Observation of secondary sound generation in a liquid with volume boiling induced by laser radiation

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(Submitted 26 October 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **52**, No. 12, 1261–1263 (25 December 1990)

Secondary sound generation has been observed when a liquid surface is irradiated by a single laser pulse. The nature of the secondary acoustic signal is discussed.

Excitation of acoustic waves in liquids by means of optical radiation has occupied the attention of many researchers, since acoustic sources of this type have a number of advantages over conventional sources of sound waves. The thermoelastic mechanism has been extensively studied,[1] but this mechanism is not very effective in transforming optical energy to acoustic energy. An increase in intensity of the laser radiation leads to a change in the aggregate state of the liquid and the dominant mechanism becomes more effective: vaporization. Unfortunately, there is no systematic, complete theoretical description of the final stage of the vaporization mechanism—volume boiling, and therefore experimental data is of great interest.

We used a CO_2 laser (wavelength 10.6 μm) and absorption coefficient $\mu = 870$ cm^{-1}) with an output energy greater than 100 J and total pulse duration of 9 μsec. The optical radiation was focused by a lens on the surface of the water into a spot of radius 1.5 cm. The energy density in the spot exceeded 2.5 J/cm^2, which is large enough to induce explosive boiling. The acoustic signals were detected with the help of a calibrated hydrophone with a bandwidth of up to 300 kHz, which made it possible to correctly reproduce the shape of the pulses. The signal from the hydrophone was amplified and then digitalized and fed to the computer memory. The experiment was carried out at sea.

An oscillogram of the acoustic signal detected at a depth of 20 m along the axis of

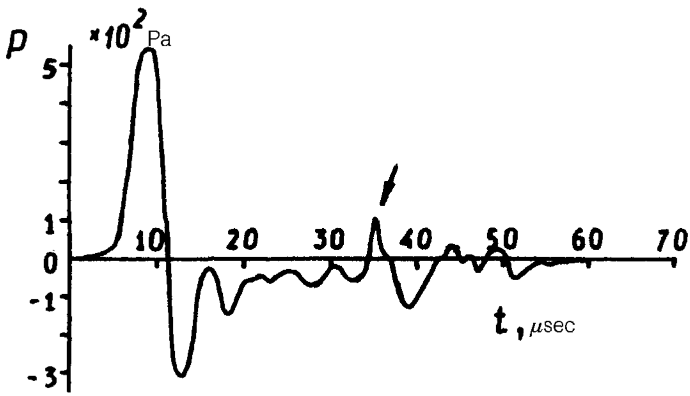

FIG. 1. Oscillogram of the acoustic signal measured at a depth of 20 m along the axis of radiation.

the radiation is shown in Fig. 1. Analysis of its form shows that in addition to the primary pulse resulting from the release of jets of vapor bubbles formed as a result of volume boiling, there is another signal (shown by the arrow) that occurs about 20 μsec after the first. This time lag was nearly constant in all of the experiments which were carried out using different angles and depths down to 100 m. The ratio of the

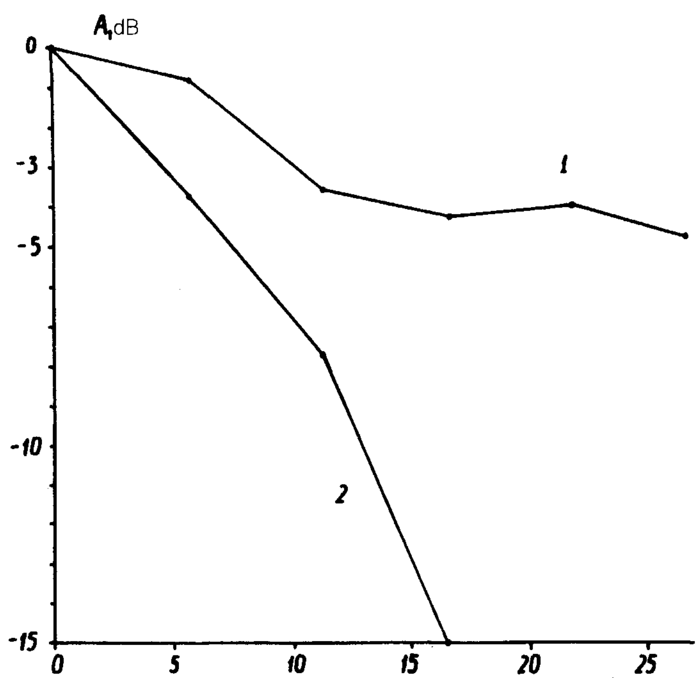

FIG. 2. Angular dependence of the acoustic signals: *1*—Primary; *2*—secondary.

amplitudes of the first and second pulses was nearly constant and equal to 5 to 1 on the axis of the radiation. The duration of the secondary signal was less than that of the primary one.

The experiment was constructed in such a way that all possible reflections (due to the spatial location of the hydrophone, as well as internal reflections caused by its structural features), were eliminated. In addition, the possibility of a secondary signal due to diffraction effects (because of differences in arrival times from the different edges of the aperture) was also eliminated.

The angular dependence of both signals was measured and the results are shown in Fig. 2, where the angle θ is measured with respect to the vertical. Note that the secondary signal has a stronger angular dependence, which is an indication that its source is a region on the surface of the liquid, i.e., the laser spot.

The physical picture of the evolution of surface vaporization and subsequent volume boiling is very complicated. In Ref. 2 the heat-conduction equation with a moving boundary and the equations of gas dynamics for the dispersing vapor in the presence of unsteady surface vaporization were solved simultaneously, and the results were compared to experiment. Condensation of vapor in the flow was disregarded. For volume boiling the temperature of the liquid inside the layer reached 600 K, and after the explosion of vapor bubbles formed at a depth corresponding to the maximum temperature, the surface of the liquid was overlaid by a thin layer of vapor and then cold air. Vaporization then proceeds into a medium with low back pressure and then the velocity of the vapor becomes larger than the local speed of sound, a condensation jump forms,[3] i.e., a sudden condensation of vapor, which results in a secondary signal, was observed here. The possibility of this effect was predicted in Ref. 4.

The authors thank A. O. Maksimov for useful discussions.

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Translated by J. D. Parsons