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Alteration in the Transmission and Reflection of Ultrasound Under the Action of Intense Light on the Surface of a Body in a Liquid

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A new effect is investigated experimentally[1], in which the propagation of sound is changed under the action of intense light on the medium. A flash of unfocused, unmodulated light of a neodyumium laser sharply reduces the reflection and transmission of ultrasound from and through the surface of a steel plate immersed in water. The buildup time of the overlap, which is due to the formation of vapor-gas bubbles or of a nonuniform film, is comparable with the energy liberation time, but could be as large as 0.3 sec. For high laser powers with Q-switching, fast film formation was obtained, which suppresses the transmission and changes the reflection of the sound. The suggested applications are interruption and removal of reflection or transmission of the sound, superfast modulation of sound when short laser pulses are used, and others.

THIS paper is concerned with the experimental investigation of a new effect—the influence of intense light on the transmission and reflection of ultrasound.[1] This effect is of interest not only as a variant of nonlinear optical-acoustical interaction, but also because it has various practical applications.

The change in the transmission and reflection of ultrasound has been studied under the action of intense light on the surface of an absorbing body immersed in the liquid. A strong change should be observed when the temperature T of the surface becomes sufficiently high for formation of vapor or gas. If the energy liberated per unit surface of the medium in the time t is q(t), then the temperature of the medium is determined by the formula

$$T \approx \frac{q(t)}{C\rho\delta(t)} \approx \frac{\alpha}{C\rho\sqrt{\varkappa t}}\int_0^t I(t)\,dt \approx \frac{\alpha I_{\text{av}}}{C\rho}\sqrt{\frac{t}{\varkappa}},$$

where $\delta(t)$ is the thickness of the heated layer, which is determined by the temperature conductivity κ and the time: $\delta \approx \sqrt{\kappa t}$. Therefore, the threshold of the effect will occur at an averaged light flux density $I_{cr} \approx (C\rho/\alpha)\sqrt{\kappa/t}\cdot T_{cr}$. Here $C\rho$ is the heat capacity of 1 cm^3 of the material of the surface and α is the fraction of absorbed light. For example, when $C\rho \approx 1$ cal, $\kappa \approx 0.1$ cm^2/sec; $\alpha \approx 1$, $T_{cr} \approx 100°$C, and $t \approx 10^{-3}$ sec, we obtain $I_{cr} \approx 4$ kW/cm^2. The ordinary unfocused beam of unmodulated lasers delivers such a flux density.

Figure 1 gives the experimental arrangement. The beam of the laser 1 falls on the surface of the steel plate 3, which is immersed in water filling the vessel 6. The source of the ultrasound 2 is a piezoelement of radius 1 cm, which sends a directed ultrasonic wave at a frequency of 2 MHz from the generator 5 such that the sound wave passes through the region of the surface irradiated by the laser beam in the flash. The piezoreceiver 2′ records either the passage of the ultrasonic beam through the plate (Fig. 1a) or its reflection from the plate (Fig. 1b). The signal from the receiver was fed to the long-persistence S1-29 oscilloscope 4.

In the first series of experiments, the laser was not Q-switched, with maximum energy ~10 J, pulse length ≈0.5 millisec and beam radius 1 cm.

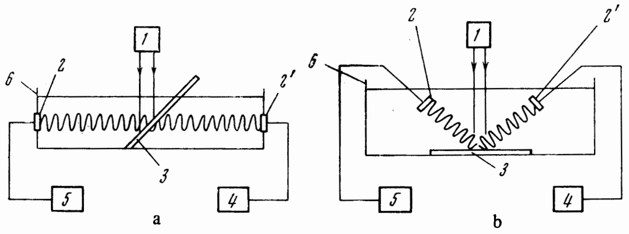

FIG. 1. Experimental setup for the investigation of the change in transmission (a) and reflection (b) of sound under the action of unfocused laser light on the surface.

Figure 2 shows the signal from the piezopickup, recording the passage of the sound (a) before the action of the light and (b) with the effect of the light. The time scale is 10 millisec.

Figure 3, with a time scale of 400 millisec, gives the signals which characterize the decrease in the sound reflections for various power levels of the light: (a) before action of the light and (b) during action of the light at full power; the remaining frames were obtained with the light reduced to (c) 75%, (d) 60%, and (e) 50%. It is seen that the amount of overlap becomes appreciable at a definite intensity of the light (~5 kW/cm^2 in case (e)) and beyond this point the effect grows sharply with increase of light intensity. The time of formation of the overlap is of the order of 0.1 millisec, which is commensurate with the growth time of the spiked lasing. The duration of the overlap is increased with increase in the flux density and even for a light flux density ~ 10 kW/cm^2 amounts to ~200 millisec, which is many times greater than the duration of the laser flash (~1 millisec). The decrease in the transmission of the sound is evidently connected with the formation of a vapor-gas layer at the surface of the body; the decrease in the reflection is associated with the small-scale inhomogeneity of the heating or the small-scale roughness of the vapor-gas layer, which produces scattering but not reflection of the sound.

