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PHYSICS

1970

SovietRxiv

Abstract

Full Text

UDC 534.26:534.28:621.31.54

PHYSICS

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ON THE AMPLIFICATION AND ABSORPTION OF ACOUSTIC WAVES UPON THEIR REFLECTION FROM A CdSe CRYSTAL IN WATER

(Presented by Academician A. P. Aleksandrov on 9 III 1970)

In the work ([1]) it was noted that, at certain angles of incidence of an ultrasonic wave on a piezo-semiconductor crystalline thin plate bounded in a liquid, strong reflection of ultrasonic vibrations should be observed in the direction opposite to the direction of the incident wave—the so-called nonmirror reflection. Nonmirror reflection arises as a consequence of sound radiation by the free vibrations of the plate, which appear as a result of reflection from its edge of forced vibrations. The latter are excited by an ultrasonic wave incident on the plate from the liquid. The amplitude of the nonmirror reflection depends on how rapidly the free vibrations in the plate decay. As a result of energy exchange between charge carriers and free vibrations, the latter may not only decay but also grow, which should lead, respectively, to absorption or amplification of the waves nonmirror-reflected by the plate in the liquid. The considerations indicated also lead to the conclusion that, in the case of thick piezo-semiconductor plates whose thickness is large in comparison with the length of the elastic wave, amplification (absorption) is possible in their material of nonmirror-reflected waves in the liquid, caused by free normal waves in the plate.

Experiments were set up for the purpose of experimentally detecting the indicated phenomenon. Some results of these experiments are presented below. The experiments were carried out on an apparatus consisting of a water-filled tank with sound-absorbing walls, of dimensions $200 \times 50 \times 50$ cm^3, a generator of ultrasonic pulses having a rectangular envelope, a vibrator with an X-cut quartz plate (the vibrator performed both transmission and reception of pulses), a receiving amplifier, a pulsed electronic oscilloscope that served as an indicator of the amplitudes of the reflected signals, a high-voltage generator of dc-voltage pulses, and a generator of synchronizing pulses. The pulse duration could be varied within the range from 10 to 100 μsec, the pulse repetition frequency was 200 Hz, and the filling frequency was 5 MHz.

At a distance of about 150 cm from the vibrator, on a rotating rectangular frame, in its center, a plate of size $3.5 \times 3 \times 9$ mm^3, cut from a CdSe crystal so that its length coincided with the optical axis of the crystal, was fastened by means of thin threads. Miniature electrodes were attached to the ends of the plate in the direction of the optical axis for applying pulses of a constant electric "drift" voltage. At some distance from the plate, above the surface of the water, an electric incandescent lamp was placed, rigidly connected with the frame. The electric voltage supplied to the incandescent lamp could be varied by means of a potentiometer.

Initially, the polar characteristics of reflection of the CdSe plate were measured under conditions when the incandescent lamp was not switched on and pulses of constant electric voltage were not applied to the plate. For this purpose the frame with the plate was rotated and the amplitude of the reflected echo signal was measured as a function of the angle of rotation. As follows

one should expect that, at angles of incidence of the ultrasonic wave on the plate satisfying the relation $\sin\theta = c/c_n$, where θ is the angle of incidence formed by the direction of propagation of the incident ultrasonic wave on the plate and the normal to the surface of the plate; c is the speed of sound propagation in water and c_n is the velocity of the normal wave of number n in the plate, non-specular reflection of sound was observed, whose amplitude was approximately 20 dB less than the amplitude of the echo signal at normal incidence of the ultrasonic wave on the plate.

The polar characteristic of reflection of the unilluminated plate is shown in Fig. 1 by the solid line. Along the vertical axis is plotted the amplitude of the echo signal in decibels relative to the amplitude of the reflected signal at normal incidence of the ultrasonic wave on the plate. Along the horizontal axis are the values of the angle of incidence in degrees. When the CdSe plate was illuminated by an incandescent lamp, the amplitude of the echo signals decreased, and only at normal incidence of the ultrasonic wave on the plate did it remain unchanged. In Fig. 1 the dashed line shows the polar characteristic of reflection of the illuminated plate at the normal brightness of the incandescent lamp, when the rated voltage of 12 V was applied to its terminals.

Fig. 1

It also turned out that in a number of cases the amplitude of non-specular reflection depends substantially on the intensity of the light incident on the plate. In Fig. 2 a graph is given characterizing changes in the amplitude of non-specular reflection for the angle $\theta = 37^{\circ}$ as a function of the voltage on the incandescent lamp, i.e., as a function of illumination. As can be seen from the data presented, the amplitude of non-specular reflection decreases with increasing illumination of the plate, and then increases somewhat. These changes in the amplitude of non-specular reflection are due to the fact that, under illumination, the attenuation of free normal waves in the plate changes because of their interaction with conduction electrons.

Fig. 2

Fig. 3

Figure 1: Fig. 3

If an external drift electric field is applied to the piezosemiconductor plate, then, at certain values of the drift velocity of the charge carriers, as indicated in works ([1], [2]), amplification of waves in the liquid reflected by the plate should be observed. Indeed, at values of the voltage in the pulse $V = 900$ V applied to the illuminated plate, significant, comparatively slow fluctuations of the amplitude of non-specular reflection were observed; initially the amplitude of non-specular reflection increased, and then, fluctuating, decreased—

remained unchanged. In this case the amplitude of the reflected echo signal, for normal incidence of the ultrasonic wave on the plate, remained unchanged. Constant-voltage pulses of duration 200 μsec were applied to the plate at the moment when the ultrasonic oscillations in the incident wave reached the plate. In the absence of a drift voltage, no fluctuations of the echo signal are observed on the oscilloscope screen. In Fig. 3 the solid line shows the polar characteristic of the reflection of the illuminated plate in the absence of a drift voltage. Fluctuations of the amplitude

Fig. 3

of the reflected echo signal upon application to the plate of a drift voltage of about 900 V were observed within the hatched region.

Fluctuations of the echo signals and the decrease in the amplitude of nonspecular reflection when the plate is illuminated and a drift voltage is applied may be due to a substantial change in the attenuation of ultrasonic normal waves in the plate as a result of electron–phonon interaction and, apparently, are explained by the fact that all measurements were performed in a pulsed regime rather than with a continuous tone. Indeed, the amplitude of nonspecular reflection may decrease because the oscillations of the plate do not reach their limiting steady-state amplitude, since, when a drift voltage is applied to a piezosemiconductor plate, owing to electron–phonon interaction the attenuation of normal oscillations in the plate decreases and the time constant of the oscillations becomes greater than the duration of the ultrasonic pulse.

On the basis of the results obtained, the following conclusions may be drawn.

1. The polar characteristic of reflection of a plate made of the piezosemiconductor crystal CdSe changes depending on the illumination and the magnitude of the drift field.
2. The considerations previously expressed by the author in paper (1) are experimentally confirmed: electron–phonon interaction in piezosemiconductor crystals can lead to amplification (absorption) of acoustic waves in a liquid when they interact with piezosemiconductor crystals.

3. A fundamental possibility is opened for controlling the acoustic reflection characteristics of plates made of photoconducting piezosemiconductor crystals by acting on them with light or with a drift electric field.

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Received
19 II 1970

REFERENCES

1. L. M. Lyamshev, *Akust. zhurn.*, **15**, 2, 303 (1969).
2. L. M. Lyamshev, *Akust. zhurn.*, **15**, 3, 460 (1969).

Note: Figure translations are in progress. See original paper for figures.