Study on the oscillation property of laser-produced cavitation bubbles in water

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In this paper, by means of a high-sensitive optical beam deflection technique combined with electrical delay technique, shock wave and cavitation effects by laser ablation of a metal in water are investigated in detail. The system is quite handy, and of high time resolving ratio and spactial precision. The experimental results present the propagation of shock waves, the expansion and contraction of laser-induced cavitation bubble in the vicinity of a solid boundary, the maximum and minimum radii during the first two oscillating cycles and the corresponding pulsation durations, the formation and development of bubble-collapse-induced shock waves. With the increase of oscillating cycles, the maximum bubble radii are decreased sharply, as well as the corresponding expanding and contracting durations. The minimum bubble radius at the first oscillation is larger than that of the second. Besides, the duration of bubble expansion is obviously longer than that of contraction at the same oscillating cycle.

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The physical process of laser and liquid material is a complex one which comes out of a series of sound, light, heat, and mechanical effect. When a high-intensity laser pulse focus in the liquid material, if the laser energy density is beyond the material breakdown threshold, there will produce high temperature and high-pressure plasma, shock wave, and cavitation bubble.

Cavitation is a special phenomenon occurring in liquids. Generally, in liquid flows and hydraulic machines, from the flowing blood to water pump, turbine or propeller, cavitation is widely in existence. It not only leads to the loss of mechanical efficiency and destructive erosion of hydraulic devices, but also damages the artery or heart during the blood flowing. Therefore, the investigations of cavitation and its associated destructive mechanisms are the current interest in the corresponding mechanical design and manufacturing, scientific research and hydropower station.

The experimental system is shown schematically in Fig. 1. A Nd:YAG laser with a wavelength of 1.064 μm and pulse width of 10 ns is used to generate cavitation bubble. The maximum pulse energy is 500 mJ. In order to maintain a bubble in hemispherical shape and good repeatability in experiment, the laser pulse is expanded and collimated to have a relative large cone angle in water, so that the probability of generating multiple plasmas can be reduced. Besides, the aluminum target is placed at the front part of the laser focal area to avoid water breakdown so that the inception of a single bubble is just on the boundary. The laser focal spot is about 100 μm in radius, and the laser power density at the spot surpasses the optical breakdown threshold of aluminum that is about 7.5×10^7 W/cm^2.

Figure 2 is a typical signal. It directly indicates four major phenomena during the laser-matter interaction

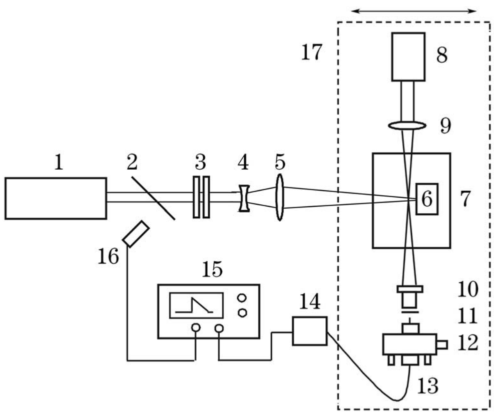

Fig. 1. Schematic diagram of experimental setup based on optical beam deflection. 1: Nd:YAG laser; 2: beam splitter; 3: attenuator group; 4: concave lens; 5: convex lens; 6: aluminum target; 7: container; 8: He-Ne laser; 9: aspherical lens; 10: microscope objective; 11: interference filter; 12: fiber regulating stand; 13: fiber; 14: photomultiplier; 15: oscilloscope; 16: PIN photodiode; 17: console.

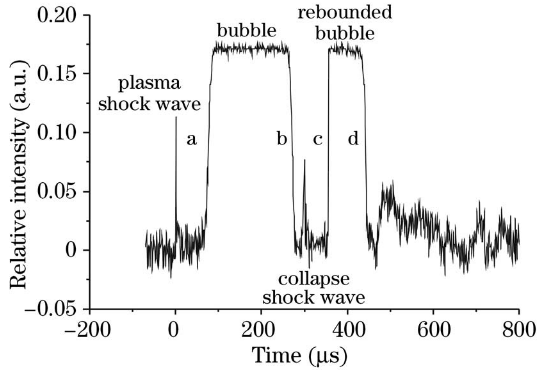

Fig. 2. Typical signal detected by optical beam deflection system.

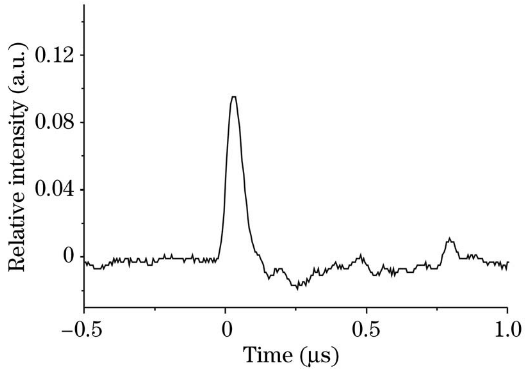

Fig. 3. Typical profile of laser-induced plasma shock wave.

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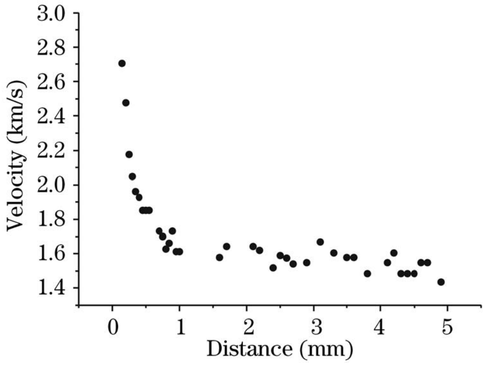

Fig. 4. Velocity of laser-induced plasma shock wave as a function of time.