At large light-flux densities, a vapor-gas layer can very quickly be formed on the surface, overlapping the

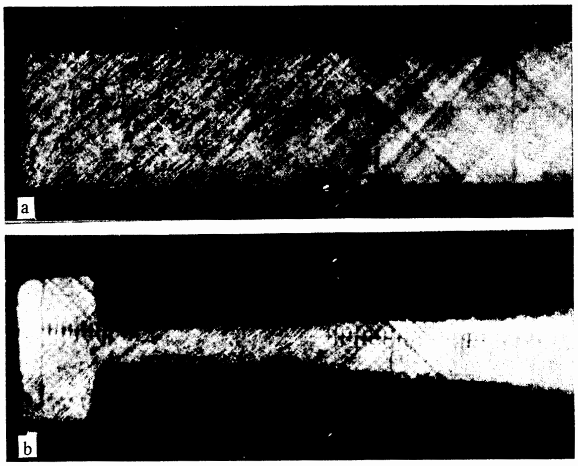

FIG. 2. Decrease in the intensity of transmitted sound. The time scale is 10 mill sec, a—before the action of the light, b—during action of unmodulated light at full power.

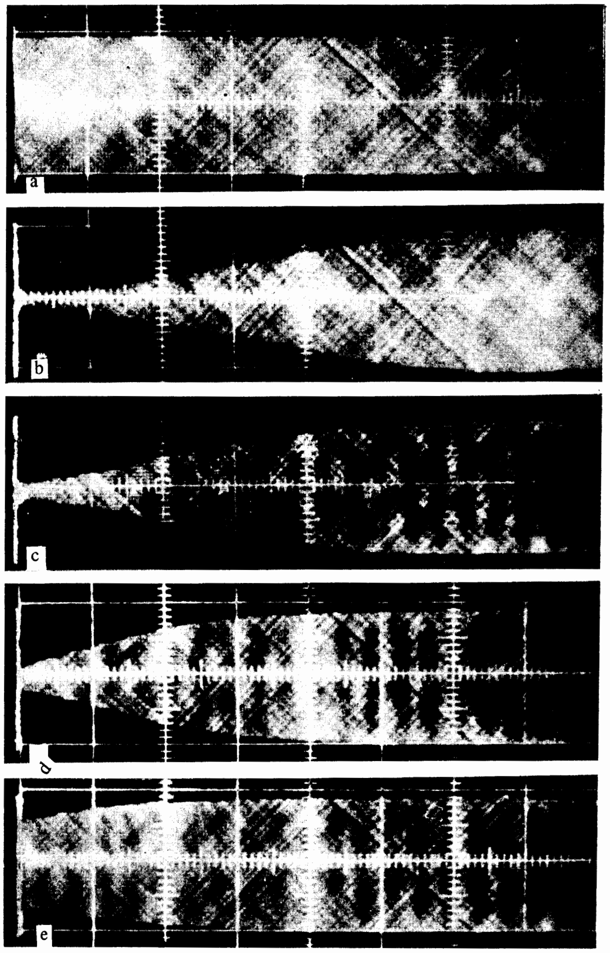

FIG. 3. Decrease in the intensity of reflected sound: a—before the action of the light; b—during action of unmodulate light at full power; the remaining frames are for reduced power: c—to 75%, d—to 60%, e—to 50% of the initial power. The time scale is 400 millisec.

sound transmission or changing the reflection (if the sound is incident from one side of the plate, and the light from the other, then amplification of the sound reflection is possible because of the suppression of the transmission). This effect was observed in a second series of experiments by means of a Q-switched unfocused laser, which gives a radiation pulse with a half width of 30—40 nanosec. Here we observed a change in reflection because of the decrease in the transmission within a time not exceeding several microseconds (a shorter time could not be resolved by our receiver because of the characteristic damping time). The overlap of the transmission of the sound amounted to ~1 sec.

By changing to short intense light pulses (of a Q-switched laser or a picosecond laser) we can use a lower energy flux and to increase the area of action, decreasing the rising front of the overlap.

We note that similar effects can be observed not only on an absorbing surface, but also in the presence of small absorbing particles in the liquid.[1] Vapor-gas bubbles, formed on such particles under the action of intense light, cause strong scattering of the sound or refraction and reflection because of the change in the compressibility of the liquid.[1] The light-acoustical effect described above can be used also for fast sound modulation.

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[1] G. A. Askar'yan and T. G. Rakhmanina, Zh. Eksp. Teor. Fiz. **61,** 1199 (1971) [Sov. Phys.-JETP **34,** 699 (1972)].

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