on the bottom of the closed container of foamed polystyrene, was employed. The cavity resonator with the sample was located in different positions in the nitrogen atmosphere and at the same time the liquid nitrogen evaporation was controlled by electric heating (from 0 to 10 W). The temperature was measured by the thermocouple (copper-constantan) placed on the sample and the measurements were made at the constant temperature. A sensitive detector of the steady state of temperature was also the cavity resonator itself, because of a very strong dependence of echo-amplitudes (and therefore their number too) on the resonance of the cavity resonator. When it is far from resonance no echoes apear. If the resonator is for any reason detuned (e. g. thermal expansion) in the course of measurement, echo-amplitudes decrease. This echo-amplitudes decreasing could distort the measurement, so that higher values of the attenuation coefficient would be measured. For this reason the steadiness of the adjusted temperature was required in the course of the whole measurement. This steadiness was verified besides by thermocouple indications also by checking the agreement between the initial echo-amplitude and the reference pulse adjusted to the initial attenuation value after particular measurements. In this way the measurement reproducibility within values plotted in Fig. 3 was achieved (curve I).

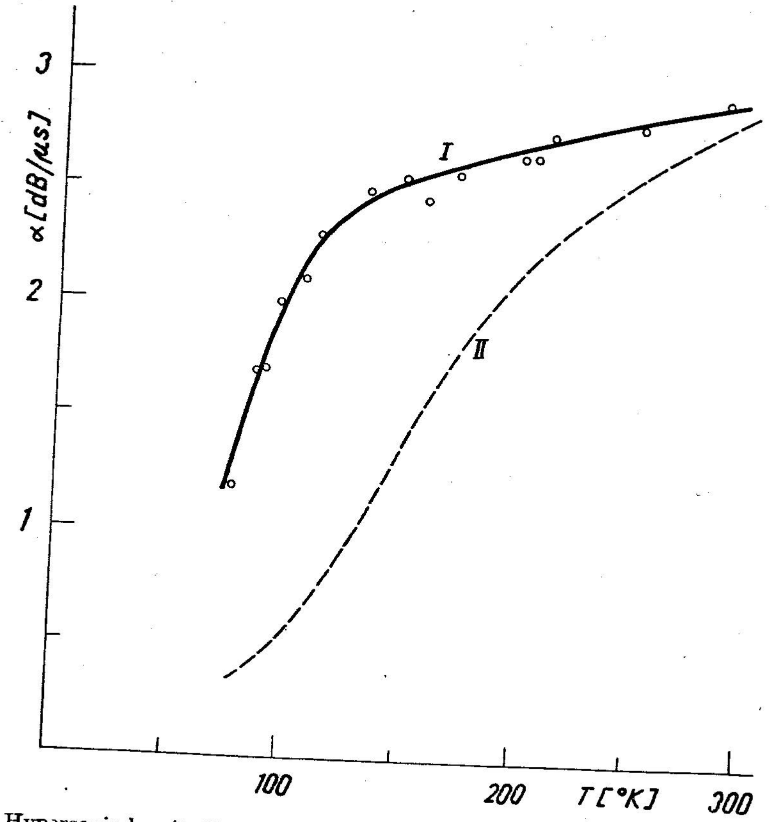

Fig. 3. Hypersonic longitudinal-wave attenuation in the c-axis of the sample of $LiNbO_3$ as a function of temperature at 2620 MHz (curve I — measured by the author; curve II — after [3]).

III. DISCUSSION

For comparison with our results, the dependence of the absorption coefficient α from T for the $LiNbO_3$ sample of the same orientation measured by Grace et al. [4] at 2640 MHz is also plotted in Fig. 3 (curce II). The attenuation in this frequency range increases with the square of the frequency, so that results of our measurements at 2620 MHz obviously point to a higher attenuation in our sample. However as it follows from Silverman's theoretical analysis [5] the absorption of acoustic waves, owing to their interaction with thermal phonons, is affected by crystal lattice perturbations in such a way that the thermal phonon lifetime τ is reduced. For frequencies where the condition $\omega\tau < 1$ is fulfilled this results in reducing the attenuation in dielectric crystals with perturbations more than in perfect crystals, while in the temperature region where $\omega\tau > 1$ the attenuation will be higher in crystals with a higher imperfection density. Since for our frequency and temperature range the condition $\omega\tau < 1$ is fulfilled, we can conclude that the sample we have investigated contained less defects than that investigated by the above mentioned authors.

A similar defect influence was experimentally found by Bömmel and Dransfeld [6], who have studied the neutron irradiation influence upon hypersonic attenuation in quartz and by Mason and Bateman [7] in ultrasonic attenuation investigation of oxygen-contaminated silicon.

Thus we can conclude that the investigation of hypersonic attenuation yields valuable information about the quality of the given type of the single-crystal. For a more detailed analysis of the temperature dependence of the hypersonic attenuation it will be necessary to perform measurements within a very low temperature region.

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