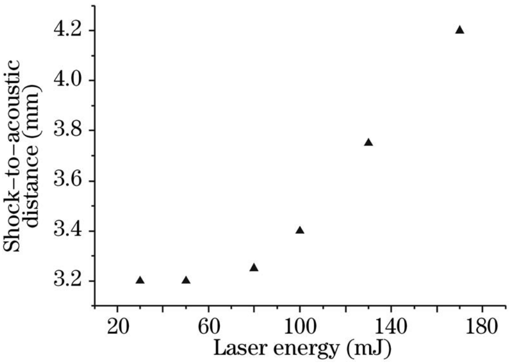

Fig. 5. Distance of shock wave decaying to acoustic transient as a function of laser energy.

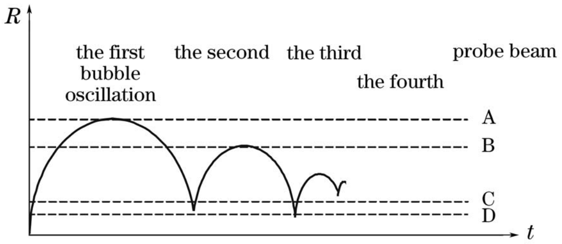

Fig. 6. Diagram of probe beam passing through an oscillating cavity.

underwater: the laser-induced plasma shock wave, the initial bubble, the bubble collapse shock wave, and the rebounded bubble.

Figure 3 shows the typical profile of laser-induced plasma shock wave. The velocity of laser-induced plasma shock wave can be calculated by the time of wave shock signal arriveing while the position of detecting ray changed. Velocity of shock wave as a function of time is shown in Fig. 4. Figure 5 shows the distance of shock wave decaying to acoustic transient as a function of laser energy. The distance linearly increases with laser energy from 80 mJ.

Figure 6 shows the diagram of probe beam passing through an oscillating cavity. The experiment results show that: $R_{1\,\min} > R_{2\,\min}$; $R_{1\,\max} > R_{2\,\max}$; $T_1 > T_2$. With the increase of oscillating cycles, the maximum bubble radii are decreased sharply, as well as the corresponding expanding and contracting durations.

With the time-lag function of oscilloscope, the development of bubble-collapse-induced shock wave with the detection distance can be observed, as shown in Fig. 7. The laser energy is 150 mJ.

The experimental results present the propagation of shock waves, the expansion and contraction of laser-induced cavitation bubble in the vicinity of a solid boundary, the maximum and minimum radii during the first two oscillating cycles and the corresponding pulsation durations, the formation and development of bubble-collapse-induced shock waves. With the increase of oscillating cycles, the maximum bubble radii are decreased sharply, as well as the corresponding expanding and contracting durations. The minimum bubble radius at the first oscillation is larger than that of the second. Besides, the duration of bubble expansion is obviously

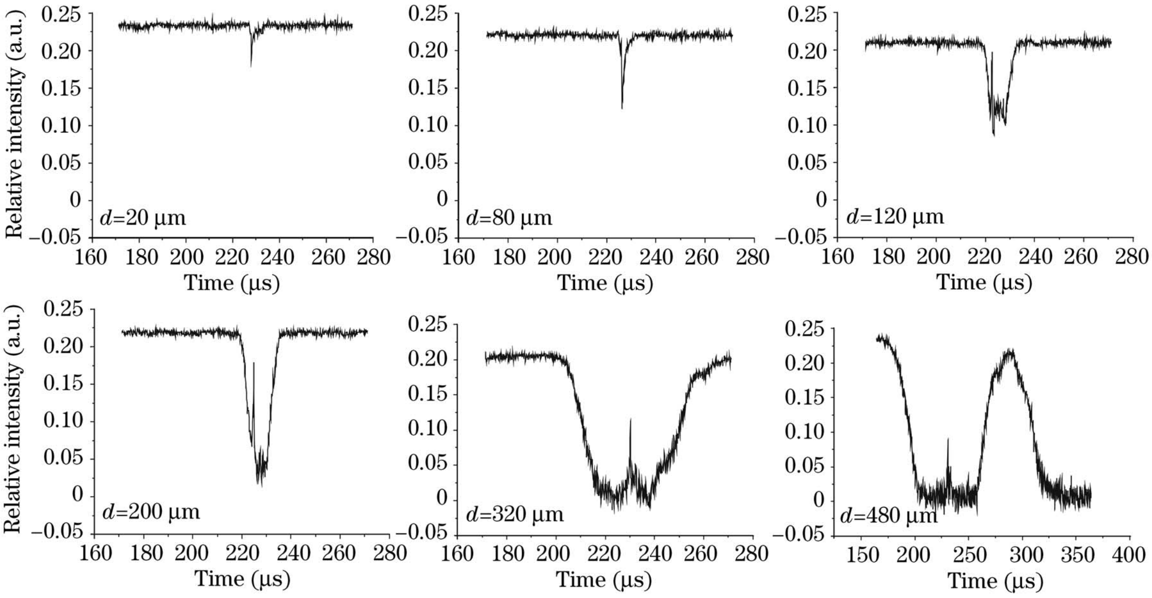

Fig. 7. Development of bubble-collapse-induced shock wave with the detection distance.

longer than that of contraction at the same oscillating cycle.

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